Energy and the Environment: The Tradeoffs for New England

James J. MacKenzie*

I. Introduction

The consumption pattern of energy in the United States, like that of other resources, is determined by many variables. Principal among these are price and convenience. The price of energy has been and continues to be a complicated function of physical availability, international politics, government price regulation, import controls, technological innovation, and environmental regulation, to name but a few of the more important variables.

Contrary to popular belief, however, environmental regulations have never been the primary reason for either the growth or decline of any major source. The consumption of coal, the dirtiest of our fossil fuels, hit its peak, at 77 percent of total energy supply, in 1910. Its relative use has declined since that time because of the availability and convenience of liquid and gaseous fuels — not because of air pollution regulations. Similarly, the consumption of natural gas, the cleanest of our fuels, grew dramatically after World War II because of its convenience and low price, the latter largely the result of Federal price controls.

Recent environmental laws have of course made it more costly to burn dirtier fuels. But within the last five years sulfur oxide scrubbers have been developed to meet EPA emission restrictions. Moreover, a whole range of alternative (if not new) technologies promises to allow the burning of coal essentially without air pollution.

Environmental regulations, therefore, can and will affect the pattern of energy use primarily through the pricing adjustments necessary to produce "clean" energy as measured by the various standards of environmental quality. One of the major goals of the environmental movement is to include within the price of energy all of the social, environmental, and public health costs and risks incurred in its production and consumption. In adopting this essentially economic goal, we environmentalists appear to stand alone. Consumer advocates, energy producers and converters, and politicians continually press for a wide

*Member, Joint Scientific Staff, Massachusetts and National Audubon Societies. He has a Ph.D. in nuclear physics and before joining the Audubon staff in 1970 was a research associate in the Center for Theoretical Physics at the Massachusetts Institute of Technology. He is chairman of the Union of Concerned Scientists, a trustee of the Environmental Defense Fund, and a member of the energy policy committee of the National Sierra Club.

range of subsidies to reduce prices (e.g., through natural gas price regulation), to increase profits (e.g., by continuing depletion allowances and foreign tax credits), or to allow the continued violation of prudent and reasonable environmental safeguards (e.g., those requiring the rehabilitation of strip-mined lands). With the resulting patchwork of subsidies and regulation it is little wonder that the Nation finds itself today faced simultaneously with rampant energy waste in every sector of the economy and a growing gap between supply and demand. Presently, energy prices do not reflect the true and total incremental costs of developing new sources. Consumers are not getting accurate signals about the seriousness of our shortages and the normal brakes of higher prices that should be operating to slow the growth in consumption are absent. Perhaps the clearest example of this unfortunate fact is the severe capital crunch plaguing the electric utilities in the face of continued, albeit reduced, growth in demand.

As an environmentalist I am quite willing to allow an informed and functioning market place (one that is truly competitive) decide which energy sources New England and the Nation will utilize. But in so doing I insist that the price of energy include all of the environmental damages and risks. We are a long way from that situation.

In this paper I review what I believe to be the major risks associated with our energy options. Unfortunately, it is not always possible to quantify these risks. Indeed, in several instances the magnitude of the hazards are subject to ongoing controversy and debate. This is so for several reasons including incomplete research (nuclear safety) and insufficient experience (imported liquefied natural gas, LNG).

In Section II recent trends in New England energy consumption are presented. In Section III the environmental trade-offs among various energy sources available to New England are reviewed. In Section IV some personal views are presented on the direction that I believe we should be taking in planning an environmentally sound energy future.

II. Pattern of New England Energy Consumption

The energy supply picture for New England is substantially different from that of the United States as a whole.

- First, per capita use of energy in New England is only three-fourths of the national average. No doubt this is the result of higher prices here, in turn resulting from our long distance from supplies.
- New England is nearly twice as dependent on oil as the Nation as a whole (85 percent vs. 46 percent of total supply).
- Natural gas plays a relatively minor role in the New England supply picture (9 percent vs. 32 percent for the national average).
- New England electric utilities are heavily dependent on petroleum (60 percent) and nuclear energy (24 percent) as fuels for electricity generation.

These facts are presented in Tables 1 and 2. The trends in New England's energy supply since 1960 are presented in Figure 1.

The most significant changes in New England's supply pattern over the past 15 years include the decline of coal from 13 percent of supply to its present 1.3 percent, and the expansion of oil, natural gas, and nuclear energy by 6, 3, and 3 percentage points (of total energy supply), respectively.

The precipitous decline in the consumption of coal since the mid 1960s is due to the switch by electric utilities to cheap, imported residual oil.[1] This switch is sometimes attributed to environmental regulations, but this is not so. The changeover to oil occurred as soon as import quotas on residual oil were dropped in 1966, long before air pollution regulations required low-sulfur fuel. (See Figure 2.) It was not until 1970, when utilities began to burn lower-sulfur fuel, that coal became once again cheaper than oil.

For our purposes it is important to note that domestic production of New England's two largest sources of energy, petroleum and natural gas, has been dropping steadily over the past few years. It will be difficult to substitute in a massive way for these two fuels in periods short of decades. For the short run, suppliers will have to rely on foreign sources. Discoveries of oil and gas off the Atlantic coast could conceivably reduce our regional need for imports, though not the national need. If the resources of the Atlantic shelf are not substantial, and in the absence of any imaginative political action to utilize new sources of energy, New England will probably continue on a longer basis to import petroleum and natural gas. Since Canada is reducing its exports to us, natural gas will probably be imported in the form of liquefied natural gas (LNG) from North Africa or other sources.

Of course, further reliance on imported oil and gas flies directly in the face of our national policy to reduce dependence on foreign sources. For this reason an effort might be made to fill our growing oil and gas gap with synthetic fuels from coal or via new sources, such as wind and solar energy.

Apparently then, we can expect to have, at least, the following options for direct sources of energy (that is, not including electricity): imports of petroleum from foreign sources or from the outer continental shelf; imports of liquefied natural gas; synthetic fuels from coal; and energy from the sun, including wastes, or from the winds.

In addition to direct sources we must consider the options available to the electric utilities. At the moment New England utilities account for one-fourth of total energy consumption. As indicated in Table 2, 60 percent of our electricity is now generated in oil-fired plants, and 25 percent

[1] In 1965 utilities accounted for 83 percent of New England coal consumption. At that time twice as much electricity was generated by coal as by oil.

Table 1

SOURCES OF ENERGY, 1972

	New England	United States
	Percent	
Petroleum	84.6%	45.7%
Coal	1.3	17.3
Natural Gas	9.1	32.1
Nuclear	3.2	0.8
Hydro	1.8	4.1

Source: "Fuel and Energy Data, United States by States and Regions, 1972", U.S. Department of the Interior, Information Circular 8647.

Table 2

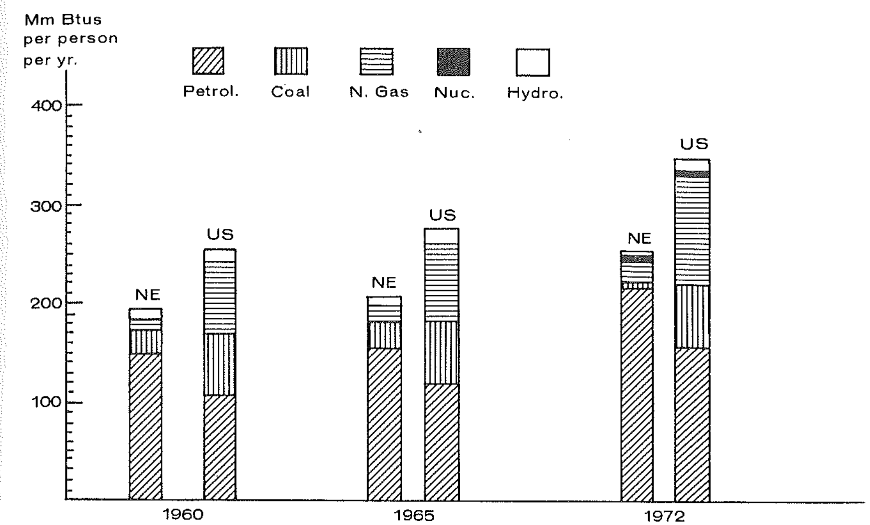
SOURCES OF ELECTRICITY, 1974

	New England	United States
	Percent	
Coal	7.4%	44.4%
Petroleum	60.0	16.0
Natural Gas	1.2	17.1
Nuclear	24.4	6.0
Hydro	6.8	16.1

Source: Federal Power Commission.

Figure 1

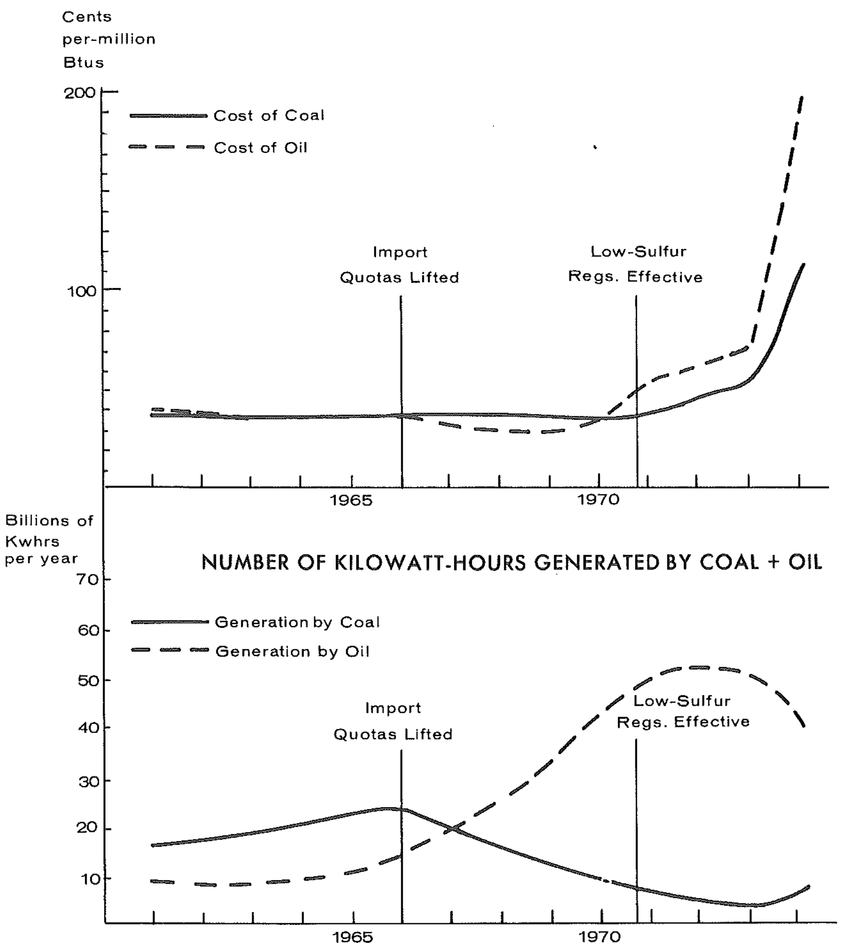
PER CAPITA ENERGY CONSUMPTION
NEW ENGLAND AND THE UNITED STATES
(BY SOURCE)



Source: Bureau of Mines, Fuel and Energy Data: United States by States and Regions, 1972.

