Chapter 4

# Potential Scenarios for Future Energy Trends

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# Chapter 4

# Potential Scenarios for Future Energy Trends

Previous chapters have described historical energy trends and identified the major components of our energy future. The relative emphasis on these various components will guide our energy future along one path or another. There is considerable variation among the potential paths. In general, the Nation can remain on a course that emphasizes conventional fossil supply patterns. Alternatively, an emphasis on high efficiency can reduce projections of energy demand. Such a shift would entail radical changes in energy supply planning and use, and in their economic and environmental impacts. If concern over global climate change increases, then increased emphasis on energy sources that do not produce carbon dioxide ($CO_2$)--nuclear power and renewable energy--could be necessary. These different paths entail many choices, such as which technologies to emphasize, and the technologies have large differences in their impact.

Of all the factors influencing energy trends, three of the most important are the growth rate of the economy (commonly measured by the gross domestic product (GDP)), the price of oil, and the status of technology. The GDP is a measure of the demand for the goods and services that require energy. Prior to the energy crisis of 1973-74, there was a general assumption that energy growth was intimately linked to GDP. That assumption has been disproved by the flat energy demand from 1972 to 1985 while the GDP grew by 39 percent in real terms.[1] Had historical trends held, U.S. energy use would have reached nearly 100 quads (quadrillion British thermal units) in 1985, up from 72.5 quads in 1972. Instead, only 74.9 quads were required that year.

Two factors accounted for this loosening of the connection between economic and energy growth. Improvements in energy efficiency accounted for almost two-thirds of the difference. Shifts in the structure of the economy (e.g., decline in energy-intensive heavy industries and growth in services that require relatively little energy) accounted for the remainder of the difference.

Since 1985, energy demand has resumed higher growth trends, increasing 8 percent by the end of 1988. Low oil prices and strong economic growth (the latter partly a result of the former), particularly in energy-intensive industries including steel and aluminum, appear to be responsible for this shift.

Neither economic growth nor the resultant effect on energy demand can be predicted confidently. The U.S. Department of Labor's moderate economic growth scenario for 1988 to 2000 assumes a 2.3-percent rate, lower than the 2.9-percent rate of the previous 12 years. This is consistent with other projections, but growth could be substantially higher or lower. In any case, it can be assumed that as long as economic growth is a national goal, demand for the services that energy provides will increase substantially.

The amount of energy that will be required to perform these services is a function of the efficiency with which it is used. As discussed in chapter 2, a particular service (e.g., transportation in a car, heating a house, making steel) can be performed in a variety of ways, some of which use far more energy than others. If the cost of energy rises (or if other incentives are applied), energy users will consider improving existing processes (e.g., insulating their house), buying more efficient equipment (e.g., higher mileage automobiles), or altering their behavior. However, rising energy costs also reduce consumers' ability to afford these investments.

Different forms of energy have different costs, but the most variable is petroleum. The price of petroleum is dependent to a large degree on political and market decisions that occur outside of the United States. The prices of other fuels are influenced by petroleum but are not subject to such large swings.

Changing technology will affect energy use by providing new options, especially as environmental regulations and resource constraints eliminate older options. For example, more stringent air emissions requirements could curtail industrial coal use, but emissions are easier to control in small facilities using the emerging technologies of fluidized-bed combustion and gasification. Improved technology is necessary for widespread use of solar energy and

[1]This discussion is drawn from U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy, OTA-BP-E-57* (Washington, DC: U.S. Government Printing Office, June 1990).

may be important for nuclear power. As discussed in chapter 2, a variety of technologies are available now in all sectors to raise efficiency, and many more could be developed and implemented.

## PROJECTIONS FOR THE FUTURE

As discussed above, the qualitative aspects of the energy situation are not by themselves very useful in projecting future energy trends. Nor do they allow any quantification of the potential impacts of future policy options. For such purposes, scenarios have been derived from the analyses developed for the OTA report on climate change.[2] A simple accounting model modified the results of the energy/economic model of the Gas Research Institute, which in turn was based in part on the Data Resources, Inc. energy model, to estimate the effectiveness of various technical options for lowering $C0_2$ emissions. The reader is referred to the OTA report on climate change for a detailed explanation of the models used and the specific assumptions involved. Two scenarios are modifications of one of these cases in order to explore a higher emphasis on solar and nuclear energy. One additional scenario (number 2) involving higher demand was created and analyzed for this study.

These scenarios reflect the major issues discussed in chapter 1 that energy decisionmakers are likely to confront in the coming years: how to reduce $C0_2$ emissions to slow global climate change, should that prove necessary, and minimize other environmental and health impacts of energy use; how to reduce dependence on imported oil; how to assure that a reasonable diversity of supply options is available at the lowest possible cost.

All the scenarios except high growth used the same economic and energy cost assumptions: gross national product (GNP) growth of 2.3 percent (a moderate projection); price increases of 3.7 percent per year for oil, 4.8 percent for natural gas, and 1.7 percent for coal. These costs are based on production costs and do not necessarily reflect prices to consumers, which may be affected by temporary market perturbations and various policies, including energy taxes. The baseline projection, which assumes no major policy changes and no major constraints, is shown under scenario 1. Higher economic growth and lower energy prices are considered in scenario 2 to explore a future where very optimistic projections are realized. This scenario differs from the others in that a higher level of goods and services requiring energy are assumed. Scenario 3 is based on the moderate scenario in the OTA climate change report and emphasizes efficiency of energy use in order to reduce demand. Scenario 4 is based on the tough scenario and represents an intensification of the measures in scenario 3 to reduce energy demand. Scenarios 5 and 6 are modified versions of scenario 3 that exploit alternative energy sources (renewable and nuclear) to reduce emissions of $C0_2$, in contrast to the major emphasis on efficiency in scenario 4.

Collectively, these scenarios are representative of the main energy choices facing the country even though four of them were created to test $C0_2$ reduction decisions. Steps to reduce $Co_2$ emissions are largely congruent with steps to address the other energy issues. One notable exception is the development of synthetic fuels to reduce dependence on imported fuels, a topic discussed in scenario 2.

These scenarios should be viewed as guidelines only, not predictions. If one proves accurate, that will be largely accidental. Energy events of the last two decades have been too capricious and turbulent to allow much confidence that all problems in making energy projections have been anticipated. Unexpected disruptions will almost certainly occur, and so may some pleasant surprises, e.g., technological developments that permit the economic extraction of our vast domestic reserves of unconventional natural gas. The scenarios are sketches of plausible energy futures and what has to be done to get there. They provide a consistent framework for decisionmakers to compare the desirability of different energy futures we could work toward, and they suggest the costs and risks involved in the necessary decisions.

### *Scenario 1: Baseline*

This scenario assumes no major policy initiatives are undertaken and present trends are largely continued. In particular, fossil fuel use continues to grow because it is the most convenient energy source available and is still affordable under the price increases assumed here. Total energy use rises

[2] U.S. Congress, Office of Technology Assessment Changing *by Degrees: Steps To Reduce Greenhouse Gases, OTA-O-482* (Washington, DC: U.S. Government *Printing Office,* February 1991).

**slowly from 83.9 quads in 1989 to 112.4 in 2015, about 1 percent per year. Demand for electric power increases at 2.3 percent per year, equaling economic growth, as has been the case in recent years. The breakdown by fuel and end-use sector is shown in table 4-1. Electricity is listed separately because it is an intermediate carrier, neither supply nor demand, and accounts for the largest single use of primary energy.**

**The baseline growth rate is slower than that of the past few years but faster than the prior 15 years. It is consistent with slowly rising energy prices and an economy that largely maintains its current mix of activities. Some improvements in efficiency are implemented so that energy intensity (energy per dollar of GDP) continues to decline. Of particular interest are the following:**

- **The highest energy growth is in the commercial sector. Industrial sector energy growth is the largest in absolute terms, but it remains modest for this sector, primarily due to reduced manufacturing growth. Transportation increases at a slightly slower rate than industry. The residential sector is essentially flat, largely because population growth is low.**
- **U.S. oil production is expected to decline from 9.73 million barrels per day (MMB/D) in 1990 to 8.61 in 2000 and 6.94 in 2015.[3] Even keeping to this schedule will require the discovery and exploitation of new fields, which are most likely to be offshore or in Alaska.**
- **Future domestic production of conventional natural gas resources will be supplemented by tight gas formations plus coal seam methane and Alaskan gas. Predictions of total production are tentative, largely because the economics of the unconventional resources are uncertain. This scenario projects a slowly rising production curve for about a decade, followed by essentially flat production.**
- **Coal remains the fuel of choice for electric power generation because of its long-term availability at low cost and the lack of major new environmental restrictions. Nuclear power declines after 2000 as plants are retired and no compelling reason arises to start many for operation before 2015.**

