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Electricity Generation Choices for the Near Term

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The use of electricity in the United States has increased from a minor level at the turn of the century to a point where it now accounts for about 30 percent of our national energy consumption. The increase has been steady, outstripping by a considerable margin the overall rate of increase in energy use. Thus, in the 30-year interval from 1948 to 1978, electricity production by the utility industry increased almost eightfold, while total energy consumption rose by a factor of 2.4 (*1*).

Summary. Electricity demand is expected to increase during the next few decades, especially if it is accepted that the primary goal of energy conservation is to reduce oil consumption. Although the renewable resources in principle have unlimited potential, it is not clear that they can make a major contribution to electricity expansion within the 20th century. Coal and nuclear power are the practical alternatives. The adverse effects of nuclear power probably remain less than those of coal, despite the impact of the Three Mile Island accident. It is important to explore and exploit all options, especially the endangered nuclear option.

It is clear that the historical rate of growth in electricity use cannot continue, and since 1973 there has been a marked decline in the growth rate. Nevertheless, electricity is now so important a part of our national energy budget that its rate of future growth and the means by which that growth is achieved will largely determine our success in achieving the chief goals of our energy policy, namely, to decrease the demand for oil, to restrain the inflationary impact of higher energy costs, and to improve the environment.

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Present Sources of Electricity

Before considering the alternatives available for electricity generation in the next few decades, it is useful to review our present status and the trends of the recent past. The primary energy sources used for electricity generation by the utility industry are shown in Table 1 for the years 1972 and 1978. Electricity generation is expressed here in units of gigawatt-years, where 1 GW-year is the amount of electricity produced by a 1000-megawatt plant operating uninterruptedly for 1 year.

Total output increased from 200 GW-year in 1972 to 252 GW-year in 1978, an average rate of increase of 3.9 percent per year, well below the 8 percent average rate (*2*) for the preceding 25 years. The largest contribution to the increased output between 1972 and 1978 was from nuclear power; coal was a close second in absolute amount but with a smaller relative expansion. The use of gas dropped, but in a significant failure of national energy policy 140 million more barrels of oil were used in 1978 for electricity generation than in 1972 (*3*). The contribution from other sources, including geothermal power, wood, and refuse, was very small throughout this period, increasing to only about 0.4 GW-year in 1978; most of this increase was from geothermal power.

Electricity production continues to remain a significant burden on our oil supplies. In 1978, over 9 percent of the total U.S. oil usage was for electricity production, amounting to 636 million barrels or the equivalent of over one-fifth of our oil imports (*3*). A further potential for the reduction of oil imports lies in reducing the use of gas in electricity generation, freeing the gas to replace oil in heating applications. To the extent that the use of oil for electricity generation is an offense, California, New York, Florida, and Massachusetts are the largest offenders, together accounting for about half of this use in 1978 (*4*).

Projections of Future Electricity Demand

Estimates of future electricity demand vary widely. A sampling of results from recent studies (*5–9*) is presented in Table 2. Within each study, different sets of assumptions led to different projections, here termed the low and the high estimates. For the year 2000, they range from below 300 GW-year to more than 1000 GW-year (*10*).

With such a large range of estimates, any prediction is uncertain. Moreover, there is probably a self-fulfilling element in prediction, as potential users will base their plans in part upon expectations of the future availability of resources. Successful conservation programs, which could have a major effect, for example, in reducing gasoline consumption, are not likely to do more than moderate the growth in electricity demand. In fact, there can be substantial disagreement about future electricity demand, even when there is agreement about total energy demand.

This is illustrated by two recent conservation-oriented projections. One of these, contained in the 1973 Ford Foundation study, *A Time to Choose* (*5*), described a "zero energy growth" (ZEG) scenario in which total energy use would rise from 75 quads (1 quad = 10^{15} Btu ≅ 10^{18} joules) in 1975 to only 100 quads in the year 2000 (as opposed to 187 quads for a continuation of the historical rate of growth). The ZEG estimate has received gross confirmation from the 1976 study

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of the Institute for Energy Analysis (IEA), which gave two estimates for the year 2000: 101 quads in the "low case" and 126 quads in the "high case" (6).

The two low estimates for the year 2000, each about 100 quads, are in impressive agreement. Total energy use in 1978 was 78 quads, so that this estimate implies an average annual growth rate until the end of the century of 1.1 percent, well below past levels (11). However, the two estimates differ substantially in their projections for electricity use in the year 2000 (Table 2). The Ford Foundation ZEG scenario corresponds to a 2.0 percent average annual rate of growth from 1973 to 2000, whereas the IEA scenario corresponds to a 3.5 percent rate from 1975 to 2000. [It now appears very unlikely that the ZEG scenario will be followed as far as electricity is concerned. For example, if present trends continue, electricity use in 1980 will probably exceed the 264 GW-year projected for 1985 in the ZEG case (12).