Figure 2

COST OF COAL + OIL



Source: Statistical Year Book of the Electric Utility Industry, published by the Edison Electric Institute.

in nuclear plants. In the short term — ten years or less — there are only two energy sources available for electricity production in new plants, coal and nuclear energy. Some time in the 1980s it is possible that wind power could begin to make a contribution. Less certain than wind power would be solar power generated in a "photo thermal" plant. In summary, the options for the utilities are coal and nuclear energy, and perhaps wind and solar power for the longer run.

III. Environmental Trade-offs

Petroleum Impacts

The environmental impact of producing and importing the petroleum needs of New England will fall mostly on the coastal zones and the oceans and will be in the form of oil pollution and land disruption.

Offshore Drilling

Of the remaining domestic oil reserves considered recoverable with present technology, about 40 percent are located in offshore waters. Half of this oil in turn is at water depths of more than 600 feet. The chief hazard of offshore drilling is the danger of a large blowout. After the Santa Barbara blowout many birds were killed and entire plant and animal communities in the intertidal zone were killed by a layer of encrusting oil which was often 1 to 2 centimeters thick.[2] Although recovery from this blowout appeared to be complete less than a year later, no behavioral, physiological, chemical, or biological studies have been performed to confirm this belief.[3]

Other problems occur when the drilling is in shallow coastal waters. These include mechanical, physical, and navigational problems associated with the structures; physical and ecological effects from production activities in unstable marsh lands; and adverse ecological effects from mechanical, hydrological, and physical changes. There is apparently little information on the long-term effects of low level oil pollution. However, documented short-term effects include: 1) the poisoning of marine life filter feeders such as clams, oysters, scallops and mussels; other invertebrates; and fish and marine birds; 2) the disruption of the ecosystem resulting in long-term devastation of marine life from mass destruction of juvenile forms and of food sources of higher species; and 3) the degradation of the environment for human use by reducing economic, recreational, and aesthetic values on both short- and long-term bases.[4]

[2] *The Water's Edge, Critical Problems of the Coastal Zone,* MIT Press, 1972, p. 117.

[3] *Ibid.*

[4] Roger Revelle et al, "Ocean Pollution by Petroleum Hydrocarbons," in *Man's Impact on Terrestrial and Oceanic Ecosystems,* MIT Press, 1971, p. 307.

Tanker Accidents

Petroleum can be imported into New England either in a refined form, as it is now, or as crude oil. Since the United States has a far greater refining capacity than is needed to process domestic oil, the need for more refineries is at least questionable. Nonetheless, if one should be built in New England, it would have to be supplied by large tankers, the accident potential of which is discussed next.

Supertankers have several advantages over a large number of smaller ships. They can be unloaded in areas requiring less shelter than smaller ships. With better trained crews the small losses of oil in port could probably be kept below those of an equivalent number of smaller tankers.

The effects of an accident involving a supertanker are, of course, potentially greater than with a smaller tanker. Supertankers lack maneuverability and require long turning and stopping distances. A 300,000-ton tanker, proceeding at normal speed, would require five miles to come to a stop, while a 16,000-ton tanker requires only half a mile. A collision or grounding of a supertanker, carrying 2 million barrels of oil (330,000 tons), would far overshadow the effects of the Torrey Canyon disaster where 800,000 barrels of oil were lost. Such an accident, leading to a total loss of cargo could add 15 percent to the total amount of petroleum directly entering the oceans in a single year.

Liquefied Natural Gas (LNG)

As the shortage of domestic natural gas deepens, New England gas utilities are turning to foreign sources to supplement declining pipeline supplies. At present, 15 percent of New England's gas supply is supplemental, that is, in the form of LNG, substitute natural gas (identical to natural gas) made from naptha or other feedstock, or propane. In 1972 the National Petroleum Council estimated that by 1985 New England might have to import up to half of its gas supply. In light of our recent experiences with imported oil one must question the wisdom of once again becoming so dependent on foreign sources. It is easy to imagine U.S. companies financing a huge, costly liquefaction, transportation, and storage network only to have the exporting countries arbitrarily and sharply raise prices or even nationalize the holdings.

Our concern here, however, is not with security of supply but with the risks to public health and safety that may arise from importing large amounts of LNG into heavily populated areas. LNG has special properties that make it unique among liquid fuels. First, it must be stored at an extremely low temperature, -260 F. At this temperature natural gas condenses to form a clear, light-weight liquid occupying only 1/630 of the original volume of gas. It is this large reduction in volume that makes shipping gas in the liquid state so attractive.

The major issue of public concern is the possibility of a major accident involving an LNG tank or tanker. In the event of a tanker accident the LNG from a ruptured compartment would spread over the water and

vaporize rapidly to form a large cold cloud of methane. Once vaporized the entire LNG cloud, if ignited, could burn completely within a matter of seconds.

A collision or grounding of an LNG tanker could release 50,000 barrels of LNG, a typical volume of the cargo hold of such a vessel. If ignited shortly after spilling, this volume of fuel would give persons radiation burns from the heat up to 2.5 miles from the spill. If the LNG ignited later, after vaporizing, it would burn as a giant fireball which would rise to over a mile in the air and burn persons up to five miles from the spill. A small spill, say, 30,000 gallons, which is about the volume of a tank car, would burn persons up to a half-mile from the accident. These fires would be extremely difficult to extinguish and could in fact burn to completion before firefighters could even arrive at the scene.

Although high quality control is exercised in the construction of LNG tanks and tankers, the same statement can be made relative to almost any costly industrial activity. The sad fact remains that totally unexpected accidents can and do occur. The most prudent safeguard to protect the public from serious LNG fires is the remote siting of the storage tanks. Storage facilities for LNG near population centers should be minimized. (There are, alas, already over 1.5 million barrels of LNG storage capability in the Boston Harbor area alone.) Transport of large quantities by truck or rail should be avoided. Transportation of small quantities by truck would be reasonable provided the route and time of transport are carefully chosen to avoid risks to large numbers of people.

Low Heating Value Gas from Coal

As we have indicated in Table 1, New England is dependent on oil and natural gas for 94 percent of its energy supply. These two fuels are likely to grow ever more expensive as domestic oil production drops further, as the oil-exporting nations continue to raise their prices, and as the price of natural gas rises because of both its (likely) deregulation and the high cost of producing new supplies (OCS gas, LNG, and substitute natural gas — SNG). For these reasons increased attention is being given to developing cleaner methods of burning coal whose domestically recoverable resources are almost 20 times those of oil and natural gas taken together.

The environmental and safety problems posed by the use of coal are, of course, legendary. Its history is one of extraordinary risks for its workers, acid mine drainage destroying streams and soil, burning refuse banks, subsidence beneath worked-out mines, unreclaimed strip mines, and lastly, sulfur and particulate air pollution that has shortened the lives of countless Americans living in heavily populated areas.

Fortunately, and largely as the result of the environmental movement of the past decade, the problems that have characterized its past are now being seriously addressed for the first time. Since passage of the Federal Coal Mine Health and Safety Act of 1969 the risks to underground coal miners have been reduced and are now comparable with those faced by other underground miners. For between pennies per ton (in the west) and perhaps a dollar per ton (in the east) strip-mined lands can be rehabilitated. Long-wall mining techniques are now being tested in this country that can effectively deal with the problems of subsidence. And a host of technologies, some new, some old, are being developed and analyzed and promise to allow the consumption of coal with virtually no air pollution at all.

Several of these processes are now commercially available and could be utilized by New England consumers, particularly industry, to supply clean, secure fuel at prices competitive with oil. Table 3 lists the energy sources for New England industry. More than 75 percent of this sector's (direct) energy is derived from oil and natural gas. As the curtailment of natural gas grows, industry will be forced to switch to oil or other sources; gasified coal offers a viable alternative.

Coal can be converted into a low heating value gas (100-300 Btus per cubic foot), or, with additional cost and effort, into methane (1000 Btus per cubic foot), which is the same as natural gas. For industrial purposes the lower cost, low-Btu fuel is quite adequate.

For small scale industrial users (equivalent to less than 100 barrels of oil per day) many proven gasifiers could be in operation in New England within two to three years if the coal could be made available. These could meet the needs of industrial parks as well as manufacturers of brick, glass, ceramics, baked goods, and the like.[5] These "producers" use air and could burn low-sulfur anthracite. These units would be ideal if the coal reserves on the Narragansett basin prove to be commercially and environmentally exploitable. The resulting "power gas," mostly hydrogen, carbon monoxide, carbon dioxide, and nitrogen, could easily be cleaned of its ash and would meet environmental standards.

Larger gasifiers, using oxygen, that will accept any kind of coal no matter how dirty, are also available. The Koppers-Totzek unit, marketed for more than two decades by the Koppers Company, Inc. of Pittsburgh, can burn as little as 400 tons per day (equivalent to 1800 barrels of oil), to produce 300 Btu gas, free of sulfur and ash. The unit costs for the gas are lower for large installations. For the largest New England industries (paper mills with oil consumption on the order of 3500 barrels per day) the gas would cost about $2.50 per million Btus, using $25 per ton coal.[6] This is only slightly more than oil at $13 per barrel. Obviously, import tariffs and oil price rises could easily tip the balance in favor of coal.