**Table 4-l—Baseline Energy Use and Supply (quadrillion Btu)**

| | | 1989 | | 2015 |
|---|---|---|---|---|
| Demand | | | | |
| Residential | | | | |
| Natural gas . . . . . . . . . . | | 5.0 | | 4.2 |
| Electricity[a]. . . . . . . . . . . | | 3.1 | | 4.0 |
| Oil . . . . . . . . . . . . . . . . . | | 1.8 | | 1.1 |
| Coal . . . . . . . . . . . . . . . . | | 0.1 | | 0.1 |
| Renewable . . . . . . . . . | | 0.9 | | 1.5 |
| Total . . . . . . . . . . . . . . . | | 10.9 | | 10.9 |
| Commercial | | | | |
| Natural gas . . . . . . . . . . | | 2.7 | | 3.4 |
| Electricity[a]. . . . . . . . . . . | | 2.7 | | 5.2 |
| oil . . . .'.. . . . . . . . . . . | | 0.7 | | 0.9 |
| Coal . . . . . . . . . . . . . . . . | | ne | | 0.1 |
| Total . . . . . . . . . . . . . . . | | 6.1 | | 9.6 |
| Transportation | | | | |
| Oil . . . . . . . . . . . . . . . . . | | 21.6 | | 27.5 |
| Natural gas . . . . . . . . . . | | 0.6 | | 0.7 |
| Electricity . . . . . . . . . . . | | ne | | ne |
| Total . . . . . . . . . . . . . . . | | 22.2 | | 28.2 |
| Industrial | | | | |
| Natural gas . . . . . . . . . . | | 8.3 | | |
| Oil (fuel) . . . . . . . . . . . . . | | 3.8 | | 7.7/5.0 |
| Oil (nonfuel) . . . . . . . . . | | 4.4 | | 5.7 |
| Electricity . . . . . . . . . . . | | 3.2 | | 5.3 |
| Renewable . . . . . . . . . | | 1.9 | | 3.5 |
| Coal . . . . . . . . . . . . . . . . | | 2.9 | | 4.6 |
| Total . . . . . . . . . . . . . . . | | 24.5 | | 31.8 |
| Total demand[a]. . . . . . . . . | | 63.6 | | 80.5 |
| Electricity[b] | | | | |
| Coal . . . . . . . . . . . . . . . . . . | | 16.0 | | 29.1 |
| Nuclear . . . . . . . . . . . . . . . | | 5.7 | | 3.8 |
| Gas . . . . . . . . . . . . . . . . . . | | 2.9 | | 6.3 |
| Oil . . . . . . . . . . . . . . . . . . . | | | | |
| Renewable . . . . . . . . . . . | | 1.7/3.0 | | 1.6/5/7 |
| Total . . . . . . . . . . . . . . . . . . | | 29.2 | | 46.4 |
| Supply Oil | | | | |
| . . . . . . . . . . . . . . . . . . . | | 34.0 | | 41.8 |
| Domestic . . . . . . . . . . . . | (18.3) | | (12.0) | |
| Imported . . . . . . . . . . . . | (17.0) | | (27.8) | |
| Exported . . . . . . . . . . . . | ( 1.8) | | ( 0.0) | |
| Synthetic . . . . . . . . . . . . | (ne) | | ( 20) | 22.3 |
| Gas . . . . . . . . . . . . . . . . . . | | 19.5 | | |
| Domestic . . . . . . . . . . . . | (17.5) | | (16.5) | . |
| Imported . . . . . . . . . . . . | ( 1.4) | | ( 5.8/ne | |
| Synthetic . . . . . . . . . . . . | (ne) | | | |
| Coal . . . . . . . . . . . . . . . . . . | | 18.9 | | 33.8[c] |
| Produced . . . . . . . . . . . . | (21.2) | | (40.7) | |
| Exported . . . . . . . . . . . . | ( 27) | | ( 4.0) | |
| Synfuel feed . . . . . . . . . | (ne) | | ( 29) | 3.8 |
| Nuclear . . . . . . . . . . . . . . . | | 5.7 | | |
| Renewable . . . . . . . . . . . . | | 5.8 | | 10.7 |
| Total . . . . . . . . . . . . . . . . . | | 83.9 | | 112.4 |

KEY: ne = negligible.

a Does not include conversion losses at powerplants, Which make up about two-thirds of the total consumed there.

b All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

c Note that a total of 40.7 quads of coal are mined, 2.9 quads of which are converted into 2 quada of synthetic fuel, which are included under oil.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review* 1989, DOE/EIA-0384(89), May 24, 1990, tables 1,2,3,4,5, 11, 17,25,88, and 99; Office of Technology Assessment, 1991.

[3] Derived from the U.S. Energy Information Administration, *AnnualEnergy Outlook 1990,* DOE/EIA-0383), Jan. 12, 1990, by OTA for a forthcoming update of its 1984 report *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability.*

- Security concerns increase with oil imports, but import growth rates are not so high that additions to the Strategic Petroleum Reserve (SPR) cannot keep up. By 2015, however, the Middle East supplies a very large and rising fraction of U.S. imports. Depending on the geopolitical environment at that time, the SPR might have to expand to several times its current size. The anticipated price of oil is substantially higher, which seriously aggravates the balance of trade.
- $CO_2$ emissions would rise almost 40 percent by 2015. While no environmental constraints are envisioned for the duration of this scenario, such a large additional contribution from the United States would pose a substantial risk of accelerating global climate change.
- The near doubling of coal consumption will aggravate problems in meeting local and national air quality standards unless better technology such as integrated gasifier, combined-cycle combustion becomes available.

Conclusions-This traditional approach is feasible if several conditions are met: 1) domestic oil and gas reserves prove adequate to support the projected production at reasonable prices; 2) chronic shortages of imported oil do not develop; 3) the costs of renewable energy become more competitive; 4) $CO_2$ and other pollution problems are not so serious as to restrict the coal option; and 5) economic growth does not greatly exceed the assumed level. If these conditions are not met, energy prices will rise with tighter supply, and demand will shrink to fit (as it always does in principle), but not without likely economic penalties, e.g., increased inflation.

### *Scenario* 2: *High Growth*

Scenario 1 does not represent an upper limit on energy growth even though there are more potential constraints on supply (e.g., resource depletion, siting difficulties, regulations, etc.) than on demand. In fact, there is no absolute upper limit on energy supply growth that could be usefully defined at this time.

Scenario 2 was created for this report to explore the implications of higher energy growth. It is not found in the OTA report on climate change.[4] Though even higher growth could be envisioned, the assumptions made for this scenario are sufficiently optimistic that higher growth is unlikely. Economic growth is assumed to be in the high range of projections, perhaps 3 percent, resulting in higher demand for energy services. Energy costs have to stay low despite higher demand, either because of technological breakthroughs or unexpected resource discoveries. No major new environmental regulations are expected in this scenario.

A guiding principle behind this scenario is that the United States maintains an orientation toward energy production rather than energy conservation. The result will be higher demand for energy services, tempered by the faster replacement of older, less efficient facilities and equipment. Total energy demand grows 1.7 percent annually, reaching 127 quads in 2015. Energy use in all sectors increases faster than in scenario 1. The industrial sector experiences 2-percent growth, consistent with a resurgence in manufacturing. The commercial sector rises faster at 2.7 percent, which is slightly above the rate assumed in scenario 1. Transportation energy demand increases 1.2 percent annually over the study period. Lower fuel prices provide less incentive to purchase efficient automobiles, and commercial traffic will be higher than in scenario 1. Residential sector energy demand grows at 1 percent with demand for new and larger houses; no such growth occurs in the base scenario. Table 4-2 summarizes the details.

Electricity demand increases 3 percent annually in this scenario. However, it is important to note that the additional power, relative to scenario 1, is produced with little additional fuel consumed. Under the conditions of this scenario-higher, sustained growth and greater confidence--utilities will be more willing to build new plants and replace older ones. New plants adopting modern technology should have significantly higher efficiency. Gas turbines should be over 50-percent efficient, and coal plant efficiency may reach 45 percent for some technologies. Transmission losses should be reduced as well, as a result both of new transmission technology and because much of the growth will be from small units close to load centers (e.g., cogeneration plants on-site at manufacturing facilities), minimizing the need for transmission. The net delivered efficiency assumed in this scenario is 35 percent, compared to 31 percent in the base scenario.

[4] U.S. Congress, Office of Technology Assessment, op.cit., footnote 2.

### Table 4-2-High Growth Energy Use and Supply (quadrillion Btu)

| | 1989 | 2015 |
|---|---|---|
| **Demand** | | |
| Residential | | |
| Natural gas | 5.0 | 5.5 |
| Electricity[a] | 3.1 | 4.8 |
| Oil | 1.8 | 1.3 |
| Coal | 0.1 | 0.1 |
| Renewables | 0.9 | 1.5 |
| Total | 10.9 | 13.2 |
| Commercial | | |
| Natural gas | 2.7 | 3.6 |
| Electricity[a] | 2.7 | 5.5 |
| Oil | 0.7 | 0.9 |
| Coal | 0.0 | 0.1 |
| Total | 6 . 1 | 10.1 |
| Transportation | | |
| Oil including synfuel... | 21.6 | 32.6 |
| Alcohol (biomass) | | 0.5 |
| Natural gas | 0.6 | 1.5 |
| Electricity[a] | ne | 0.7 |
| Total | 22.2 | 35.3 |
| industrial | | |
| Natural gas | 8.3 | 10.9 |
| Oil (fuel) | 3.8 | 5.6 |
| Oil (nonfuel) | 4.4 | 6.5 |
| Electricity[a] | 3.2 | 6.4 |
| Renewables | 1.9 | 3.8 |
| Coal | 2.9 | 5.3 |
| Total | 24.5 | 38.5 |
| **Total demand[a]** | 63.6 | 97.1 |
| **Electricity[b]** | | |
| Coal | 16.0 | 27.4 |
| Nuclear | 5.7 | 8.2 |
| Gas | 2.9 | 7.0 |
| Oil | 1.7 | |
| Renewables | 3.0 | 1.6/5.5 |
| Total | 29.2 | 49.7 |
| Supply Oil | 34.0 | 48.5 |
| D o m e s t i c . | (183) | (140) |
| imported | (17.0) | (26.5) |
| Exported | (1.8)/ne | (0 0) |
| Synthetic | | (8.0)/28.5 |
| Gas | 19.5 | |
| Domestic | (17.5) | (21.0) . |
| imported | (1.4)/ne | (3 5) |
| Synthetic | | (4.0)32.9 |
| Coal[c] | 18.9 | |
| Produced | (21.2) | (540) . |
| Exported | ( 2 2 | ( 4 0 ) |
| Synfuel feed | | (17.1) |
| Nuclear | 5.7 | |
| Renewable | 5.8 | 11.3 |
| Total | 83.9 | 129.4 |

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of thetotal consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

[c] Note that a total of 54.0 quads of coal are mined, 17.1 quads of which are converted into 12 quads of synthetic fuel, which areindudedunderoiland gas.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989,* DOE/EIA-0384(89), May *24,1990,* tables 1,2,3,4,5,11,17,25,88, and 99; Office of Technology Assessment, 1991.

Twenty years ago, these energy growth rates would have been considered unrealistically modest. Now they appear high, largely because we have learned that it is easier to control energy growth than to meet high demand growth. In addition, economic growth forecasts are lower and projected energy prices are higher. However, if energy prices remain at current levels (about $20 per barrel for petroleum and equivalent for other fuels), the higher growth of the late 1980s could continue. Energy prices significantly higher than those in scenario 1 would not be consistent with high demand growth (except for improbably high economic growth rates), because they would trigger efforts to increase efficiency of use.

Therefore, significant advances in energy production technology must be assumed for this scenario in order to control costs. Moreover, the modest energy price increases assumed here would be insufficient impetus to spur these advances. As a result, Federal and private sector efforts--especially for research, development, and demonstration (RD&D)--would be critical to achieving the supply outcomes. It must also be assumed for this scenario that $CO_2$ emissions are determined by policymakers to be a minor problem.

A substantial number of electric vehicles (EVs) are postulated for this scenario, largely because of local air pollution problems. About 2.4 quads of fuel would be required to produce and store the 0.7 quads of electricity that EVs would consume. This electricity would replace about 3.5 quads of oil, because EVs are more efficient than gasoline-powered automobiles. The use of natural gas in vehicles increases significantly as well.