Lurgi gasifiers using air rather than oxygen are also available to supply clean gas from coal. These units have the advantage of producing gas

[5]Arthur M. Squires, "Coal: A Past and Future King," in *Ambio 3*, No. 1, 1974. "Clean Fuels from Coal Gasification," *Science 184*, April 19, 1974.

[6]"Coal Gasification: Neglected Response to America's Energy Needs," Koppers Co., Inc., March 1975.

Table 3

ENERGY SOURCES FOR NEW ENGLAND INDUSTRY, 1972

	Percent
Petroleum	55.9%
Electricity	22.2
Natural Gas	20.3
Coal	1.4

Source: Department of the Interior.

under pressure suitable for generating electricity by utilities in gas turbines, or better, in highly efficient combined cycle power plants in which the exhaust from the turbines is used to raise steam for a conventional steam turbine.

Fluidized bed gasifiers of French design are also available commercially to convert coal into a low heating value gas. In these gasifiers the coal is burned while suspended in an upward-directed stream of air. These units are even more efficient and cleaner than the Lurgi and Koppers designs. They can also be scaled up more easily to supply a pollution-free fuel for electric utilities.

Although gasifiers to make clean power gas are commercially available, none has yet been built in the United States. The basic reason is uncertainty over national energy policy. Companies are justly concerned that if they construct gasification plants their investments may be jeopardized through arbitrary decreases in the price of imported oil. Similarly a company opting for relatively more expensive gasified coal would be at a competitive disadvantage if others were still able to obtain cheap regulated natural gas. The Congress by continuing the present unwieldy system of gas regulation and by failing to deal with the problem of imports is simultaneously discouraging conservation, the exploration for more domestic gas, and the use of somewhat more expensive but more secure energy sources such as coal and solar energy.

SNG and Synthetic Oil from Coal

Besides being converted into low-Btu gas, coal can also be converted into methane (Substitute Natural Gas). The production of SNG from coal is a much more difficult and expensive task than producing power gas. Consequently, it may well be ultimately easier and cheaper to convert industry and the electric utilities to low-Btu gas and to divert the natural gas saved (65 percent of all natural gas) to residential and commercial sectors.

At least seven commercial processes are being developed domestically to produce methane from coal. Two of these are in the pilot-plant stage and are apparently experiencing some engineering problems. The El Paso Natural Gas Company plans to build a gasification plant in New Mexico utilizing cheap, low-grade coal and Lurgi gasifiers followed by clean-up and methanation. This particular process has been demonstrated to be technically feasible through tests in Westfield, Scotland using U.S. coals. The El Paso plant will probably cost over $300 million to build (1974 dollars), will produce 250 million cubic feet per day of gas, about 1/2 percent of U.S. demand, at a cost of about $2 per million Btus at the plant, about four times the cost of regulated domestic gas at the wellhead.

Many difficult engineering problems still have to be faced before large-scale coal conversion plants begin producing methane. Structural problems, corrosion and agglomeration problems, and problems with introducing coal continuously into the vessel without losing pressure, all remain to be satisfactorily solved. Commercial-sized coal-gasification plants using any of the new processes would seem to be still a decade or more away.

The commercial liquefaction of coal in New England or anywhere else appears to be yet a step further away than SNG production. A number of processes, all expected to be expensive, have been developed on a small scale but pilot plants and full-scale commercial plants have yet to be built. Such plants will probably not make any important contribution before the late 1980s.

Solar Energy

Energy from the sun can be captured in a variety of ways ranging from the heating of flat-plate collectors to the growing and harvesting of algae in ponds. Some applications are nearly commercial, such as the heating and cooling of buildings; some, including wind power, need large-scale demonstrations to test potential commercial designs; still other applications — large-scale electricity generation either on earth or in a synchronous orbit in space — need a great deal more research and development.

The environmental, social, and institutional impacts of using solar energy obviously depend on the particular technology employed. Those effects accompanying the heating and cooling of buildings are receiving the most attention while potential impacts of less developed systems are still only elements in large-impact matrices.

The economic feasibility of using solar energy is similarly very much dependent on the process and on geographic location. The location is important because of regional variation in both the amount of sunlight received and the costs of competing energy sources.

Heating and Cooling of Buildings

Without question the most nearly commercial application of solar energy is for water heating and the heating and cooling of buildings. In every part of the country solar-assisted homes and commercial buildings are now being constructed.[7] In most of these buildings part or all of the conventional roofs are replaced by collectors through which air or water is circulated and heated. The collectors themselves are usually just flat aluminum or steel sheets painted black, covered with glass to prevent heat losses, and insulated on the back to prevent excessive heating of the building's highest floor. The air or water passes through insulated ducts or pipes to a storage system usually in the basement and containing crushed stones or just water. Enough heat can be stored on a sunny winter day to carry the building through two or three consecutive cloudy days. For longer sunless periods an auxiliary heating system would supply the extra needed energy.

Used in this way solar energy will add 10 to 15 percent to the initial cost of the building. Because of the expense, buildings to be heated with the sun should be well designed and well insulated. Double or even triple glazing, well-insulated walls and floors, and "passive" collective systems such as large thermopane windows facing south, should all be considered in the design of a solar-assisted building (or for any other building, for that matter).

The Energy Research and Development Administration (ERDA) has estimated that by 1985 the United States could have 600,000 new solar homes, 55,000 new solar commercial buildings, and 13,000 commercial retrofits.[8] The combined annual fuel savings in 1985 would be about 36 million barrels of oil. One study performed for the National Science Foundation concluded that two-thirds of the 60,000,000 buildings to be constructed in the United States in the next 25 years are viable, cost-effective candidates for solar-energy systems. If all of these buildings were in fact solar-equipped, the annual electrical savings (assuming solar energy would be competing with electric heating) would amount to 1,500 billion kilowatt-hours, the total electrical output of the United States in 1970.[9]

The principal environmental effects of using solar collectors include the reduced need for conventional fuels, the consequent reduction in land use and pollution associated with conventional energy production, and the increased consumption of materials needed to produce the collectors and components. Since collector systems would be constructed of common

[7] William A. Shurcliff, *Solar Heated Buildings, A Brief Survey,* 1975. Available for $7, postpaid, from W. A. Shurcliff, 19 Appleton Street, Cambridge, MA 02138.

[8] "National Plans for Solar Heating and Cooling," ERDA-23, March 1975.

[9] Reported in "Solar Energy for Earth," American Institute of Aeronautics and Astronautics, New York, 1975, page 24.

building materials such as steel, aluminum, glass, insulation, concrete, pipes, etc., the direct environmental impact of their manufacture would be similar to those of the general construction industry. The energy payback time for these systems is typically two years or less.

In addition to these environmental effects there will be legal and institutional problems to deal with. The definition and determination of "sun rights" associated with property will have to be settled. Building and zoning codes will have to be examined to be sure that they do not inadvertently preclude the use of solar-space conditioning. Local property taxes, if applied to the added cost of solar heating systems, could reduce the effective fuel savings and remove the incentive for installing them.

Because of our dependence on oil we in New England are vulnerable to both embargoes and escalating fuel prices. Solar technology for heating and cooling offers an environmentally clean, essentially inflation-proof alternative to continued dependence on outside sources of energy. In addition it offers economic development opportunities for our sagging economy. Innovative engineering, system design and analysis, and light manufacturing and assembly are the key ingredients for a successful solar economy. They also characterize the best qualities of our regional economy. Federal funds will be increasing to help accelerate the process of commercialization. I fervently hope that we will have the wisdom and foresight to move aggressively and take advantage of the many opportunities that this new source of energy affords.

Wind Power

The use of winds to provide useful power is as old as history itself. In western Europe tens of thousands of windmills have been used since the Middle Ages to grind grain, pump water, and saw lumber. Windmills to generate electricity date back to 1895. By 1910 windmills in Denmark were supplying the equivalent of 200 megawatts of electrical power. During both world wars Denmark relied heavily on windmills for its electricity. During the 1940s the world's largest wind generator, the Smith-Putnam machine with a generating capacity of 1.25 megawatts, operated successfully in Vermont. In 1945 because of war-time limitations a known structural defect that had developed in one of the blades could not be repaired and the blade failed on March 26. By any standard, however, the experiment was a success, and a more efficient, less costly model was proposed for full commercial operation. Unfortunately further funds were lacking and the project died.

Interest in the United States in power from the winds has renewed because of our energy shortages. In 1975 NASA began testing a 100 kilowatt machine at Sandusky, Ohio. From the experience gained with this machine three large commercial units will be designed and installed in various parts of the country with construction beginning in 1976. Design of a one-megawatt machine will also begin in 1976. By the late 1970s large

wind generators in the one-megawatt range should be available for commercial operation. Additional research is being undertaken into various methods of storing the energy using flywheels, hydrogen storage, and compressed air. Further study is also needed on possible environmental impacts such as the effects of large numbers of windmills on local weather, bird population, and perhaps radio communications.

New England is fortunate in that it has a vast potential for using the winds as a source of power. The most productive sites are located on the continental shelf, followed by sites in the White Mountains. Professor William E. Heronemus of the University of Massachusetts has made a very detailed engineering and economic analysis of the feasibility of an ocean-based wind power system for New England.[10] Heronemus has designed a system to supply New England with 160 billion kilowatt-hours of electricity per year, almost 2 1/2 times its entire 1973 demand. Using proven marine techniques and commercial equipment for the electrolyzers (to make hydrogen from sea water) and fuel cells (to convert the hydrogen back to electricity when needed) he would deploy 83 floating generating units, each unit containing 165 wind stations, for a total of 14,000 wind stations. Each station would consist of three 200-foot-diameter, 2-megawatt generators mounted on a floating platform which would be anchored to the ocean floor. The generators would make electricity to electrolyze water into hydrogen and oxygen. The hydrogen would be stored in underwater chambers to be pumped ashore and converted into electricity on demand. The entire system would cost an estimated $22 billion to build. He calculates that a kilowatt-hour of electricity would be available, on shore, for less than 2.5 cents (1972 dollars).

Admittedly this system is not going to be built, full blown, within the next few years. Heronemus would have it constructed in phases and completed by 1990 to meet all of the new growth between now and then. The careful engineering and economic analysis that he has put into it and the relatively low costs that he foresees for the generated power clearly indicate that more detailed feasibility studies are warranted. Included in these would be an examination of possible effects on marine navigation and offshore fisheries.

Solid Waste

The burnable fraction of solid waste is composed mostly of paper and is therefore considered to be an indirect form of solar energy. During 1971 the United States generated about 880 million tons of dry, organic wastes. About 15 percent of this material, 136 million tons, was in the form of urban wastes and was readily collectable. It could have been used

[10]Heronemus is a naval architect and marine engineer with 27 years of practical design and engineering experience in the U.S. Navy.

for its energy value rather than being buried or burned without heat recovery. It is estimated that the combustible portion of this refuse (40 percent of refuse is water or nonburnables) had a heat value of 1,400 trillion Btus, or about 2 percent of total national energy consumption. If these wastes had been used to generate electricity they could have produced about 9 percent of all the electricity generated in the United States in 1970.

Three processes are now being developed to recover energy from solid wastes. The first shreds and then burns the trash in an incinerator or boiler to produce process steam or electricity. In the other two processes the trash is treated in a large vessel and converted into oil, or into a combination of oil, char, and low heating-value gas.

According to the EPA about 50 percent of urban refuse (by weight) is paper, and if burned would account for 70 percent of the total energy recovered from solid waste. In New England about 76 percent of the population (9.2 million in 1973) lives in urban areas. At five pounds of solid waste per person per day, about 8.4 million tons of waste are generated annually. (This figure includes moisture and non-combustible objects.) The heat content of this waste is about 84 trillion Btus, equivalent to 15 million barrels of residual oil, or about 9 percent of all the residual oil consumed in New England in 1973. If the trash had been burned to generate electricity, it would have met about 12 percent of New England's 1973 electricity demands.

Burning solid waste in a modern resource recovery plant has many environmental advantages. A new plant would be equipped with scrubbers adequate to meet EPA emission requirements. Moreover, the size of the investment would justify hiring a professional staff to ensure proper operation and maintenance of the facility. A large plant could serve many communities and thereby eliminate the need for individual dumps and landfills. The reclamation of metals in addition to energy would be another step in the direction of reducing demands for virgin raw materials. While the burning of solid waste is not the complete answer to New England's energy problems, it obviously can make a significant conbribution to it.

Electric Power Production

The trend in New England and in the United States has been toward an increasing dependence on electricity as a source of energy. In 1960 electric power generation accounted for 16.6 percent of total New England energy consumption; by 1972 this figure had reached 24.3 percent. Several reasons explain this gradual shift. First and most important is the low cost of installing electric heat. Speculative builders of residential and commercial buildings are usually undercapitalized and make every effort to lower first costs, even at the expense of higher operating costs. The growth in the use of heavy electric appliances such as freezers, washers, dryers, and air conditioners accounts for much of the remaining growth.

Fuel Options

In the mid 1960s the east coast utilities made a major shift from coal to imported oil as a source of electricity. This change was dictated by the momentary economic advantage of oil over coal; in retrospect it was a mistake. The utilities would be far better off now if they had sponsored the research necessary to burn coal cleanly and obtained long-term contracts with domestic coal producers. As things stand today, oil is no longer a reliable or economic fuel and no electric company would consider constructing a new oil-fired power plant.

For the near term only two fuel options are really available for new generating plants, coal and nuclear energy; neither is an environmental bargain. The problems with these sources, however, are not inherent in the fuels. Rather they reflect a chronic political failure (in the broadest sense) to commit the funds and resources necessary to allow their clean and safe utilization.

Electricity from Coal

Coal resources in the United States are enormous. Present annual production is about .6 billion tons compared with proven reserves of 433 billion tons. One-third of these reserves are low in sulfur, less than 1 percent. Total remaining recoverable coal resources are estimated at 1,600 billion tons. At present consumption rates we have more than 700 years supply from proven reserves alone.

Many public health and environmental problems are associated with the use of coal. They range from the safety risks experienced by coal miners to the acid sulfate air pollution affecting the eastern third of the Nation. Fortunately, most of the ill effects from coal use are preventable. Most lands that are being strip mined can be rehabilitated to productive uses without severe economic penalty. According to recent studies sponsored by the Department of Interior, reclamation costs range between $.12 per ton in the west to $1.37 per ton in the east.[11] These costs represent, at most, a small percentage increase in the final delivered cost of coal and should rightly be borne by consumers. Similarly, underground mines have been made considerably safer over the past five years, albeit at a loss of productivity, especially in older mines.

Air pollution is probably the most serious environmental impact of burning coal. Sulfur dioxide and particulates are presently the two principal pollutants of direct public health concern. Recent studies, however, performed by EPA suggest that the sulfates into which sulfur dioxide is converted may be a more serious health hazard than the sulfur dioxide.

[11]"Impact of Higher Ecological Costs on Surface Mining," NTIS No. PB 240 441AS, July 1975.

Fuel Gas Desulfurization

Since the late 1960s a great deal of time and money has been spent in developing flue gas desulfurization (FGD) technology. FGD systems, or "scrubbers" as they are frequently called, remove the sulfur oxide pollutants before they enter the chimney. According to the Environmental Protection Agency, a number of scrubbers are now commercially available and "...can be used continuously, reliably and effectively to control sulfur oxide emissions from power plants..."[12] Many of these units have shown higher than a 90 percent reliability for periods of five to eight months of boiler operation. Recently one major manufacturer announced the successful 12-month operation of a scrubber with a 90 percent reliability and a 90 percent sulfur oxide removal efficiency.[13]

With the successful demonstration of FGD technology users of large amounts of coal will now have available to them the means for burning high sulfur coal in new installations while still meeting EPA emission standards. In addition, in many instances FGD systems can be retrofitted to existing boilers.

While FGD technology capable of reducing sulfur emissions by 90 percent offers an immediate means to reduce pollutant emissions, it may not be adequate on a long-term basis to achieve air quality standards if the use of coal increases substantially. Also, FGD systems do not remove the sub-micron sized particles of ash that seem to pose the most serious health hazard because of their ability to penetrate deeply into the lungs. For these reasons FGD technology is generally viewed as an intermediate means for burning coal, but not the ultimate answer. For this, coal will have to be either thoroughly cleaned before combustion or else converted into a clean liquid or gaseous fuel.

Low Btu Gas

As we mentioned in an earlier discussion on coal, gasifiers are now available that can be used to supply clean gas from coal for either existing fossil-fuel plants or for new combined-cycle units. For the proven Koppers-Totzek unit, for example, we can state the following:[14]

- Sulfur emissions would be less than those from burning 0.1 percent sulfur oil;
- The entire gasification system can be started up within 30 minutes from a hot-standby mode;

[12]"EPA Releases Scrubber Reports," EPA News Release, September 25, 1974.

[13]"Stack Gas Scrubber Makes the Grade," *Chemical and Engineering News,* January 27, 1975.

[14]"Utility Gas by the K-T Process," Koppers Co., Inc., 1974.

- Little equipment change would be required on existing boilers;
- A very high conversion efficiency of 79 percent is achieved between eastern coal and the resulting (cold) gas.

The capital costs for installing such a system on a large 1,000 megawatt power plant would be about $120 per kilowatt. These charges on a new plant might be more than offset, however, by the elimination of both the precipitator and sulfur scrubber system.

Solvent Refined Coal

Gasified coal presents an attractive, clean option for New England utilities. The process would be particularly suited for a new power plant that could utilize both gas and steam cycles. For older, coal-fired plants the solvent refining of coal offers another environmentally attractive possibility.

Solvent refining is a method of treating coal which leads to a heavy liquid or a low-melting organic solid, suitable for burning in present coal plants. The coal is first dissolved in a coal-derived solvent. The solution is then filtered to remove the ash and other insoluble materials. The final product has a very high heating value (16,000 Btus per pound), less than 0.1 percent ash, and very little sulfur. A pilot solvent refining plant will soon be in operation in Tacoma, Washington.

Nuclear Energy

Without too much doubt nuclear power is the first choice of New England utilities for new base-loaded capacity. The New England Power Planning Organization, as of October 1, 1974, projects that 41 percent of New England's electrical capacity will be nuclear by 1984.

Nuclear power has several attractive features. Most important is its lack of air pollution. Anyone who has wrestled with the sulfur and particulate problems of the Northeast will appreciate this feature. Nuclear power plants also emit no carbon dioxide. There is evidence to suggest that the build-up of this gas in the atmosphere from burning fossil fuels may trigger a global warming trend with deleterious effects on the climate. According to some calculations this trend could begin at almost any time and once started would be difficult or impossible to reverse. A conservative approach to this problem would be to emit as little carbon dioxide as possible; that is, to burn as few fossil fuels as we can.[15]

Nuclear plants do emit small amounts of radioactivity to the environment but so far these emissions have caused no perceptible harm. This situation could change through a gradual build-up of radioactivity,

[15]We note that the virtue of no sulfates, particulates, or carbon dioxide is also shared by solar and wind energy. These latter sources have the additional benefit of not adding to the total heat load of the earth.

such as from the radioactive gas krypton-85, if and as more and more reactors are built. However for relatively modest sums of money no radioactivity at all need be released from them.

Supplying uranium for nuclear power plants (and weapons) has caused environmental problems in much the same fashion as coal mining has. Underground miners have suffered from silicosis and from excessive lung cancer. Several of the rivers of the Southwest have been polluted with radium from uranium mills. And thousands of homes and schools were built on radioactive mill tailings in the Southwest because of negligence on the part of the AEC.

Future uranium mining also promises to be as environmentally destructive as coal mining. At present all known and speculative high-grade uranium reserves (2.5 million tons) are sufficient to last for only two decades or so. Without a successful, economic breeder supplying a substitute fuel (plutonium), uranium will have to be obtained from low-grade ores by the 1990s. This implies the same kind of destructive large-scale strip mining and rock crushing that we associate with coal mining and oil shales. And at present the breeder program is in serious trouble because of escalating costs and design problems related to safety and breeding efficiency.

The current switch by utilities from oil to nuclear power is disturbingly reminiscent of their switch ten years ago from coal to oil. The fuel economics look favorable, provided that one does not look too far into the future.

More serious, though, than fuel availability are the problems of accidents, plant security, international terrorism, and waste storage. In my view controlling power plant accidents is the most immediate and pressing problem faced by reactors. Nuclear power plants generate large amounts of radioactivity as they "burn" uranium during day-to-day operations. This radioactivity normally stays almost entirely within the thousands of 12-foot-long fuel rods that comprise the core assembly. The core in turn heats (and is simultaneously cooled by) the water passing up through it, generating steam from which electricity is made.