In order to meet the supply projections, coal, natural gas, and nuclear energy would all have to be expanded significantly. Domestic oil production is almost certain to continue its decline, though improvements in enhanced oil recovery techniques could sustain production levels at existing fields. Exploration and development of presently protected areas in Alaska and offshore are probably necessary to keep the rate of production from declining faster than assumed here. Oil imports will rise considerably, unless synthetic fuel technologies are extensively applied. Renewable energy technologies are not likely to be widely competitive with relatively low cost conventional sources, but some penetration

Photo credit: Electrk Vehicles SA

Prototype electric minibus.

is likely, and technological breakthroughs are possible.

Coal will be used both directly (primarily for electric generation as it is now) and for synthetic fuels. The additional 300 gigawatts of electric power output (GWe) of coal-fired generating capacity should present no insurmountable technical or resource difficulties, even though most plants will use relatively new technology (most probably integrated gasification combined cycle (IGCC)) to meet air pollution emission regulations. The efficiency of new plants should average about 40 percent, but system efficiency will be lower because of older plants on line and increased use of storage to meet peak loads.

Few coal plants have been ordered over the past few years, because utilities have shied away from capital-intensive, long leadtime investments due to uncertainties about growth, capital availability, and regulatory treatment. This attitude is likely to change in a period of sustained economic growth. Both utilities and independent power producers (IPPs) could favor coal-fired plants if they are the lowest cost options in the long run. Even now, some gas-fired facilities are being designed to accommodate coal gasifiers should that prove more economical. The costs of constructing generating facilities and purchasing coal are likely to remain relatively stable and predictable over the next several decades under the assumptions of this scenario.

Synthetic liquid fuels from coal or oil shale are unlikely to be sufficiently competitive with petroleum by 2010 that much production capacity would be built without government incentives. However, security concerns over high petroleum imports may provide compelling policy reasons to ensure at least a modest level of such production. This scenario provides for liquid fuel production of 4 MMB/D by 2015. As discussed in chapter 3, several liquid fuel technologies could be used. At present, all of these technologies raise significant concerns over environmental impacts as well as costs, so major development and demonstration programs will be necessary in addition to promotional programs.

The national security rationale is less pertinent to synthetic pipeline gas, because foreign gas sources are more stable (Canada is the main supplier) and, unlike petroleum, the production of domestic natural gas can be increased appreciably. In fact, this scenario is largely contingent on an increasing supply of relatively inexpensive gas. Natural gas production, however, is unlikely to be rising by 2015, and may well be falling significantly. Therefore, the need for replacement sources may be substantial. In addition, an industry that produces synthetic oil would find it simple to produce synthetic gas, so the costs may be reasonable. Therefore, this scenario assumes that about 4 trillion cubic feet (Tcf) of synthetic gas will be produced annually.

Nuclear energy could be important in this scenario if the problems that have immobilized it are overcome. In particular:

- Costs must be predictable, stable, and competitive with coal;
- The institutions that build, operate, and regulate nuclear powerplants must perform their tasks more efficiently than has been the norm; and
- The public must be convinced that nuclear energy is safe, environmentally benign (including waste disposal), and in their best interest.

If these conditions are met, virtually any number of nuclear plants could be built. Yet the availability and competitiveness of alternatives to nuclear power suggest it is unlikely that huge numbers of new plants will be built. The viability of nuclear power will have to be demonstrated anew before any major commitment to construction is made. Even if relatively familiar light water reactor (LWR) technology is used, no reactor is likely to be ordered much before 1995 or completed before 2000.

**Assuming a** construction schedule of 5 years,[5] only those reactors ordered by 2010 would be ready for electricity generation by 2015. Since much of the industry would have to be revamped, only a few thousand megawatts of electric power output (MWe) per year could be supplied at first. Less familiar technology, e.g., high temperature gas reactors, will require longer to develop.

This scenario optimistically projects the construction of approximately 70,000 MWe to supplement existing nuclear capacity (about 100,000 MWe) by 2015. Accounting for existing plant retirements, total nuclear capacity of about 140,000 MWe would be online by 2015. Only a major national commitment to nuclear energy could result in faster growth, but that would be a high risk strategy considering the history of nuclear power in this country. Such a strategy is discussed under scenario 6. If no nuclear plants are ordered, an equivalent amount of coal- and gas-fired capacity would have to be added to meet the supply projections of this scenario.

Renewable supplies are only slightly higher than in scenario 1. The lack of urgency to replace fossil fuels assumed here leads to slow development of renewable, and the low costs of fossil fuels limit competitiveness. Much of the renewable energy depicted in table 4-2 is hydroelectric power, but contributions from wind, solar thermal, and photovoltaics could become significant over this period. The transportation sector is assumed to consume about half a quad of alcohol from biomass. Alcohol fuel could become quite important in urban areas for environmental reasons, but it is not clear how much will be made from biomass instead of coal or natural gas unless $CO_2$ emissions are a limitation. Therefore, most of the synthetic fuel in this scenario is derived from coal. As with nuclear energy, renewables have more promise beyond the timeframe of this scenario.

Conclusions—Where scenario 1 assumed no major policy initiatives and no major energy supply surprises, scenario 2 depends on several pleasant surprises: costs stay low because fossil fuels are plentiful; domestic oil production declines more slowly than some observers currently expect; natural gas production increases because discoveries keep abreast of depletion; and technology advances in these and other supply areas help keep these fuels competitive. In addition, features of the scenario probably would require policy measures to encourage production (e.g., synthetic fuel initiatives to limit imports and expanded offshore oil exploration and development). Finally, as noted above, it is assumed that no new major environmental constraints emerge.

If these assumptions prove out, the nation's mid-term energy future will present few problems. Some of the assumptions are likely to prove accurate, but depending on the entire package would be extremely risky, and would do little to prepare the country for longer-term problems such as climate change and the depletion of the lowest-cost fossil fuel reserves. Petroleum prices are almost certain to be much higher by the mid-21st century when U.S. production will be considerably lower than now. Whether or not serious global climate changes are imminent, they are likely eventually, probably by 2050. Rapid exploitation of fossil fuels would increase that risk and make the transition to alternative fuels more difficult and costly.

The energy system under this scenario is vulnerable to disruptions-petroleum import interruptions, environmental constraints, and increasing public opposition to energy facilities. Hence, policy measures encouraging production are likely to be required to ensure the supplies assumed in this scenario. Synthetic fuel to moderate reliance on imported petroleum has already been mentioned. To compensate for the higher rate of imports, the SPR would have to be enlarged. Nuclear power will require policy leadership to rebuild public confidence. Additional Federal RD&D on clean coal combustion could be necessary in order to reduce total emissions from a greater number of plants if current efforts prove inadequate. Siting policies may also be required to minimize delays to powerplants, transmission lines, and other facilities. Some of these measures are likely to be expensive and controversial.

The costs involved in this scenario are difficult to compare directly with the other scenarios, because the assumptions are not entirely consistent. Capital investments are higher than scenario 1, because

[5] Small modular reactors might be installed faster with concurrent on-site preparation and factory construction but this approach introduces additional uncertainties related to economics and operability that would delay their introduction.

more energy must be produced, but higher economic growth supports the new construction.

Overall, this scenario is notable for its failure to take advantage of efficiency opportunities that make economic sense even at fuel prices lower than assumed here. In keeping with long-term past trends, efficiency improves, but only slowly because energy costs are a small portion of overall costs, and because relatively little attention is focused on efficiency. The one exception is the electric utility industry, where new generating technology is emerging with significantly higher efficiency.

### *Scenario* 3: *Moderate Emphasis on Efficiency*

As has been noted several times in this report, many opportunities exist for reducing energy consumption in all sectors of the economy. Most of these opportunities require some investment. Some offer compelling economic benefits, while others are too expensive to warrant consideration unless energy costs rise considerably above expected levels.

This scenario explores the results if the policies discussed in the next chapter are implemented to encourage investments that would yield net economic benefits when amortized over the expected lifetime of the equipment, in the context of the fuel price increases noted at the start of this chapter. Few energy users make their decisions on this basis. Most consumers, insofar as they consider energy costs at all, look for a payback of no more than a few years on additional investment to reduce energy consumption, a rate of return greatly exceeding prevailing interest rates. Industrial users are the most cost-conscious, but even well-run manufacturing companies fail to make attractive investments to save energy for a variety of reasons, e.g., overall corporate strategy, technical and economic uncertainty, and capital spending limits. Therefore this strategy will require significant policy changes even though all the steps are in the long-term interests of the individual decisionmakers as well as the Nation.

Several significant advantages would accrue to the United States from a higher level of energy efficiency:

- If global warming is confirmed as a serious problem, reduced emissions of $CO_2$ would become important. Higher efficiency will be the most effective strategy to reduce carbon emissions over the next several decades. Even without clear indications of significant warming trends now, many analysts have argued that efforts to offset carbon emissions would be prudent now. In addition, lower demand for energy would reduce other environmental insults stemming from the production and use of fossil fuels.
- The economy would benefit, especially in the long-run, because energy inputs would be used at a more nearly optimal level. Thus, U.S. products would generally become more competitive in world markets.
- Resources of low-cost premium fuels would last longer because of the reduced demand for petroleum and natural gas. The forced transition to less convenient fuels could be delayed by a decade or more.
- Vulnerability to petroleum import disruptions would be lessened, and the SPR could be kept smaller.
- There would be less intrusion from energy facilities on society, which often resists such construction and operation.

The major drawback to this strategy is that the Government would have to induce people to do things that apparently most have no particular interest in doing. Tax credits, information programs, and other initiatives have had some impact, but the biggest single motivation for efficiency improvements appears to have been higher prices.[6]

The major effect of implementing this scenario is to moderate the growth of energy demand. Table 4-3 compares the energy supply and demand for this scenario with that of scenario 1. Overall, demand is down about 13 percent by 2015 from the base case but still up about 10 percent from current levels.

The efficiency improvements that would be implemented and their potential effect on energy consumption are listed in table 4-4. These measures are described in chapter 2. The assumption here is that each energy consumer always chooses the improvements that are expected to repay their incremental added costs with energy savings over their lifetimes. Considering the diversity of deci-

[6] In the United States, the major exception to this general rule has been the corporate average fuel economy (CAFE) standard for light-duty vehicles. American made vehicles have nearly the same mileage as the equivalent models made in Europe or Japan, but the U.S. fleet has a lower average because Americans buy bigger cars. One of the major reasons for this difference is that gasoline costs several times as much in most other countries.