If a large pipe in a reactor's cooling system should rupture, the normal cooling water would be quickly lost from the reactor vessel (a Loss of Coolant Accident — LOCA). If emergency cooling water is not supplied within a minute from the Emergency Core Cooling System (ECCS), the heat in the hot radioactive core will begin to melt the fuel. The fuel will melt first through the reactor vessel and then through the concrete below. Large amounts of radioactivity could escape into the environment and under the worst circumstances there could be lethal effects for tens of miles from the power plant and land denial, because of radioactive contamination, over tens of thousands of square miles.

The ECCS now installed in reactors have never been tested under accident conditions. Instead, elaborate computer codes have been developed and relied upon to predict their performance during accidents. According to a recent review of reactor safety by the AEC,

> . . .the current generation of industry and AEC calculational codes are not able to describe the detailed behavior of the injected water from first principle considerations, and the applicable confirmatory experimental work has not been completed.[16]

Indeed, most of the work lies in the future, including crucial work bearing on ECCS performance. The most important experimental program, the Loss of Fluid Test (LOFT), is almost a decade behind schedule and will not be able to supply useful information on ECCS behavior for at least a few more years.

We thus find ourselves in the position of having the performance of crucial safety systems in $100 billion worth of power plants still uncertain.

The probability of having major accidents which would require the ECCS is also uncertain. The AEC sponsored a major study (the so-called "Rasmussen Study" after its director Dr. Norman Rasmussen of MIT) to estimate the likelihood of a major accident. However, the computer methods used here are also of questionable reliability. The basic criticism is that nuclear power plants are so complex that one cannot think of, and therefore model, all of the important ways in which they can get into trouble. Estimates of probabilities of accidents will of necessity be too optimistic, that is, too low. In a lengthy review of the AEC study the American Physical Society (APS), the professional society of physicists, concluded that they (APS authors) did "...not now have confidence in the presently calculated absolute values of the probabilities..." of accidents, as estimated in the AEC study. The APS study also concluded that "...no comprehensive thoroughly *quantitative* basis now exists for evaluating ECCS performance, because of inadequacies in the present data base and calculational codes."

Reactor meltdowns need not result solely from accidents. They could be caused deliberately by saboteurs from either within or from outside. Sabotage against utilities has become more frequent during the past few years, particularly on the west coast where substations and transmission lines have been blown up. Nuclear power plant security is now inadequate to deal with these threats. It seems certain that as few as three or four well-trained commandos, of the sort trained in great numbers by our own military forces, could take over most reactors and using shaped charges or other means cause incalculable damage. The whole security problem is just beginning to receive the attention it deserves.

More global problems are presented by the increasing availability of plutonium, an extremely toxic waste product of all reactor operations. As the use of nuclear power plants spreads so will the technology for processing and storing the spent fuel. Plutonium, a valuable by-product of

[16]"The Safety of Nuclear Power Reactors and Related Facilities," WASH-1250, Final Draft, July 1973, pp. 7-15.

these operations can be used either to fuel reactors or to create nuclear weapons. One can imagine international terrorist groups hijacking shipments of plutonium and using the material to extort huge ransoms under the threat of either destruction from a crude bomb or an attack on civilian populations using radiological weapons. How could an industrialized nation resist such a threat? Indeed, it may already be too late to avoid the prospect of nuclear blackmail. The United States is only one of many suppliers of nuclear technology. And the know-how to construct nuclear bombs can be found in numerous unclassified documents.

The permanent storage of nuclear wastes away from the environment is a problem that should have at least one good technical solution. Unfortunately waste storage has not received the care and attention that it deserves. Numerous leaks of radioactive wastes have occurred from storage tanks in the state of Washington and the only permanent waste disposal site chosen by the AEC, in Lyons, Kansas, turned out in the end to be totally unsuitable. The AEC had simply not done its homework. As with safety, the symptoms of the waste problem are technological, but the real problem is one of poor management. We can only hope that no further large releases of radioactive wastes will occur before a permanent storage site is selected and the materials are solidified and buried.

IV. New England's Energy Future — A Personal View

The response so far of the New England states to the energy crisis has been disappointing. The first tendency among government leaders seems to be to assume a grand conspiracy and to deal with the problem on that basis. Thus we hear unsubstantiated claims that vast quantities of domestic oil and natural gas are being withheld from market until prices rise even more. Or that the electric utilities are somehow gouging their customers through the fuel adjustment clause. Unfortunately the problem is not that simple. The underlying fact that we all must face is that domestic oil and gas supplies will continue to decrease and that long-term substitutes will have to be found and used, and the sooner the better. We have reviewed in this paper the major options that we in New England have available. Coal is plentiful and could be used, after gasification or refining, by both industry and utilities. It offers the possibility of long-term contracts and price stability. But if the carbon dioxide problem worsens over the next few decades, the use of coal and other fossil fuels may have to be reduced.

Nuclear energy likewise is an option and is in fact the preferred one among the utilities. It presupposes, nonetheless, the solution of many outstanding problems and the successful development of a safe and economical breeder reactor. Alvin Weinberg, the former director of Oak Ridge National Laboratory, has described the acceptance of nuclear power as the acceptance of a Faustian bargain. For its great benefits we must forever exercise extreme care and diligence. To prevent the possibility of serious accidents all nuclear power plants must be built with the

highest possible degree of quality control; security procedures around power plants must be tight; international terrorism must be effectively curtailed; and high-level wastes must be guarded for at least a thousand years after burial. Having been deeply involved in the nuclear controversy for the past six years I (and many others) have concluded that the requirements of a nuclear economy are too much for us, at least for now. Just on the safety issue alone we have experienced ignorance and insensitivity among regulators, continued suppression of adverse experimental data, the truncation of important safety research programs, and poor quality control in the construction of power plants.

Solar energy, in its various forms, offers a future free of almost all of these problems. Today it can be used to heat and cool buildings, and to generate electricity from the winds. It creates no radioactivity and no air pollution. In my view New England should begin a major program to introduce this source of energy. We should be building solar-assisted buildings and gaining experience with wind generators both large and small.

Solar energy is obviously not the complete or immediate solution to all of our problems. As an interim means for generating electricity I would prefer gasified coal to nuclear energy. The unsolved problems presented by the latter source are too many and too serious to make further commitments at this time. Within five to ten years it is possible that many of these problems could be solved. A continuing assessment is warranted.

In this paper we have focused on energy supply. A final observation on demand management seems to be in order. Conservation — the optimal use of resources — and accurate energy pricing, without subsidies, should be the cornerstones of New England and national energy policy irrespective of our energy choices. A vigorous program of consumer education in every sector of the economy is long overdue, as is an overhaul of our complete energy pricing system from natural gas regulation to electric rate structures.

Discussion

Peter Judd*

I want to take issue with the premise, which is stated at the beginning, that the price of energy should incorporate all of the associated social, environmental, and public health costs and risks. It sounds good but it abates the major question. The environmental cost depends on three things. 1) What is being done? In some cases this can be quantified and in some cases, such as the solar reflectors in the city or a windmill on the White Mountains, it cannot. 2) Judgment as to its effect, whether it is good or bad. This depends upon information, some of which can be quantified and some of which cannot. Often the information is disputed and experts disagree. An example is the question of nuclear power. 3) What does it cost to mitigate the problem? This raises the problem of trade-offs.

Let us consider some examples of environmental costs in which the questions of judgment about what is being done, how bad it is and what the costs of mitigating the problems are all raised in various forms. For example, the So2 controversy is one in which scientists and public health experts still disagree about the effects on health. Now it appears that there may be new hazards, such as sulfur acids, which are considered to be even more severe. However, our society has already made the decision that So2 is injurious to human health and now the question is how much control is to be exercised on the burning of So2. Various states have different answers to that, beginning at .5 percent sulfur for fuel burned in the power plants and home heating installations in Connecticut. Now that matter affects human health and is rather grave. Many of the water pollution environmental costs do not affect human health, for example, as the objective of having swimming pool water in, say, the lower Delaware Bay by the year 1985. This costs a great deal of money and the money could be spent elsewhere to provide swimming facilities. There is no access to the water anyway since it is an industrial area. Is the cleaning up of that particular area an environmental cost? Cooling towers for some power plants are also examples of environmental costs about which one can have serious reservations. There is a cooling tower in Connecticut which runs all year round although it really need run only 10-12 weeks in the summer.

*Consultant and writer on environmental affairs. At present he works primarily for the Northeast Utilities Service Company in Hartford.

Yet the year-round operation is considered an environmental cost. Finally, let me give two examples of environmental cost which are going to be accepted in New England and which involve large sums of money about which I think there could be considerable disagreement. In one case a fish ladder is to be built to bring salmon, of which one has appeared, up the Connecticut River at a cost in excess of $10 million. No study has been done of who is going to benefit from this and of the relationship between the benefits and costs. In another case $10 million of capital, which we learned yesterday is scarce, is going to be spent on the Connecticut River to place two 245 KD transmission line crossings, which have been in place since 1966, underground for one mile. These crossings are located on land the utility gave to the state park. Are these all environmental costs? One must decide what an environmental cost is and what the value of mitigating it is.

Now in our society these questions are decided not by systematic analysis but by the push and pull of interest-group politics. Sometimes that turns out to be extremely beneficial. However, at this time of scarcity we face very serious conflicts some of which are mentioned in Jim MacKenzie's paper. The question of determining the environmental cost is really what this is all about. However, the paper also appears to endorse the goal of reducing the region's reliance on the fossil fuels, gas and oil. It says so in words, not in numbers. It says that for the next ten years new plants for electric generation must be coal or nuclear and that we must continue our dependence on imported oil for the foreseeable future as well. It also presents a cornucopia of possibilities, technological possibilities, which have as their basis the additional goal of providing a flexible supply.

Thus I would propose that we add to the environmental objective: first, the two objectives of reducing dependence and increasing diversity, and secondly, the use of technology of proven reliability. These two add very important constraints to what this paper has proposed. They limit our ability to place major reliance, for example, on coal, a major implication of this paper. In principle coal could take over much of what the utilities have planned to be nuclear. We're talking about eastern high-sulfur coal, about a delapidated railroad system, about scrubbers, and I think the paper is very optimistic about the use of scrubbers. I think that it is going to be very unfortunate for New England if we have to install scrubbers. In Connecticut it costs as much or more to put scrubbers on some of the old plants than the plants' depreciated value. We have to remember that when we are talking about additions to capacity we are speaking of very large plants but at present the scrubbers that have partially worked out in the West, in the Mid-west and Philadelphia are not on the size plants that we are discussing.

The technology for coal, removal of gases, fluidized lead combustion and various new techniques of burning coal, will not be developed in New England but by utilities in the Middle West and the Far West that use great quantities of coal. I don't think that there is any prospect of our utilities taking the lead in developing coal technologies; I think we must follow. At the moment the $25 ton coal that is referred to in the paper is not available and we should not minimize the problems of ash disposal. Ash was disposed of for many years by utilities in this region but the region has grown up a great deal since then.

Now the solar technologies may also be given too much emphasis here, although they have a very important role to play. I think MacKenzie is correct in emphasizing the direct use potential for space conditioning and its environmental benefits. The economics, of course, are a real problem. There is no sign whatsoever in my state that people as a matter of course are installing solar systems because of higher oil or electricity costs. They simply aren't doing it. There are some experiments but the builders, who build most houses, aren't doing it and further the houses are not sited to the south as they should be. So if we are to have a large number of houses heated in part by the sun by the year 1985, we haven't even begun on it. I myself believe that solar heat will become economically attractive along with bulk peak rates and storage systems for electricity and that it's in keeping with certain economic and financial objectives for utilities to offer these rates. Consequently, I think that by the 1980s we are going to see solar use supplementing electricity for direct heating, perhaps for cooling as well.

The wind example in the paper, Professor Heronemus's grand design of 16,000 windmills on Georges Bank, has been given a great play, and again I find this internally inconsistent with criticisms of utilities for plans made in the past that don't bear out in the future. Here is a great plan for supplying all of New England's power from Georges Bank which would be extremely vulnerable to interruption by weather or by hostile means. I think we're not talking about a real possibility except for supplementary use, perhaps in the distribution system and perhaps to supplement some residences or industrial plants.

In solid waste, again a great plan is made for something like 13 percent of the region's energy supply to come from this source. But to put this in perspective, there's a plant in Bridgeport, Connecticut which is preparing a shredded material to be used by United Illuminating Company in their Bridgeport Harbor plant. Twenty percent of the capacity is to be supplied by waste. The waste is mixed with oil in a one-to-ten relationship. So although we're using more combustion of solid waste, it is not going to provide anything like the amount that has been suggested here because it has to be burned in conjunction with fossil fuel and can only be burned in these cycling plants, and there are likely to be many, many problems in collecting it from suburban and rural areas.

I think first, we should begin with conservation which was not emphasized sufficiently in the paper, although it was cited at the end. This allows time; there's been considerable conservation in New England in the electrical consumption area in late 1973 and 1974. My state at least experienced reduced electrical use at the same time as output and employment levels remained steady or increased. However, the reduced demand

can be attributed largely to the recession. But there is still probably a great deal of room to move and to provide for conservation, particularly in the commercial sector, which is the fastest growing consumer of electricity and other energy forms. Conservation has benefits in that it buys time and I think that in terms of finances, time is important although conservation in the short term does affect earnings. Conservation allows time for new technologies to develop. However, let us remember that reduced demand also has its price. It has a price in that while it removes wastefulness, it also removes part of the buoyancy of the American economy and part of the whole American character of expensiveness and the expanding-pie philosophy and practice which we followed successfully for many years. It will also result in more stringency in public expenditures. Even in the environmental area we may suffer: parks will not be bought and museums and cultural institutions will not receive the funds that they need to keep their programs going. So that is a double-edged sword but on balance, desirable.

The utilities here have planned a nuclear expansion program. Mr. MacKenzie says that over the next ten years there is no alternative to nuclear and coal.

Now over the longer term, by which I mean the year 2000, the question is whether we can rely on these technologies that have been discussed in the paper. I don't think so. It doesn't look as though for the large increments of power that are going to be required we can rely on solar, wind, and the coal-pacifying technologies unless we're willing to pay what I expect to be a nonacceptable price. So we must work within the most realistic course which is in the direction of a steadily expanding use of electricity and does permit a diversity and flexibility of supply which the other forms do not and within the economic constraints which are overwhelmingly important now. And we should have the same expectation that technology and good management will guide us in the nuclear area that the paper seems to assume will provide better solutions for us in the coal, wind, and solar area. Again, I don't see how we can say in one case technology, management and new developments will help and in the other it will not. The pie is not growing as fast as it did in the past which means that the groups which are concerned with bettering themselves are going to be increasingly ornery and concerned about increased prices, which means that we cannot play with technologies as expensive as some of those proposed here.

Response to Judd

James J. MacKenzie

In his opening remarks Mr. Judd states that environmental costs are 1) difficult to measure, 2) may be considered "good" or "bad" depending on the "experts," and 3) may cost too much to mitigate. I would certainly agree that environmental values are sometimes difficult to quantify. But it does not follow that these values do not possess great worth, irrespective of our poor ability to assign a dollar figure to them. Perhaps windmills should not be placed in the White Mountains because of the aesthetic damage that would result. When Professor Bill Heronemus asked me my opinion on the subject a half a dozen years ago, I suggested he look elsewhere, that these mountains were too valuable to New Englanders. It was at that point that he started looking more seriously at offshore systems.

Fortunately, not all pollution costs are as difficult to deal with as visual pollution. Mr. Judd's example of sulfur pollution is such a case. The fact that the exact effects of sulfuric acid air pollution on public health are still unknown is really not the point. The point is that for years consumers were getting "cheap" electricity while the elderly, the young, and asthmatics suffered and bore excessive medical costs. The differences in the intensity of fuel use from state to state account for the different sulfur regulations; each state is aiming at essentially the same air quality standards.

Mr. Judd's observation that water pollution abatement may not be worth the cost because swimming pools could be provided more cheaply is a classic example of how we have gotten ourselves into our present environmental mess. First, he *assumes* that industrial wastes do not pose a threat. Recent history shows that information is too scarce to be able to state this as a fact. Mercury wastes, asbestos tailings, PCBs, and other organic chemicals were all presumed innocent. They would stay where they were put. They would not affect public health. Yet scarcely a week goes by without some carcinogen being identified in our food or water, usually with no obvious source. Recall that 80 percent of human cancers are believed to be environmentally caused. If there is any lesson to be learned from the past ten years it is that we must be more cautious in our industrial activities. We must bear the added costs of pretesting chemicals before releasing them into the environment, or else we must not release them at all. In the absence of conclusive proof, we must take a conservative approach to environmental pollution and control it at its source.

This means meeting environmental standards, set as wisely as we know how, and paying the additional costs. These are the environmental costs to which I was referring.

Mr. Judd makes several other points on which I would like briefly to comment. He says that coal is not really a likely source for electricity in New England because of lack of transportation facilities, high cost, and lack of scrubbers. First, coal is now being burned in power plants in New England. Two-thirds of New Hampshire's electricity and about 6 percent of Massachusetts's electricity come from coal.[1] In a personal communication with the fuel buyer of a large New England utility, he assured me that if the utility were to commit itself to coal, it would buy its own mine and obtain coal delivered to New England at about $25 to $30 per ton. As I indicated in my paper, scrubbers in fact are being commercially used. There are over 100 scrubbers in operation, under construction or planned, with most to be in operation by 1977. But my own belief is that we would be better off removing the sulfur either before combustion, through solvent refining, or in a modified burning process, using gasifiers or fluidized beds. Commercial low-Btu gasifiers are now available and are in use throughout the world. They can be used here to produce clean electricity without air pollution.

As for floating wind turbines, I am always amused that the utilities cannot imagine them, yet have little difficulty in accepting floating nuclear power plants, first introduced in the comic strips about ten years ago.

With regard to solid waste, I suggested that solid waste could supply about 12 percent of our *electricity* needs, *not* total energy needs.

In his last paragraph Mr. Judd states that: 1) large increments of power are going to be needed; 2) that we cannot rely on coal, solar, or wind unless we are willing to pay an "unacceptable price"; and 3) good management will take care of the nuclear problems. My answers are that: 1) with any kind of a conservation program in this country, large increments in electricity demand will not occur, 2) that coal is or will soon be competitive with nuclear everywhere, including New England, and that without its many Federal subsidies nuclear power would not be competitive at present. The nuclear subsidies range from Federal insurance programs limiting the liability from accidents, to a host of unpaid social costs that we are simply deferring to future generations. And 3) because of the qualitatively and quantitatively more serious risks posed by nuclear energy a management effort far superior to what we have experienced over the past 30 years is needed to make it acceptable. The prospects of increasing the quality of the Federal management effort do not seem bright.

[1] *FPC News*, October 7, 1975.

Discussion

Louis Cabot*

I am Chairman of Cabot Corporation, which imports liquefied natural gas into Boston Harbor through its subsidiary, Distrigas Corporation. I would like to refute some of Dr. MacKenzie's statements.

First, I would like to tell you that I worked on that Smith-Putnam windmill in Vermont he mentioned back in the early forties when I was at college. I would like you to visualize a Boeing 747, standing on its tail on top of one of the highest mountains around in full view of the beautiful, rustic city of Rutland, Vermont, waving its wings around like arms. When the wind was really blowing, which would be some but not all of the time, the windmill would produce less power than one World War II single-engine fighter plane. You can draw your own conclusions as to how useful a system of such installations would be in solving our energy needs.

One image created by Dr. MacKenzie's paper concerned coal gasification, which he depicted as a socially more desirable source of additional gas than LNG. But if you really look at all the health hazards and environmental problems involved in coal gasification, with the constant dangers of men working underground, with strip mines devastating the landscape, with enormous consumption of precious fresh water, with new railroads criss-crossing the countryside, and with ever higher sulfur pollution going to the atmosphere, it is clear that the safety and environmental problems are as great and probably much greater than those for oil or gas.