**Table 4-3-Moderate Efficiency Scenario Energy Use and Supply (quadrillion Btu)**

| | 1989 | 2015 |
|---|---|---|
| Demand | | |
| Residential | | |
| Natural gas | 5.0 | 3.6 |
| Electricity[a] | 3.1 | 3.3 |
| Oil | 1.8 | 0.9 |
| Coal | 0.1 | 0.1 |
| Renewable | 0.9 | 1.2 |
| Total | 10.9 | 9.1 |
| Commercial | | |
| Natural gas | 2.7 | 3.0 |
| Electricity | 2.7 | 3.4 |
| Oil | 0.7 | 0.7 |
| Coal | ne | 0.1 |
| Total | 6.1 | 7.2 |
| Transportation | | |
| Oil | 21.6 | 24.8 |
| Natural gas | 0.6 | 0.7 |
| Electricity[a] | ne | ne |
| Total | 22.2 | 25.5 |
| Industrial | | |
| Natural gas | 8.3 | 7.5 |
| Oil (fuel) | 3.8 | 4.4 |
| Oil (nonfuel) | 4.4 | 5.7 |
| Electricity[a] | 3.2 | 4.4 |
| Renewables | 1.9 | 3.2 |
| Coal | 2.9 | 3.3 |
| Total | 24.5 | 28.5 |
| Total demand[a] | 63.6 | 70.3 |
| Electricity[b] | | |
| Coal | 16.0 | 17.8 |
| Nuclear | 5.7 | 6.6 |
| Gas | 2.9 | 4.1 |
| Oil | 1.7 | 1.5 |
| Renewable | 3.0 | 4.5 |
| Total | 29.2 | 34.4 |
| Supply Oil | 34.0 | 37.9 |
| Domestic | (183) | (120) |
| imported | (17.0) | (249) |
| Exported | ( 1.8) | ( 00) |
| Synthetic | (ne) | (1.0) 188 |
| Gas | 19.5 | |
| Domestic | (17.5) | (17.0) . |
| Imported | ( 1.4) | (1.8)/ne |
| Synthetic | (ne) | |
| Coal[c] | 18.9 | 21.1 |
| Produced | (21.2) | (2%5) |
| Exported | ( 27) | (5.0) |
| Synfuel feed | (ne) | (1.4) |
| Nuclear | 5.7 | 6.6 |
| Renewable | 5.8 | 8.9 |
| Total | 83.9 | 93.3 |

KEY: ne = negligible.

[a]Does not include conversion lossesat powerplants, which make up about two-thirds of the total consumed there.

[b]All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

[c]The 1.0 quad of synthetic fuel made from 1.4 quads of coal is included under oil.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 7989,* DOE/EIA-0384(89), May 24,1980, tables 1,2,3,4,5,11,17,25,88, and 99; Office of Technology Assessment, 1991.

**Table 4-4-Potential for Energy Demand Reduction From Base Case by 2015 (quad/year)[a]**

| | Moderate efficiency | High efficiency |
|---|---|---|
| Residential buildings | | |
| Envelopes | 0.96 | 1.48 |
| Heating and cooling | 0.07 | 0.37 |
| Hot water, appliances | 0.89 | 1.41 |
| Retrofits | | |
| Envelopes | 0.59 | 0.67 |
| Lighting | 0.44 | 0.59 |
| Total | 2.89 | 4.51 |
| Commercial sector | | |
| Envelopes | 1.70 | 2.96 |
| Heating and cooling | 0.74 | 1.15 |
| Water heating | 1.55 | 2.22 |
| Lighting | 1.18 | 1.55 |
| Office equipment | 0.07 | 0.07 |
| Cogeneration | 0.15 | 1.41 |
| Retrofits | | |
| Envelope | 0.59 | 0.59 |
| Lighting | 0.37 | 0.37 |
| Total | 6.29 | 10.36 |
| Transportation | | |
| New auto efficiency | 0.59 | 2.70 |
| New light trucks | 0.37 | 1.92 |
| New heavy trucks | 0.30 | 1.77 |
| Non-highway vehicles | 0.37 | 0.89 |
| Public transit | 0.15 | 2.59 |
| improved maintenance | 0.22 | 0.30 |
| Improved traffic flow | 0.89 | 1.04 |
| Ride sharing, etc. | 0.30 | 0.74 |
| Total | 3.11 | 10.73 |
| Industry | | |
| Cogeneration | 0.59 | 4.07 |
| Lighting | 0.44 | 0.71 |
| Electric motors | 0.89 | 2.85 |
| New processes | 2.22 | 6.07 |
| Process retrofits | 1.41 | 1.48 |
| Total | 5.62 | 17.06 |

[a]Because of the form of the data and the conversion method, all values are approximate andshould be used for general guidance only. Totals are not always equal tothesum of the parts because maximum values maybe inconsistent, and other factors may reinvolved.

SOURCE: Derived from U.S. Congress, *Changing by Degrees: Steps To Reduce Greenhouse Gases, OTA-O-482* (Washington, DC: U.S. Government Printing Office, February 1991), table A-3.

sionmakers and their different situations, this is a highly artificial assumption. However, regulation (e.g.,fuel economy standards for automobiles) and transfer of decisions to energy service companies (perhaps gas and electric utilities with incentives to increase efficiency) could produce many of the needed choices. In addition, unanticipated, improved technology is likely to appear that makes possible even greater savings. In general, therefore, this assumption provides a useful standard to compare the potential efficacy of policies, as described in the next chapter.

### Residential/Commercial Sector

In the residential/commercial sector, new buildings require only 50 percent of the energy used in current new buildings for heating because of better construction techniques, insulation, and windows. Improved lighting and equipment provide additional savings. For the most part, the technology for these improvements is familiar. Some of the gains depend on the commercialization of new technology, e.g., heat pump water heaters, but none of the required advances is particularly dramatic or risky. Nor are consumers required to accept many technologies that would be significantly more difficult to manage than existing equivalents.

The uncertainties are primarily with the decisionmaking to implement the improvements, particularly what it will take to induce consumers to invest in more expensive houses and appliances in order to save on operating costs. In no case would the additional investment be extremely high (e.g., anew house might cost a few thousand dollars more because of improved insulation and appliances). However, the decisionmaking in this sector has been less predictable than in the others. Overall, energy use in the residential/commercial sector could actually decline by 2015 with these changes despite a substantial increase in per capita wealth.

Electricity use increases in both the residential and the commercial sectors. Natural gas declines in homes because the average thermal efficiency of houses increases. Natural gas and electricity will dominate the supply of energy under any conditions. The balance between the two will depend on relative costs and availability, as well as the success of various RD&D and commercialization programs. Policy decisions will strongly influence the successful implementation of new technologies, and the implications for the country of the various choices are significant, as described in the following chapter. Oil is likely to continue its decline because of cost and convenience considerations. Wood and other forms of solar energy could be increased by various policy initiatives but, as discussed in scenario 5, the initiatives would have to be powerful for the additional contribution to be large in this timeframe. In the long term, renewable could become very important in the residential/commercial sector.

### Transportation Sector

Energy use in the transportation sector is much less likely to drop than in the residential/commercial sector, but the growth rate can be slowed. Cost-effective improvements in the mileage of new cars, trucks, and airplanes will reduce demand significantly, but the increase in miles traveled will outweigh them. In the long term, improved mileage will make a dramatic difference. With improvements to already existing technology, the fuel economy of new automobiles in this scenario increases to 39 miles per gallon (mpg) by 2010, as compared to 36.5 mpg in the base case and 27 mpg now, using only evolutionary improvements to existing technology, as discussed in chapter 2. However, over the next 20 years, nontechnical measures, e.g., increased van pooling, improved vehicle maintenance, and reinstatement of the 55 mile per hour (mph) speed limit, will have more impact.

Achieving major fuel economy gains in the transportation sector may be hindered by conflicting demands. For example, reducing vehicular emissions often results in some compromise to fuel efficiency and vice versa. The expected growth of alternative fuels resulting from the 1990 amendments to the Clean Air Act may reduce oil imports but does not promise greater efficiency. Indeed, the recent revisions to the Clean Air Act mandate several changes that will affect how the transportation sector uses fuel. Gasoline will still be the dominant fuel by 2015, but the large, powerful cars that many consumers prefer now will be squeezed between demands for cleaner emissions and higher mileage. In some metropolitan areas, alternative fuels, e.g., methanol and electricity, will be favored, but it is assumed here that their penetration is too small to be significant.

### Industrial Sector

The diversity of the industrial sector complicates any analysis of future fuel use. Several fuels, various processes, and different industries with a variety of financial situations must be considered. Over the past 17 years, industry has made notable” strides in increasing energy efficiency for economic reasons. More improvements are possible, particularly through electric motor improvements, process modification, lighting, and energy management systems, and with processes specific to certain industries, but the gains will be relatively modest. About 15 percent

(4 quads) of the energy required in the base case is saved by these measures by 2015, but a net increase of 4 quads over 1987 is still required.

Fuel shifting within the industrial sector is relatively easy for applications such as process heat and cogeneration (about 60 percent of all energy used in manufacturing), but quite difficult or impossible for other categories. Many boilers and heaters incorporate dual-firing capability to switch between oil and natural gas as economics and emission regulations dictate. Coal can also be a major energy source, actually surpassing oil by 2015 in this scenario. Policy incentives or disincentives focused on natural gas and coal are likely to have more effect than those aimed at efficiency.

### Electric Power Sector

The electric power sector consumes more primary energy than any of the three sectors discussed above. One of the main issues related to electric power involves nonfossil energy sources, which are discussed in scenarios 5 and 6. There are also some important options to raise the efficiency of the sector through improved generation and transmission, but few are implemented, because so little new generating capacity is required. In this scenario, demand for electricity is lower than in the base case because the efficiency of use increases. Demand rises from 2.7 trillion kWh (kilowatt-hours) in 1987 to 3.4 trillion kWh in 2015, compared to 4.6 trillion kWh in 2015 in the base case.

In the long term, new plants can be significantly more efficient than existing ones. The efficiency of new technologies, e.g., fuel cells and intercooled steam-injected gas (ISTIG) turbines, may approach 50 percent, higher than any existing technology. Advanced pulverized coal or IGCC technologies should also have significantly higher efficiency than current plants. The competitiveness of the new technologies will depend in part on environmental constraints. Tighter restrictions on sulfur oxides ($SO_x$) and nitrogen oxides ($NO_x$) will favor new technologies that can be cleaner as well as more efficient.