There were other pieces of imagery, derogatory to LNG, used in Dr. MacKenzie's talk which did not appear in his printed paper. For example, he tried to arouse anti-Algerian feelings by evoking chauvinism and arousing us to the dangers of relying on foreigners for energy. The facts are that the amount of LNG to be brought into New England by Distrigas represents about 3 percent of the total gas consumed in the area its facility can service. That's not a tremendous exposure. Dr. MacKenzie appealed to our sense of economic outrage by talking about $3 or $4 per thousand cubic feet of gas when, in fact, the price is substantially less and comparable to imported oil per unit of energy. He frightened us by saying liquefied gas is tremendously concentrated, 600 to 1. The fact is that liquefied gas has a little less than the same amount of energy per gallon as gasoline, or heating oil, or propane, energy sources which Dr. MacKenzie

*Chairman of the Board, Cabot Corporation and of the Federal Reserve Bank of Boston. In addition, he is a director of many corporations and a trustee of innumerable institutions.

implied are not hazardous. He conjured up an image of 100 square miles of devastation. There is no realistic set of circumstances under which that could happen. He talked about a million and a half barrels of LNG being stored in Boston Harbor. This too is misleading because the storage is at several well-separated locations, and the biggest tank in the area holds 600,000 barrels, comparable to large oil storage capacities. Every opportunity was made to scare you. Is the use of imagery a sound method for arriving at balanced judgments about complex issues?

Cabot and all of the LNG industry have made careful studies of every aspect of LNG safety. Serious quantitative analyses always come to the conclusion that the critics are off by orders of magnitude. Of course, a large fire would be bad. Any large fire is bad. But enormous precautions have been taken to avoid fires, and to keep those that do occur small and under control. I object to the cavalier assumption that the LNG importer is insensitive to matters of public safety. Boston Harbor was selected after a tremendous amount of research. Remember that one of the issues is not to mar the beauty or disturb the ecology of any presently unspoiled coastline area. The site for the Distrigas tanks was a semi-abandoned gas works, already a gross eyesore in a long-standing industrial area. We worked with all the authorities who had any jurisdiction over siting, including the City of Everett authorities who very much welcomed it and the Coast Guard who have dealt with similar issues for years. Our objective was to make the facility as safe as humanly possible and to make the area more attractive than it was. This we have done.

The Coast Guard has taken special measures to avoid shipping accidents in connection with LNG ships coming into our harbors. It controls all traffic whenever an LNG ship comes into harbor and creates a completely traffic-free envelope around the ship, two miles ahead and one mile behind it. If under those circumstances a collision should somehow still take place, the collision could only be minor and the chance of a major spill infinitesimal. LNG tankers have a much safer hull design than ordinary gasoline or oil tankers. They have five feet of insulation and at least two separate skins between the cargo and the outside, compared to one inch of mild steel for ordinary tankers. Furthermore, the Navy, the Coast Guard, and the Air Force have conducted tests to determine how even large LNG spills on water and fire can be controlled.

Theoretical analyses of the worst possible case, the one Dr. MacKenzie described, have been done by many other careful scientists. They strongly refute his estimate of the size of the affected area and the number of casualties.

To supplement all the work by Distrigas, its engineers and contractors, and all the relevant government authorities, Cabot Corporation also set up an independent Safety Committee, reporting directly and independently to the parent company's board of directors, to review all matters of safety for the project. It was made up of engineers and scientists from universities, government, and industry, widely experienced in cryogenics, hazard analysis, and other related technologies.

The real issue is the relationship between the risks a facility creates and the benefits it produces. If you look seriously and objectively at risk-benefit analyses for the various energy systems, LNG is one of the safest.

I can only say that the public must some day realize it is being misled if if follows those who only forecast doom and discredit all serious efforts to find the best solutions for meeting real human needs.

Response to Cabot

James J. MacKenzie

At the beginning of his remarks Mr. Cabot dismisses the potential for wind to make any contribution to the solution of our energy problem. The power from a 1000 kilowatt wind turbine would be no greater than that from a World War II fighter he asserts.

According to the *Project Independence Report* (Solar Energy Task Force) there is a very large potential in the United States for extracting energy from this renewable resource. "An estimate of the expected amount of power which could be extracted from the wind over selected areas of the U.S. by the year 2000 has been calculated to be about 1.5×10^9 MWeH/year (Megawatt electric-hours/year). This is about 80 percent of the current U.S. demand for electricity. This is neither a theoretical maximum nor an optimum, but rather the most reasonable probable value yet calculated."[1] If the price of oil remains at $11 per barrel and if incentives were introduced, the report concludes that about one-fourth of our electricity could come from the winds by 2000.

Low-Btu coal gasification is also dismissed, primarily on what Mr. Cabot sees as safety and environmental grounds. First, I am the first to admit that there are problems in mining coal. And though, as Mr. Cabot suggests, they are greater than those of finding oil and gas we shall have to solve them since we have lots of coal, but very little oil and gas. The environmental and safety problems of mining coal must now be considered essentially political. Europeans have demonstrated that mines can be made safe and that most strip mines can be rehabilitated. Obviously those areas that cannot be rehabilitated, perhaps in the steep hills of Appalachia and in the West, should not be surface-mined at all. All that we really need to solve the problems of coal mining is an enlightened administration in Washington.

As for the other effects, very little fresh water is consumed in low-Btu gasification, as opposed to the manufacturing of substitute natural gas. On balance, "criss-crossing the countryside" with railroads can scarcely be considered a major environmental problem; rather, it is part of the solution to our energy problem to rehabilitate our railroads and reduce our dependence on trucks and planes. Also, as I indicated in my paper, scarcely any sulfur at all is released to the air from low-Btu gas production.

[1]Page IV-15.

Mr. Cabot reprimands me for suggesting that we should think long and hard before becoming dependent on imported LNG. My admonition was relatively mild: "In light of our recent experiences with imported oil one must question the wisdom of once again becoming so dependent on foreign sources. It is easy to imagine U.S. companies financing a huge, costly liquefaction, transportation, and storage network only to have the exporting countries arbitrarily and sharply raise prices or even nationalize the holdings." Actually some of this is already beginning to happen. In the fall of 1974 Libya broke its contracts with both Italy and Spain by arbitrarily raising its LNG prices. Both countries refused to accept the higher prices and shipments were temporarily suspended, to be resumed later only on a ship-by-ship basis. As for Algeria, the source of LNG for Mr. Cabot's company, it has recently begun to press for a "hardship" clause in its contracts that would permit renegotiation of contracts in the event of a "major change" in the natural gas market. U.S. firms oppose such a clause claiming that it effectively reduces the length of the contract to as little as two years. Some countries such as Indonesia are relating their price of LNG directly to the cost of oil and other competing fuels. Thus there is the distinct possibility that the price of LNG will rise as arbitrarily and capriciously as the price of oil. And once committed we will have little alternative but to go along.

Mr. Cabot implies that LNG is no more dangerous than gasoline or heating oil because as a liquid it has a similar heating value. The fact is that the heat content of LNG is not the issue here. There is, after all, two to three times as much energy in a pound of firewood as there is in a pound of dynamite though we certainly view the risks from the two differently. LNG and propane are much more dangerous than fuel oil or gasoline because large volumes can quickly evaporate, posing severe fire and explosion hazards. A small, primitive LNG facility exploded in Cleveland, Ohio in 1944, killing 133 people, injuring 300, and destroying or damaging 10 industrial plants, 80 homes, 200 automobiles, and the city's sewer system over an area of 30 acres. The flames from the fire and explosion of the 25,000 barrels of LNG reached an estimated one-half mile into the sky. And as Mr. Cabot states, there is a tank of 600,000 barrels capacity in Everett.

I certainly did not state or imply in my paper that the Cabot Corporation was not taking all the safety precautions that it could imagine. Nor did I say that LNG should definitely not be imported into the United States. But the fact remains that accidents due to events entirely beyond our control can and do happen. After an LNG ship has docked to unload, tanker traffic resumes in the harbor. Is it not possible that a ship might lose control and ram a docked LNG tanker and start a fire? The consequences of such a fire are still the subject of scientific investigation. There are honest disagreements on how severe it would be. In my view the Federal Power Commission, the Coast Guard, or some other Federal authority should undertake an independent safety analysis of LNG with

the goal of establishing siting criteria for large storage tanks. In the meantime I submit that it is only prudent to locate such tanks away from heavily urbanized areas. LNG facilities are clean enough so that their impact on less-developed areas of the coast could be made acceptable.

Discussion

Nuclear Safety: The Positive Side

R. Murray Campbell*

The negative side of nuclear power — the horrific imagery of suffering and devastation — needs no further publicity; allegations have been quoted and requoted until they have become axioms. What began as a responsible note of caution has become a strident campaign to mothball nuclear power.

But there is a very positive side to the issue — and it can be summed up in the assertion that the emphasis in the nuclear industry is on safety and quality, and it is not allowed to be subverted by considerations of cost, schedule, convenience, etc.

A peculiarity of the industry is that a minor incident, or a suggestion that an incident might occur as a result of some defect that has been uncovered, receives instant and widespread publicity while the follow-up story which invariably reveals the mountain as a molehill goes unnoticed. The first public act of the new Nuclear Regulatory Commission about a year ago — ordering re-examination of reactor vessel nozzles (piping connections) for cracks at several operating plants — is a good example. To the public, it must have seemed that a careless industry was nabbed in the nick of time by a regulatory body that should have been alert sooner. To those familiar with the facts, it was merely another expression of thoroughness with which every potential hazard is identified, investigated and negated.

The Nuclear Regulatory Commission (successor to the Regulatory Branch of the AEC) does not begin, it merely continues, a severe and competent regulatory interest in safety. Those of us involved in engineering and construction of nuclear plants saw no sign that our inquisitors from the old AEC were in any way softened by influence from the promotional arm of the AEC. However, it is true that with the passage of time, more and better techniques become available to assess engineered safety features.

The aspect of regulator versus applicant, with mountains of reports and testimony available for public scrutiny, sometimes seems capricious and inefficient, but it certainly is effective. As a result, the few accidents which have occurred have been minor, and there has been no radiation-related casualty or serious injury from about 300 operating-years of nuclear plants.

*Engineer. His current position with Stone and Webster Engineering Corporation is Project Manager responsible for engineering, construction, and cost control of a large nuclear power station now under construction.

All nuclear plants must be designed, constructed, and operated in a manner which avoids undue risk to the health and safety of the public and plant personnel. This means that consequences of radiological releases due to accidents and operations must be within criteria established by AEC Regulations.

The main design feature of a nuclear plant for protecting the public from unacceptable radiation exposures is the installation of multiple barriers between the prime source of radioactivity and the public. The source of this radioactivity is the fission products in the reactor fuel assemblies. The three major barriers between these fission products and the public are:

- The fuel element barrier, which encapsulates the fuel material and the fission products.
- The reactor coolant system boundary, which contains any leakage from the fuel elements.
- A containment structure, which encloses the major portion of the reactor coolant system.