Conclusions-There are two major reasons why policymakers might choose to move the country toward this scenario. One is economic: this is the least cost scenario, and implementing it (or some of its major features) would improve the economic well-being of the country and its international competitiveness. The other reason is environmental: reducing energy use generally, though not always, reduces emissions of pollutants from both the use and supply of energy. This scenario would provide many environmental benefits without drastic curtailments. It represents a moderate response to concerns over global climate change and reducing $CO_2$ emissions, consistent with the conclusion that the problem has not been verified at present but maybe serious in the coming decades.

As noted above, however, this scenario will not occur by itself. There are too many constraints and market imperfections for people to make all the necessary decisions that would be required to implement this level of efficiency. Policy initiatives that would help overcome these constraints are discussed in the following chapter.

## *Scenario 4: High Emphasis on Efficiency*

Extreme measures to improve efficiency could be justified under some circumstances. Perhaps global warming will be confirmed as an imminent problem with potentially devastating consequences, or international political instability will severely threaten the supply of petroleum. Even in highly efficient countries, almost any activity consuming energy could be accomplished with much less. If energy were to become very expensive or limited in availability, the number of viable, alternative approaches to reduce energy use would increase. This scenario incorporates measures that are equivalent to the most efficient that have been demonstrated to date and assumes that these are widely applied. Table 4-5 shows the energy use that results. Table 4-4 lists the measures that are implemented.

### Residential Sector

Energy use in the residential sector drops sharply compared to the last scenario. Residential buildings are constructed to such high standards that heating requirements in new northern homes are reduced 85 percent from average existing stock, and air conditioning by 45 percent. These are extremely optimistic projections based on the assumptions that essentially every new house will match the most efficient houses currently available and be maintained in that condition.

Superinsulation, including the latest developments in windows (which are quite expensive) can achieve as much as a 75-percent reduction in

**Table 4-5-High Efficiency Scenario Energy Use and Supply (quadrillion Btu)**

| | 1989 | 2015 |
|---|---|---|
| **Demand** | | |
| Residential | | |
| Natural gas | 5.0 | 2.9 |
| Electricity[a] | 3.1 | 2.6 |
| Oil | 1.8 | 0.8 |
| Coal | 0.1 | |
| Renewables | 0.9 | ne/0.6 |
| Total | 10.9 | 6.9 |
| Commercial | | |
| Natural gas | 2.7 | 3.8 |
| Electricity[a] | 2.7 | 1.7 |
| Oil | 0.7 | 0.3 |
| Coal | ne | 0.1 |
| Total | 6.1 | 5.9 |
| Transportation | | |
| Oil | 21.6 | 17.7 |
| Natural gas | 0.6 | 0.7 |
| Electricity[a] | ne | 0.1 |
| Total | 22.2 | 18.5 |
| industrial | | |
| Natural gas | 8.3 | 7.7 |
| Oil(fuel) | 3.8 | 3.3 |
| Oil (nonfuel) | 4.4 | 5.7 |
| Electricity[a] | 3.2 | 3.2 |
| Renewables | 1.9 | 2.2 |
| Coal | 2.9 | 1.5 |
| Total | 24.5 | 23.6 |
| Total demand[a] | 63.6 | 54.8 |
| **Electricity**[b] | | |
| Coal | 16.0 | 5.3 |
| Nuclear | 5.7 | 6.8 |
| Gas | 2.9 | 5.3 |
| Oil | 1.7 | 0.2 |
| Renewables | 3.0 | 5.2 |
| Total | 29.2 | 22.8 |
| **Supply** Oil | 34.0 | 27.8 |
| Domestic | (183) | (120) |
| imported | (17.0) | (15.8) |
| Exported | 1.8/ne | (0.0)/ne |
| Synthetic | | |
| Gas | 19.5 | 20.3 |
| Domestic | (17.5) | (1%5) |
| imported | (1.4)/ne | (2.8)/ne |
| Synthetic | | |
| Coal | 18.9 | 7.0 |
| Produced | 21.2/2.7 | (13.0) |
| Exported | | (6.0)/ne |
| Synfuel feed | | |
| Nuclear | 5.7 | 6.8 |
| Renewable | 5.8 | 8.0 |
| Total | 83.9 | 70.0 |

KEY: ne = negligible.

[a]Does not include conversion losses at powerplants, which makeup about two-thirds ofthetotal consumed there.

[b]All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: 1989 data-U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May24,1990,tables 1,2,3,4,5, 11,17,25,88,and 99; Office of Technology Assessment, 1991.

residential heating. Exceeding 75 percent will require meticulous attention to design, construction, and materials, and possibly, compromises on appearance and lifestyle as well. For example, houses and their windows may have to be oriented toward the sun (rather than toward the street), or the number of windows could be reduced.

Very tight houses require ventilation systems to keep indoor air pollution at tolerable levels. As air exchange is reduced by tightening shells, problems arising from indoor air centaminants (radon, $NO_x$ from natural gas cooking, vapors from building materials) and irritants (particulate, aerosols) will worsen unless countervailing measures are taken. Fireplaces and woodstoves would be incompatible with supertight houses, because they require continual ventilation while in operation. Even with heat recuperators, significant heat losses from ventilation systems will interfere with the 85-percent heat reduction goal. As a result, multiunit buildings may have to be encouraged as an important alternative to single family homes in order to achieve the energy projections for this sector.

Existing building shells are aggressively retrofitted in this scenario. Energy savings of 20 to 30 percent are anticipated. This goal is less controversial than that for new houses.

In addition, appliances will have to be as efficient as currently feasible. Electric or gas-fired heat pumps or pulse furnaces would replace conventional furnaces in new construction. Electric heat pumps would be at least 50-percent more efficient than those in use now. Water would also be heated with heat pumps. Lighting will be primarily with fluorescent or halogen bulbs. Important appliances such as refrigerators, ovens, and clothes dryers increasingly are based on new technology that cuts energy consumption dramatically.

These changes will add substantially to the cost of buying a home, perhaps $6,000 to $8,000 for the supertight envelope. Total costs, including lost living space because of thicker walls and efficient equipment would be higher (though heating and cooling equipment might be cheaper than in a conventional house because small units would be adequate). The energy costs of the buildings are quite low, but the savings may not be commensurate with the additional capital costs if the price of energy to the consumer follows the assumptions listed earlier in this chapter.

### Commercial Sector

Energy consumption in the commercial sector drops 30 percent relative to the moderate projection scenario. Buildings require 25 percent of the current average for heating, and appliances are as efficient as the best available now. The most notable shift is the replacement of purchased electricity with natural gas, some of which is used in cogeneration.

### Transportation Sector

The transportation sector produces large savings relative to the last scenario, mostly because mileage standards on new automobiles are raised sharply. The previous scenario raised the 2010 average from the 36.6 mpg of the base case to 39.0 mpg, which would have little effect on consumer choice or cost. The increase to 55.0 mpg here would require an aggressive emphasis on new technology, such as adiabatic diesel engines, lighter materials, and continuously variable transmissions. Some shift toward smaller cars in the fleet mix would be required to meet this standard if the technological improvements prove inadequate. Only one or two models on the market now are rated at 55 mpg, and these are very small. In addition, there will have to be a strong emphasis on car pooling, public transportation, and advanced traffic control. The 55-mph-speed limit is reinstated under this scenario as well.

Although they are not emphasized here, alternative fuels and electric vehicles could play a large role under the conditions of this scenario. If the concern is over $CO_2$ emissions, then the replacement of gasoline by methanol from biomass would have substantial benefits. Methanol from natural gas would be beneficial (but less so), while synthetic fuels from coal or oil shale would be very counterproductive as an option to reduce $CO_2$ emissions. If energy security is the concern, any of these alternative sources would serve to reduce imports of petroleum and so would be consistent with this scenario. However, security is unlikely to be the major issue driving this scenario, because it would be cheaper and easier to enlarge the SPR. Alternative fuels and electric vehicles are discussed in the last two scenarios.

### Industrial Sector

Energy consumption in the industrial sector would decrease more than 25 percent from current levels under this scenario. The efficiency gains are even greater than this, but economic growth offsets many of them. Process changes provide the greatest energy savings, followed by improved maintenance, more efficient electric motors, and cogeneration growth. Some of the new processes will require research and development (R&D) and probably Government support for demonstrations. Industry is willing to accommodate changes to improve energy efficiency, but only if the changes are demonstrably cost-effective and of acceptable risk, suggesting that an increase in the price of energy would be the most effective motivation. The major difference between this scenario and the previous one is that the universe of acceptable technological options to save energy expands, and increased use is made of technologies implemented in scenario 3. Some of the most important changes are in industry-specific processes, e.g., direct steelmaking and biopulping for papermaking.

Widespread implementation of many of these options would require major alterations to old facilities or the construction of entirely new ones. These major changes would not be done purely for energy reasons, though the energy savings would represent a significant part of the economic benefits. Therefore, this scenario is most likely to be initiated as part of an overall upgrading of much of the industrial infrastructure in this country. Such an overhaul is beyond the scope of this report, but it should be noted that considerable promise exists for major industrial gains in both energy efficiency and economic competitiveness.

### Electric Power Sector

Efficiency gains in the electric power sector are slightly greater than in scenario 3. Improved efficiency in the other sectors controls electricity demand to the point where few (if any) new generating facilities are required. While this eliminates a source of higher efficiency, many generating plants would have to be retired, and these are likely to be the least efficient ones. Retrofits to existing plants would raise efficiency modestly. If further gains are required in the electric power sector, existing plants could be replaced with new ones.

The motivation for much greater efficiency is important here. If the goal is to increase energy security, then replacing existing plants has little value. Only 5 percent of the oil consumed in this country is used to generate electricity, and most generating plants burn coal, which is not a security problem. If the motivation is to reduce $Co_2$ emissions--generating stations produce over one-third of all the $CO_2$ emitted in the United States-then replacements may be warranted. However, the environmental benefits of replacing an old coal plant with anew one are much smaller than the benefits of replacing it with a nonfossil plant. This approach is considered in the next two scenarios.

Therefore the major assumption of the high efficiency scenario is that most existing coal plants are retired by 2015. Coal consumption in the sector drops by almost two-thirds. As noted below, this would have extremely serious economic consequences in some coal-producing areas. Most new construction is highly efficient combined-cycle, gas-fired technology. Some nuclear (5 GWe) and renewable (15 GWe, mostly hydroelectric) energy is also included. In addition, the improved operation of existing plants raises their efficiency by about 5 percent, as in the previous scenario.

Conclusions-This scenario is notably more successful in reducing energy demand than the previous one, but it relies on measures that would be even more difficult to implement. Housing and automobiles would be significantly more expensive to purchase, though cheaper to operate. Much new technology, particularly in the transportation and industrial sectors, is assumed to be available and reliable. Industry may find more compensating advantages than consumers, but companies would still find their planning processes heavily influenced by this major effort to reduce national energy use.

Therefore, this scenario is very unlikely to be implemented unless driven by major national threats. As noted above, the only threats that appear sufficiently ominous over the next 25 years are severe oil import disruptions and global warming. By itself, this scenario would not solve either problem, but it probably represents a practical upper limit for national demand reduction efforts.

The two remaining scenarios are alternative, though not necessarily incompatible, approaches to mitigating the threat of global warming. In the long term (before the end of the 21st century), some of the measures outlined in these three scenarios may be necessary merely from the worldwide depletion of petroleum if synthetic fuels prove too expensive to adopt on a wide scale. Whether any threats justify this level of action is a judgment that cannot be determined analytically at this point.

### *Scenario 5: High Emphasis on Renewable Energy*

Renewable energy sources (solar and geothermal) have considerable appeal from an environmental perspective. In most cases, the energy already exists naturally, and there are few harmful emissions from its use. However, with some exceptions, renewable currently are not economically competitive with fossil fuels or nuclear energy. As discussed in chapter 3, some renewable technologies show considerable promise for near-term competitiveness on a wide scale. Policy intervention could assure a much more rapid penetration than assumed in the previous scenarios. The impetus could be concern over global warming, other environmental issues such as air quality, or energy security.

However, it does not appear that any of these options will ever seem inexpensive by current standards. Hence, a high dependence on renewable energy should start with an economy that has built in as much efficiency as practical. This scenario builds on the energy distribution in scenario 3 (moderate efficiency) but shifts some of the supply from fossil to renewable sources. Table 4-6 outlines the supply and demand. As each sector will adopt renewable for unique functions, they are discussed separately.

#### Residential/Commercial Sector

The major direct use of renewable in the residential/commercial sector would be passive and active solar heating. As in the previous scenario, wherever possible, buildings would be oriented toward the sun and designed to maximize capture of solar energy in the winter while excluding it in the summer. Active panels to collect solar energy for both heat and hot water would become common. The use of firewood (now the dominant use of renewable energy in buildings) would also increase, but environmental and safety considerations suggest that firewood should not be a favored energy source. Processed fuels from biomass should be more benign. By 2015, the solar contribution could be displacing 1.0 quad of fossil or electric heating in buildings, and geothermal another 0.5.[7] In addition, biomass could

[7] The values in this section are derived from Solar Energy Research Institute et al., *The Potential of Renewable Energy; An Interlaboratory White Paper*, prepared for the U.S. Department of Energy, SERI/TP-260-3674, DE90000322 (Golden, CO: Solar Energy Research Institute, March 1990).

be increased by 0.5 quad. The total additional renewable contribution to the two sectors is 2 quads.

Commercial buildings may be less appropriate than residences for solar heating, because most are too large for on-site collectors. Furthermore they use heat for unique functions and often extended periods (hospitals, restaurants). However, commercial building owners can also arrange for service companies to supply heat or cooling from off-site solar stations.

The size of the solar collector industry has decreased greatly since the 1970s from the loss of tax credits and the drop in fossil fuel prices. Rapid growth would risk repeating the experience of the 1970s, when inadequate designs and unskilled or dishonest installers plagued the industry. The technology is much better now, but controls to ensure that the solar contribution is achieved efficiently would be prudent.

Other applications for renewable energy include electricity generation and the replacement of natural gas with hydrogen, which could be produced by photovoltaics. Alternatively, synthetic gas could be produced from biomass. These options also apply to the sectors discussed below.

### Transportation Sector

The transportation sector would use fuels derived from biomass. If advances in plants, cultivation, and processing are successful, methanol from wood or herbaceous crops is the most likely fuel though some of the ethanol technologies are promising. By 2015, as much as 1.2 quads could be supplied, displacing 0.6 MMB/D. Moving toward methanol would reduce air pollutants such as ozone, though handling would have to be stringent to minimize toxic exposure. Energy security would be well served, because most of the feedstock would be domestic.

However, the long-term transition to a biomass-derived, methanol-fueled fleet would be very difficult. If biomass is not to interfere with food production, presently unused farmland or forests would have to be cultivated. As much of the farmland would be marginal, environmental problems, e.g., erosion, could be potentially serious. A major industry for fuel processing and distribution would have to be established. A dual distribution system for methanol and gasoline would be required for many years. Automobiles would be either multifueled, which is less efficient, or limited to one type of distribution, as are diesel cars now. Problems such as starting the engine in cold weather would need to be solved. The transition would be eased if methanol is first introduced as an additive to "

**Table 4-6-High Renewable Scenario Energy Use and Supply (quadrillion Btu)**

| | 1989 | 2015 |
|---|---|---|
| Demand | | |
| Residential | | |
| Natural gas | 5.0 | 3.3 |
| Electricity[a] | 3.1 | 2.8 |
| Oil | 1.8 | 0.7 |
| Coal | 0.1 | ne |
| Renewables | 0.9 | 2.3 |
| Total | 10.9 | 9.1 |
| Commercial | | |
| Natural gas | 2.7 | 2.7 |
| Electricity[a] | 2.7 | 3.0 |
| Renewable | | 0.9 |
| Oil | ne/0.7 | 0.5 |
| Coal | ne | 0.1 |
| Total | 6.1 | 7.2 |
| Transportation | | |
| Oil | 21.6 | 23.6 |
| Natural gas | 0.6 | 0.7 |
| Renewable | ne | 1.2 |
| Electricity[a] | ne | ne |
| Total | 22.2 | 25.5 |
| Industrial | | |
| Natural gas | 8.3 | 6.7 |
| Oil (fuel) | 3.8 | 3.7 |
| Oil (nonfuel) | 4.4 | 5.7 |
| Electricity[a] | 3.2 | 4.4 |
| Renewables | 1.9 | 4.8 |
| Coal | 2.9 | 3.2 |
| Total | 24.5 | 28.5 |
| Total demand[a] | 63.6 | 70.3 |
| Electricity[b] | | |
| Coal | 16.0 | 12.1 |
| Nuclear | 5.7 | 4.3 |
| Gas | 2.9 | 2.7 |
| Oil | 1.7 | 1.2 |
| Renewables | 3.0 | 11.3 |
| Total | 29.2 | 31.6 |
| Supply | | |
| Oil | 34.0 | 35.3 |
| Gas | 19.5 | 16.0 |
| Coal | 18.9 | 15.4 |
| Nuclear | 5.7 | 4.3 |
| Renewable | 5.8 | 20.5 |
| Total | 83.9 | 91.5 |

KEY: ne = negligible.

[a]Does not include conversion losses at powerplants, which makeup about two-thirds of the total consumed there.

[b]All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review* 1989, DOE/EIA-0384(89), May 24,1990, tables 1,2,3,4,5,11,17,25,88, and 99; Office of Technology Assessment, 1991.

gasoline, and then as a pure fuel for urban fleets, before individuals are expected to purchase cars that burn only methanol.

An alternative is cars powered by solar-generated electricity. Electric cars have even more environmental advantages than methanol cars, emitting almost no pollution when the electricity is produced cleanly. However, significant storage improvements would be necessary before electric cars could expand beyond small niche markets. In this scenario, the penetration of electric vehicles is assumed to be small relative to methanol. (The following scenario reverses this assumption.) Solar electricity is discussed below. If the technology can be developed, powering cars with hydrogen produced from solar electric plants might be superior to using the electricity directly. The infrastructure required for hydrogen would be quite different, but the overall environmental, economic, and social impact probably would be about the same.

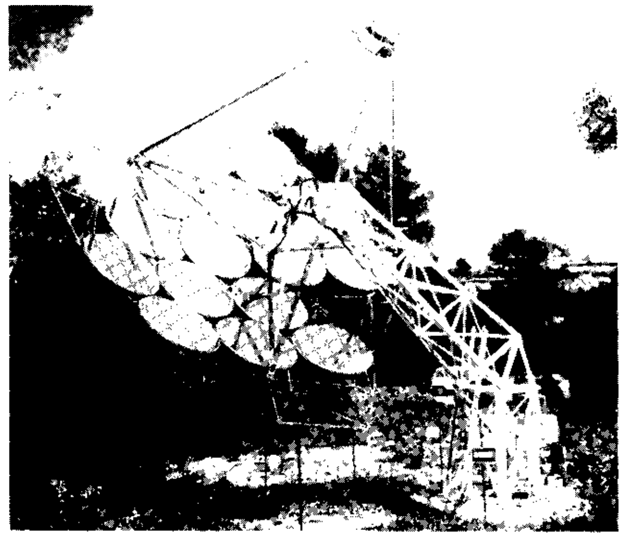

*Photo credit: Aian T Crane*

**Parabolic dishes focused on a Stirling engine to produce electricity. This assembly was designed and built in the United States and exported to France.**

### Industrial Sector

The industrial sector already uses substantial amounts of biomass, primarily through combustion of wood wastes by the forest products industry. Biomass use could be expanded about 1.5 quads by 2015.

Industry uses primary energy mainly as process heat. Most process heat requires temperatures far greater than that produced by flat solar panels, but such high heat is easily obtainable by the type of collectors used in solar thermal electric plants. Industry could replace a significant fraction of its fossil fuel use with solar energy, but only if long-term storage technology is perfected as well. No company would risk plant shut downs from something as common as several cloudy days. Backup energy supplies can be arranged, but they would add considerably to costs and complexity, which could deter many companies from adopting these technologies at all.

Penetration of these technologies is likely to be slow, because most industrial energy consumption in 2015 will be in facilities that have already been constructed and that are not necessarily appropriate for solar energy. This scenario assumes that industrial solar energy use will be small in 2015, though it could expand considerably beyond the time frame of this scenario.

### Electric Power Sector

If solar energy is to supply a large fraction of U.S. energy requirements, it will be achieved only with conversion to electricity (with storage) or perhaps hydrogen. Direct applications of solar energy are modest, and most solar technologies lend themselves to electricity generation. Hydroelectric power is the largest renewable energy source and will remain so for many years. Photovoltaics and wind produce electricity directly. Solar thermal and geothermal facilities produce high-grade heat that can be used in several ways, including processing other fuels, but electricity would be the easiest to deliver and use in the foreseeable future. Biomass already fuels a small amount of electrical generation, largely in the forest products industry, and many more opportunities could be created. Hence a commitment to solar implies increased electrification, just as a commitment to nuclear power does in the next scenario.