The fuel material, the reactor coolant, and the distance between the reactor plant and the public also serve as barriers.

The most serious event conceivable is the loss-of-coolant accident. If the coolant, usually water, were lost because of a pipe rupture, an emergency core cooling system (ECCS) should still supply adequate coolant to the fuel elements to prevent their melting or bursting and releasing fission products.

The question of ECCS effectiveness has been a subject of debate for over three years. In 1971 the AEC published a set of guidelines for ECCS requirements. These were known to be very conservative and the transcript of public rule-making hearings filled 50,000 pages.

Questions still remain concerning the scope of the investigatory programs under way. Some intervenors say that without full-scale testing we will never know the true effectiveness of ECCS. If this is so, we will also never know the true effectiveness of other facilities and endeavors with low risks and high-fatality consequences of failure. For example, jet airliners are not tested to destruction and full-scale dams are not loaded to destruction.

In all these programs, models simulating the important parameters with appropriate scientific interpretations are used to develop final design and analytical methods before scaling to full size. This technique is well understood and has enabled us to progress to our present state of advanced technological sophistication without catastrophic accidents.

The industry hoped that the logic of the now famous Rasmussen report, which considers all sorts of permutations and combinations of failures and malfunctions of the nuclear system and accident mitigating systems, would convince people that the probability of serious impact on the public is negligible. Unfortunately, although none of the many criticisms of his report have any depth, they have detracted from its tremendous potential for placing safety in perspective. It shows clearly that no reasonable assumptions could bring the nuclear hazard to a single member of the public into the realm of probability that, say, the same member might be struck by lightning. Do the public and the press worry about multiple extermination by lightning?

The more sophisticated elements of the anti-nuclear crusade seem to be abandoning the ECCS and other safety issues related to reactor plant failures *per se*. The subject of the debate is turning more to the problems of sabotage, nuclear terrorism, and waste disposal.

The multiple barriers, the massiveness of the shielding and containment, the conservative and redundant design of safeguard features make effective sabotage difficult and mitigate its consequences if it did happen. However, nuclear facilities are now closely guarded and all administrative procedures and physical features are audited by regulatory authority, such that sabotage from without or within entails a high degree of risk with little prospect for significant effect.

Given the media's tendency to excite the public on nuclear hazards, nuclear terrorism admittedly could be extremely effective — if it could be carried out. Undoubtedly, we can expect it from sources outside the United States where strictures the United States places on the utilization of nuclear power would be ineffective. A well-developed nuclear industry and related public acceptance surely would enhance, rather than detract from, an ability to deal with such terrorists.

The popular notion is that any junior scientist can make a bomb and that the only hard part is stealing enough plutonium. Perhaps it isn't too hard to come up with a conceptual design of a bomb but it is quite another matter to manufacture it — especially, the delicate machining, handling, and fitting of many pounds of highly radioactive material. The terrorists would have to acquire a facility far beyond the means, patience, management, and technical skills they are likely to have.

Disposal of radioactive waste is more of a philosophical question than an engineering problem in that one can question the propriety of leaving the monitoring and guarding of certain long-lived wastes to future generations. But we also build high dams the continued integrity of which must be the responsibility of future generations, and if we exhaust our irreplaceable fossil fuels through lack of nuclear power, we have denied future generations the use of these fossil "fuels" for recyclable non-fuel uses.

Nuclear critics represent the scientific community as being overwhelmingly against nuclear power. The principal evidence is a petition signed by 2,000 "scientists" who oppose nuclear power. Not only do these signatories represent a small fraction of the nation's scientific and engineering community but few of them have intimate knowledge of how nuclear facilities are engineered and constructed. It is unfortunate that the public hears little about the positive side, and is aware only of well-publicized statements on the anti-nuclear side. Yet the regulations, the safety

analysis that accompanies each application for a construction permit, the searching questions and detailed answers which are part of the licensing process are all available for public scrutiny and demonstrate the thoroughness with which the industry and its regulators pursue safety.

Those interested in this subject may contact the author for a more detailed technical discussion and bibliography.

Response to Campbell

James J. MacKenzie

According to Mr. Campbell there are virtually no problems with nuclear energy. In particular, the Nuclear Regulatory Commission (formerly the Atomic Energy Commission) is an effective regulator; the Emergency Core Cooling Systems (ECCS) are conservatively designed; there are no criticisms of the AEC's Rasmussen report with "any depth"; it is extremely difficult to make a crude nuclear bomb, among other reasons because the material is "highly radioactive"; and the disposal of radioactive wastes is more a "philosophical" than an "engineering" problem. I disagree categorically with Mr. Campbell on each of these issues.

First, has the AEC been an effective regulator? The answer is a clear no, not only in reactor safety design, but in essentially every other nuclear activity that it has developed and regulated. A devastating history of the failure of the AEC can be found in Peter Metzger's book, *The Atomic Establishment.*[1] In it Metzger documents how the AEC failed to protect the American public from weapons fallout in 1950s; how it failed to protect underground uranium miners from excess cancer, when they were well known at the time; how the AEC refused to regulate the use of radioactive tailings in the southwest and allowed homes, churches, schools and hospitals to be built upon them; plus other examples involving nuclear airplanes, rockets, pacemakers, etc. It has been the rule at AEC, and not the exception, to mismanage the development of its programs and to permit unnecessary risk to the public health.

The failure to develop adequate, proven safety systems in nuclear power plants is unquestionably the AEC's most serious example of mismanagement. The fact is that the critically needed emergency core cooling systems have never been tested under even the simulated conditions of a severe accident. As a result their performance under accident conditions is still unkown. And without the ECCS performing, a serious pipe rupture could lead to a melt-down of the fuel and a rupture of the containment system surrounding the reactor vessel. The stage would be set for a major release of radioactivity of which the results to the public health would depend on wind direction and population densities.

[1]New York: Simon and Schuster, 1972.

According to Mr. Campbell the AEC in 1971 published "very conservative" guidelines for ECCS performance. What he failed to say was that the guidelines were for controversial computer models describing ECCS behavior, and not for the ECCS themselves. Although the AEC's official position was that the models were adequate to describe the ECCS, AEC's internal memos showed serious doubts on the issue within the agency. In 1972, at the peak of the ECCS public hearing, environmentalists, with the threat of a law suit, forced the release of a number of AEC internal memos on ECCS. According to *Nucleonics Week,* the weekly industry newsletter:

> Study of the recently released AEC internal documents on emergency core cooling reveals a strong measure of staff concern that: 1) the interim criteria on ECCS are not conservative enough; 2) that accident-condition factors such as coolant-channel blockage are not sufficiently understood or allowed for; 3) that experimental tests conducted so far have little or no relevance to the large reactors now being built; and 4) that computer codes used for calculating the results of a hypothetical loss of coolant accident (LOCA) are relatively crude, lack much needed data, involve too much "patching" between one code and another, were intended for 1965 and 1967 reactor designs, and should be replaced by much more sophisticated codes as soon as possible.[2]

The record of the ECCS hearing shows that the staff's qualms were well justified and that major accident phenomena were not even identified at that time, much less included in the ECCS computer models.

According to Mr. Campbell there has been no serious criticism of the AEC's reactor safety study (the Rasmussen report) which claims that nuclear accidents would be very unlikely to cause public harm. He apparently ignores the year-long, federally funded study of this report by the American Physical Society, the professional society of physicists. The APS study, completed in 1975, concluded that the AEC had vastly underestimated the number of cancer deaths that would result from a serious accident. More importantly, the physicists concluded that they did not "have confidence" in the techniques used by the AEC to predict nuclear accident probabilities. As for the ECCS codes, they observed that there is a danger that "the mere existence of extremely complicated computer codes, which few people understand, will lead to an overconfidence in reactor safety."

According to Mr. Campbell it would be difficult to make a crude weapon, in part because the material is "highly radioactive" and in part because the "terrorists would have to acquire a facility far beyond the

[2]February 17, 1972, p. 8.

means, patience, management, and technical skills they are likely to have." First, *neither* plutonium nor uranium, the materials from which bombs are made, is "highly radioactive." They are alpha emitters and as long as they are not breathed in or absorbed through a cut they can be safely handled for hours without any significant radiological hazard. Is it really so difficult to make a crude bomb? According to the most thorough public study on the subject, "Under conceivable circumstances, a few persons, possibly even one person working alone, who possessed about ten kilograms of plutonium oxide and a substantial amount of chemical high explosive could, within several weeks, design and build a crude fission bomb. By a 'crude fission bomb' we mean one that would have an excellent chance of exploding, and would probably explode with the power of at least 100 tons of chemical high explosive. This could be done using materials and equipment that could be purchased at a hardware store and from commercial suppliers of scientific equipment for student laboratories."[3]

Mr. Campbell also claims that nuclear plants are impervious to saboteurs. Suffice it to say that the bomb experts from the Massachusetts State Police told us, as members of the Massachusetts Commission on Nuclear Safety, that they could easily sabotage one with very little effort using high explosives. (This was in the spring of 1975 and the security situation at nuclear plants may have improved some over the past year.)

Lastly, Mr. Campbell states that guarding radioactive wastes for hundreds and thousands of years is no more necessary than guarding dams and the like. Unfortunately, dams break, drowning people who were unfortunate enough to live on the flood plains below them. And the AEC has allowed radioactive wastes to be stored in leaky old tanks and to be buried in trenches where they proceed to leakout and enter food chains. Neither situation is satisfactory, nor does one justify the other.

It is surprising that Mr. Campbell can state that the public hears little about the positive side of nuclear power. Every day we are barraged by advertising from the utilities, the reactor vendors, their trade organizations, and their government allies in ERDA. Why is it that the nuclear industry, with all its financial and political clout, cannot convince the press, the public, and the scientific community that it is right and that its critics are wrong? Perhaps it is because their case is weak. I can assure Mr. Campbell and other members of the nuclear industry that they need only put their house in order and solve the many problems, technical and otherwise, plaguing them. When this is done, their critics will go away.

[3]Mason Willrich and Theodore B. Taylor, *Nuclear Theft: Risks and Safeguards* (Cambridge: Ballinger Publishing Co., 1974), page 20.