This scenario projects renewably generated electricity supplies to grow from 3.0 to 11.3 quads by 2015, an increase of 6.8 quads compared to the moderate efficiency scenario. Most of the potential hydropower presently economic or close to it (considering environmental constraints) is developed for an additional 32 GW (yielding 1.5 quads). Biomass for electricity increases 1.7 quads. Solar thermal and photovoltaics together could supply 2.1

quads and wind 2.2 quads. Geothermal increases 0.5 quads. Solar electricity could displace some direct fossil fuel use, but that is not assumed in this scenario. In fact, electricity generation drops 2.9 quads from displacement by the direct use of renewable energy.

**Conclusions-The** largest uncertainty for the high renewable scenario is whether the technology can be improved sufficiently to provide a reliable, affordable energy source. Only a few renewable technologies are now competitive and most of these only in special situations. Furthermore, as these intermittent sources begin accounting for larger fractions of electricity generation, improved storage will become essential. Cost projections suggest that at least several technologies will be competitive, but that is not yet certain. If the projections prove correct, renewable could grow very rapidly. Some adaptation by individuals and companies might be required to make the most effective use of renewable energy (e.g., revising energy demand profiles to track more closely solar energy availability, and increased installation of backup power equipment). In addition, wide-scale exploitation of renewable energy is likely to cause some conflicts with environmental goals (e.g., farming practices for biomass, aesthetics of solar collectors). Overall, however, if the economics are solved, renewable will follow with considerably less difficulty.

### *Scenario* 6: *High Emphasis on Nuclear Power*

Twenty-five years ago, the total capacity of all nuclear powerplants in the United States was less than 1200 MWe, about the size of one large modern plant. Today there are over 100,000 MWe in operation, producing almost 20 percent of the power in this country. Over the next 25 years, nuclear power could grow by several hundred thousand MWe, or it could shrink. No domestic energy source except coal has the potential to grow as much in this time interval, but none evokes as much opposition and distrust. The amount of nuclear power capacity that is built in the future depends almost entirely on political decisions and economic factors, but very little on resource constraints or industrial capability (although the latter would be a constraint to very rapid growth).

This scenario assumes that a major commitment to nuclear power is deemed essential, most probably because of global climate change. Table 4-7 shows the energy supply and demand figures. Under this scenario, initial orders are placed by 1994 for updated LWRs, the only proven, commercial nuclear technology. A revival of orders probably

**Table 4-7—High Nuclear Scenario Energy Use and Supply (quadrillion Btu)**

| | 1989 | 2015 |
|---|---|---|
| **Demand** | | |
| Residential | | |
| Natural gas | 5.0 | 3.4 |
| Electricity[a] | 3.1 | 3.4 |
| Oil | 1.8 | 0.8 |
| Coal | 0.1 | |
| Renewable | 0.9 | ne/1.5 |
| Total | 10.9 | 9.1 |
| Commercial | | |
| Natural gas | 2.7 | 2.8 |
| Electricity[a] | 2.7 | 3.5 |
| Renewables | | 0.3 |
| Oil | ne/0.7 | 0.5 |
| Coal | ne | 0.1 |
| Total | 6.1 | 7.2 |
| Transportation | | |
| Oil | 21.6 | 23.4 |
| Natural gas | 0.6 | 0.7 |
| Renewables | ne | 0.7 |
| Electricity[a] | ne | 0.7 |
| Total | 22.2 | 25.5 |
| Industrial | | |
| Natural gas | 8.3 | 7.2 |
| Oil (fuel) | 3.8 | 4.2 |
| Oil (nonfuel) | 4.4 | 5.7 |
| Electricity[a] | 3.2 | 4.6 |
| Renewables | 1.9 | 3.6 |
| Coal | 2.9 | 3.2 |
| Total | 24.5 | 28.5 |
| Total demand[a] | 63.6 | 70.3 |
| **Electricity**[b] | | |
| Coal | 16.0 | 12.1 |
| Nuclear | 5.7 | 12.0 |
| Gas | 2.9 | 5.0 |
| Oil | 1.7 | 1.3 |
| Renewables | 3.0 | 7.6 |
| Total | 29.2 | 38.0 |
| **Supply** | | |
| Oil | 34.0 | 35.9 |
| Gas | 19.5 | 19.1 |
| Coal | 18.9 | 15.4 |
| Nuclear | 5.7 | 12.0 |
| Renewable | 5.8 | 13.7 |
| Total | 83.9 | 96.1 |

KEY: ne = negligible.

[a]Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b]All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989,* DOE/EIA-0384(89), May 24,1990, tables 1,2,3,4,5,11,17,25,88, and 99; Office of Technology Assessment, 1991.

would involve a consortium of utilities, manufacturers, and architect-engineers implementing a prelicensed design. Under circumstances leading to high national priority, at least two separate consortia would be likely, each building a reactor of about 600 MWe. These initial reactors would require about 7 years to attain commercial operation, which would be in 2001.

If progress during construction of these test cases is reasonably smooth, subsequent orders might be placed in 2000. Some risk would be involved in ordering before completion of the construction, regulatory, and operational demonstrations, but the situation is not analogous to the premature orders in the sixties and seventies. Now the technology is much more familiar and stabilized. However, utilities are likely to be cautious, so only two more plants (1200 MWe total) are ordered in 2000, and four in 2001. These and following reactors are built on a 5-year construction program.

Alternative technology, in particular the high-temperature gas reactor (HTGR), would be available slightly later, but the net effect on this scenario would be small. Ironically, one of the major advantages suggested of advanced reactors, improved public acceptance, would not apply in this scenario, because public acceptance of conventional reactors is already assumed. However, alternative reactors should still have safety advantages. The type of accident that occurred at Three Mile Island, which entailed serious financial and public relations damage, though releasing only trace amounts of radioactivity, becomes a significant risk if hundreds of LWRs operate for decades. Since this type of accident would again damage the prospects for nuclear power, conversion to more resilient technology probably is necessary at some point. Thus, a high nuclear scenario should include an emphasis on improved technology, even though the risk of a major accident that would harm the public is already much lower than other commonly accepted risks. Rising uranium prices by 2015 may also improve the competitiveness of the liquid metal reactor, but a breeder/plutonium recycle would not be necessary until several hundred GWe have been built.

Table 4-8 shows the progression of orders and commercial operation assumed in this scenario. Reactors are assumed to average **600 MWe** each. The rate of starts is low at first, grows rapidly, and then levels out as the number of plants in the construction process becomes large. By 2015, the additional operating capacity is 116,000 **MWe** and growing rapidly. The existing 103,000 MWe can be expected to decline by about **19,000,** for a grand total by 2015 of 200,000 MWe, producing 12 quads. Even faster growth could be envisioned; in 1975, projections called for 1,000,000 GWe in 2000, 10 times what we shall have. However, the rapid growth rate at that time was the source of many of the industry's problems. This more controlled rate should give industry time to acquire qualified workers and build an adequate infrastructure. By 2015, however, the capacity reaches the levels ordered in the early seventies, so the industry may again become strained. In addition to the reactors, several enrichment plants would be required, probably using the laser technology now being developed, which should be cheaper and much more energy efficient than present mass diffusion enrichment technology. At least two high-level waste repositories will also be needed.

**Table 4-8-New Nuclear Plant Construction Schedule in High Nuclear Scenario**

| Year | Plants started in year | Total new starts | Operating capacity (MWe) |
|---|---|---|---|
| 2000 | 2 | 4 | 0 |
| 2001 | 4 | 8 | 1,200 |
| 2002 | 8 | 16 | 1,200 |
| 2003 | 12 | 28 | 1,200 |
| 2004 | 16 | 44 | 1,200 |
| 2005 | 20 | 64 | 2,400 |
| 2006 | 22 | 86 | 4,800 |
| 2007 | 24 | 110 | 9,600 |
| 2008 | 26 | 136 | 16,800 |
| 2009 | 28 | 164 | 26,400 |
| 2010 | 30 | 194 | 38,400 |
| 2011 | 32 | 226 | 51,600 |
| 2012 | 34 | 260 | 66,000 |
| 2013 | 36 | 296 | 81,600 |
| 2014 | 38 | 334 | 98,400 |
| 2015 | 40 | 374 | 116,400 |

SOURCE: Office of Technology Assessment, 1991.

In addition to nuclear, substantial amounts of gas-fired, hydroelectric, and municipal solid waste capacity are built in this scenario. The total capacity by 2015 would be 740,700 MWe. Most coal plants would be retired to reduce $C0_2$ emissions. Despite the additional energy generated by nuclear reactors, the net output of the electric power sector is only marginally higher than in scenario 3, largely because of the relative inefficiency of nuclear plants.

Relying on nuclear power will change the nature of the energy system, but not as greatly by 2015 as after. This scenario uses nuclear energy more as a means to reduce coal combustion than as an effort to increase electricity production. The use of nuclear reactors to produce industrial process heat has been proposed, particularly using HTGRs, but that is not assumed in this scenario.

The transportation sector will be especially difficult to convert to electricity, because batteries are unlikely to improve sufficiently by 2015 for EV performance to match that of present vehicles. EVs will become widespread after 2000 in this scenario, but the motivation assumed here centers on local environmental benefits rather national efforts to reduce fossil fuel use. Electricity and biomass each supply 0.7 quads in the transportation sector (table 4-7). The biomass component would be more assimilable, but the electricity will power about four times as many vehicles. Alcohol or other biomass fuels must be burned and converted to work at relatively low efficiencies (generally much lower efficiencies than at large, stationary powerplants), whereas the electricity is used directly.

Industry would be unlikely to shift its bulk process heat to electricity because of the cost, unless industrial heat pumps prove effective. Industry will enjoy the greatest benefits from electrification if process redesign exploits electricity's controllability and cleanliness.

Conclusions-Nuclear power will not solve either the $C0_2$ problem or energy security concerns by 2015, but it can make a major contribution that would grow rapidly thereafter. Before this scenario could be implemented, however, the factors that have immobilized the nuclear option must be addressed. Utilities, their customers, local residents, State rate regulators, investors, and the general public must be convinced that nuclear power in general, and specific proposed plants in particular, are necessary and in their interests.

It is not clear exactly how this consensus would emerge. Global climate change is the issue most likely to improve acceptability. The negative effects that have been suggested for climate change greatly exceed even very pessimistic projections of nuclear accidents. However, the nature of the problems are very different, and people will not necessarily accept a nuclear plant in their area in order to reduce global $C0_2$ emissions.

This scenario is impossible unless the industry can demonstrate mastery of the technology with existing as well as new plants. Furthermore, a functioning waste repository must be a near-term probability before many new plants are ordered, and proliferation risks must be strictly minimized. In addition, at least initially, nuclear power must be significantly less expensive than renewable options or fossil-fired plants for utilities to consider choosing nuclear.

All of these conditions are possible to meet, but the likelihood of meeting all of them is uncertain. The nuclear industry retains a strong commitment to a revival, but strong policy leadership will be required to convince the rest of the country, at least at frost.

### Comparative Impact of Scenarios

***The six*** scenarios discussed above are summarized in table 4-9. They represent different assumptions about the problems and opportunities facing the Nation. It would be quite difficult to specify exactly what impact would result from the implementation of any of them, because that would depend on additional assumptions, e.g., regulation of emissions and interest rates. Furthermore, the value of scenarios 4, "5, and 6 depends to a large extent on how crucial it becomes to reduce $C0_2$ emissions, which cannot be determined at this time. However, major types of impacts can be identified.

The three major parameters for the design of the scenarios were: 1) how to minimize environmental impacts, especially global warming; 2) how to minimize vulnerability to energy disruptions; and 3) how to minimize economic costs to society. Success in meeting these three goals, assuming the scenarios are implemented successfully, is the first type of impact to be considered. This has been discussed for each scenario above. As summarized in table 4-10, the high growth scenario worsens environmental and security impacts relative to the base scenario and leaves economic impacts about the same, largely because of the assumption that the scenario is improbable unless fuel prices stay lower than assumed in the other scenarios. The remaining scenarios reduce environmental impact and security risks. The moderate efficiency scenario shows a strong positive economic impact because it is the least-cost path. High efficiency and high nuclear should not cost much more than the base scenario

**Table 4-9-Summary of Scenarios**

| | 1989 | 2015 Baseline | 2015 High Growth | 2015 Moderate Efficiency | 2015 High Efficiency | 2015 High Renewable | 2015 High Nuclear |
|---|---|---|---|---|---|---|---|
| **Demand** | | | | | | | |
| Residential | | | | | | | |
| Natural gas | 5.0 | 4.2 | 5.5 | 3.6 | 2.9 | 3.3 | 3.4 |
| Electricity[a] | 3.1 | 4.0 | 4.8 | 3.3 | 2.6 | 2.8 | 3.4 |
| Oil | 1.8 | 1.1 | 1.3 | 0.9 | 0.8 | 0.7 | 0.8 |
| Coal | 0.1 | 0.1 | 0.1 | 0.1 | | | |
| Renewable | 0.9 | 1.5 | 1.5 | 1.2 | ne/2.3 | ne/1.5 | ne/1.5 |
| Total | 10.9 | 10.9 | 13.2 | 9.1 | 6.9 | 9.1 | 9.1 |
| Commercial | | | | | | | |
| Natural gas | 2.7 | 3.4 | 3.6 | 3.0 | 3.8 | 2.7 | 2.8 |
| Electricity[a] | 2.7 | 5.2 | 5.5 | 3.4 | 1.7 | 3.0 | 3.5 |
| Renewable | | | | | | 0.9 | 0.3 |
| oil | ne/0.7 | ne/0.9 | ne/0.9 | ne/0.7 | ne/0.3 | 0.5 | 0.5 |
| Coal | ne | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Total | 6.1 | 9.6 | 10.1 | 7.2 | 5.9 | 7.2 | 7.2 |
| Transportation | | | | | | | |
| oil | 21.6 | 27.5 | 32.6 | 24.8 | 17.7 | 23.6 | 23.4 |
| Natural gas | 0.6 | 0.7 | 1.5 | 0.7 | 0.7 | 0.7 | 0.7 |
| Renewable | ne | ne | 0.5 | ne | | 1.2 | 0.7 |
| Electricity | ne | ne | 0.7 | ne | ne/0.1 | ne | 0.7 |
| Total | 22.2 | 28.2 | 35.3 | 25.5 | 18.5 | 25.5 | 25.5 |
| Industrial | | | | | | | |
| Natural gas | 8.3 | 7.7 | 10.9 | 7.5 | 7.7 | 6.7 | 7.2 |
| Oil-fuel | 3.8 | 5.0 | 5.6 | 4.4 | 3.3 | 3.7 | 4.2 |
| Oil--non-fuel | 4.4 | 5.7 | 6.5 | 5.7 | 5.7 | 5.7 | 5.7 |
| Electricity | 3.2 | 5.3 | 6.4 | 4.4 | 3.2 | 4.4 | 4.6 |
| Renewable | 1.9 | 3.5 | 3.8 | 3.2 | 2.2 | 4.8 | 3.6 |
| Coal | 2.9 | 4.6 | 5.3 | 3.3 | 1.5 | 3.2 | 3.2 |
| Total | 24.5 | 31.8 | 38.5 | 28.5 | 23.6 | 28.5 | 28.5 |
| Total demand[a] | 63.7 | 80.5 | 97.1 | 70.3 | 54.9 | 70.3 | 70.3 |
| **Electricity**[b] | | | | | | | |
| Coal | 16.0 | 29.1 | 27.4 | 17.8 | 5.3 | 12.1 | 12.1 |
| Nuclear | 5.7 | 3.8 | 8.2 | 6.6 | 6.8 | 4.3 | 12.0 |
| Gas | 2.9 | 6.3 | 7.0 | 4.1 | 5.3 | 2.7 | 5.0 |
| oil | 1.7 | 1.6 | 1.6 | 1.5 | 0.2 | 1.2 | 1.3 |
| Renewable | 3.0 | 5.7 | 5.5 | 4.5 | 5.2 | 11.3 | 7.6 |
| Total | 29.2 | 46.4 | 49.7 | 34.5 | 22.8 | 31.6 | 38.0 |
| **supply** | | | | | | | |
| oil | 34.0 | 41.8 | 48.5 | 37.9 | 27.8 | 35.3 | 35.9 |
| Gas | 19.5 | 22.3 | 28.5 | 18.8 | 20.3 | 16.0 | 19.1 |
| Coal | 18.9 | 33.8 | 32.9 | 21.1 | 7.0 | 15.4 | 15.4 |
| Nuclear | 5.7 | 3.8 | 8.2 | 6.6 | 6.8 | 4.3 | 12.0 |
| Renewable | 5.8 | 10.7 | 11.3 | 8.9 | 8.0 | 20.5 | 13.7 |
| Total | 83.9 | 112.4 | 129.4 | 93.3 | 70.0 | 91.5 | 96.1 |

KEY: ne = negligible.

[a]Does not include transmission and disribution losses nor conversion losses at powerplants, which is about two-thirds of the total consumed there.

[b]All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: Reference for 1989 data—U.S. Energy InformationAdministration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tablels 1, 2, 3, 4, 5, 11, 17,25,88,and99; Office of Technology Assessment 1991.

because they use relatively familiar technology that s competitive or nearly so now. Renewable costs presently are higher, and projections of reductions are somewhat speculative.

However, other factors will be crucial in determining the national impacts of committing to one or another scenario. Some scenarios involve considerable uncertainty regarding resource availability or technical progress, and some introduce additional uncertainties for unpredictable events, e.g., nuclear accidents or major climatic events that reduce solar energy significantly. Resilience of the scenarios to

**Table 4-10-Comparative Impact of Scenarios**

| Impact | Base | High Growth | Efficiency | High Efficiency | Renewable | Nuclear |
|---|---|---|---|---|---|---|
| Environmental | 0 | – – | + | ++ | ++ | + |
| Security | 0 | – | + | ++ | ++ | ++ |
| Economic | 0 | 0 | ++ | 0 | – | 0 |
| Resilience | 0 | –– | + | ++ | + | 0 |
| Implementability | | | | | | |
| Infrastructure | 0 | ++ | – | –– | – | + |
| Public acceptance | 0 | 0 | + | – | + | – |
| Sustainability | 0 | -- | + | ++ | ++ | + |

KEY: O = about the same as the base case;+ . somewhat better or easier; ++ = much better; – = somewhat worse or harder; – – = much worse.

SOURCE: Office of Technology Assessment, 1991.

uncertainties includes both the probability of success and the consequences of failure and depends in part on the technologies involved. The high growth scenario has particularly uncertain assumptions. The high efficiency scenario is most immune against negative surprises and vulnerable principally to improbably low energy prices.

The ability to implement any of the scenarios depends on several factors. Public acceptance is one consideration. Some technologies (e.g., solar) are quite popular with the public (in the abstract), and promotional policies are likely to be widely supported. Conversely, the level of public involvement required to implement these technologies may be high, which increases the difficulty of implementation. Demand-side measures in particular require people to focus on energy decisions (purchasing and operating equipment) more than has been experienced to date. Some solar options also involve users more intensively than does the purchase of conventional energy. Industrial readiness to implement the scenarios also varies. The fossil and nuclear industries already exist. The solar and conservation industries would have to expand greatly.

Finally, there is every reason to believe that in the next century, U.S. energy supplies will have to shift from fossil fuels toward a more sustainable system. Significant changes to the energy system can take decades to accomplish, but some scenarios would make these changes faster and more efficiently than others.

Some factors are not considered here because they are too complex. In particular, employment under the different scenarios will vary in numbers, types of jobs, and geographic location. One of the most notable shifts would be the decrease in coal field employment under scenarios 4, 5, and 6. Compensating increases could be found elsewhere, but they are unlikely to help the coal miners or their regions. Nor are changes in energy demand and supply due to global warming (other than those changes deliberately implemented out of concern over climate change) considered here, even though such warming could be detectable (though probably not large) by 2015 under scenarios 1 and 2.

Table 4-9 evaluates these factors qualitatively relative to the base scenario. The scores cannot be averaged to determine totals because the six factors listed do not represent all important considerations, nor would they be equally weighted. However, it does appear that scenario 3, moderate conservation, has most of the advantages and few of the disadvantages of the others.

overall, it is clear that no one subset of energy technologies is going to solve all the problems the Nation will have to confront eventually. Each scenario has drawbacks as well as advantages, and different circumstances could invalidate any of them. We do not know: how much of the Nation's huge unconventional gas resources can be developed at reasonable cost; what technology breakthroughs will change the relative economics of the various energy sources; what new sources of demand will emerge; how serious global warming will be; or what external events will occur to change the way we think about energy.

Furthermore, if the Nation decides that global warming is a serious problem, then even the interim goal of a reduction of 20 percent in $CO_2$ emissions will be much too small. Even 50 percent could be modest under some conditions, but such a goal could only be achieved by strenuously combining scenarios 4, 5, and 6.

This argues strongly for assuring that a wide range of technologies is available in the future, and that no option be discarded prematurely.