The differences in the projections for electricity use are coupled with differences in the expectations for the relative roles of oil plus gas and nuclear power. The ZEG scenario for the year 2000 projects the use of 22 quads more of oil and gas and 24 quads less of nuclear power than the IEA "base supply" case. The ZEG scenario used oil and gas to provide over half of the residential and commercial energy demand, whereas the IEA projection is for only 12 percent.

This brings us directly to a consideration of the basic goal of conservation. Put in the simplest terms, the score on conservation success is better kept in terms of the numbers of barrels of oil consumed than in terms of the total quads of energy consumed. If this view is accepted, conservation policies will emphasize the decreased use of oil, in part through the substitution of electricity for oil. In house heating, for example, this implies moving toward some blend of electric heat pumps, electric resistive heating, and solar energy. Total energy demand and electricity demand will both depend upon the balance between these different components, but it is more consonant with conservation needs to minimize oil use than to minimize energy demand, if we may assume adequate supplies of electricity. Even in cases where the balance may include a heavy reliance on solar power, electricity is important as a backup energy source, and, if this system displaces an oil or gas system, there will be a net increase of electricity use.

Thus there does not exist a close correspondence between conservation and reduced electricity use. This is not to say that conservation steps are not important to the prudent use of electricity, but at any level of conservation there is great leeway with respect to the role of electricity. The choices society will make will depend upon economic factors, upon the importance placed on the reduction in the use of oil, and upon the perception of the environmental hazards of nuclear power and coal.

Table 1. Sources of U.S. electricity generation in 1972 and 1978. Data are from (1). Totals may not agree because of independent rounding.

Primary source	Production (GW-year)		Fraction (%)	
	1972	1978	1972	1978
Coal	88	111	44	44
Petroleum	31	42	16	17
Gas	43	35	21	14
Hydroelectric power	31	32	16	13
Nuclear power	6	32	3	13
Other	0.2	0.4	0.1	0.2
Total	200	252	100	100

Broader issues of social policy also may need to be considered. Thus, Amory Lovins in *Soft Energy Paths* (13, p. 55) argues that

> In an electrical world, your lifeline comes not from an understandable neighborhood technology run by people you know who are at your own social level, but rather from an alien, remote, and perhaps humiliatingly uncontrollable technology run by a faraway, bureaucratized, technical elite who have probably never heard of you. Decisions about who shall have how much energy at what price become centralized—a politically dangerous trend. . . .

If one shares this evaluation, then centralized electricity sources, and probably electricity itself, will appear less desirable, and one will favor policies which minimize future electrical growth. Thus prediction of electricity demand is in part a statement of technical and economic practicalities and partly a statement of social goals.

Once a prediction is made, one has gone a long way toward determining the choices we have for electricity generation. At least for the next few decades, if one wants large amounts of electricity, the choice probably reduces to coal or nuclear power. If demands are smaller, other energy sources can play a relatively more significant role. In the reductio ad absurdum, if one needs almost no electricity, there are an almost infinite number of ways of getting it.

Suppose, as a tentative middle-of-the-road estimate, that demand for electricity generation will double from 1978 to 2000, reaching about 500 GW-year by the end of the century. This amounts to a 3.2 percent average annual growth rate, significantly less than the growth rates of earlier periods but greater than the expected population growth rate. Suppose we set as a further goal the replacement, by other sources of electrical generation, of one-half of the electricity now generated by oil and gas. Together, this would imply additional production of about 290 GW-year in 2000, the equivalent of about 450 new 1000-MW facilities operating at a 65 percent capacity factor.

How will such amounts of electricity be generated? Some conventional estimates for the year 2000 are presented in Table 3 (8, 14). The renewable resources (that is, those that do not deplete a finite source) account for about 22 percent of the new capacity for the year 2000 in the highest estimate and 6 percent in the lowest estimate. The overwhelming share still comes from coal and nuclear power. This for a long time has been the conventional wisdom. For example, David Rose, writing in 1974 said succinctly (15, p. 351): "Until about A.D. 2000, the major choices are nuclear power, fossil fuels (of various sorts), or nothing, in varying proportions."

So blunt a statement is now not fashionable. It is not politically possible to discuss future energy sources without acknowledging renewable resources in general and solar energy in particular. There are two reasons for this. First, nuclear energy and coal encounter so much environmental and ideological objection that a powerful lobby exists for solar energy, almost independent of its actual potential. Second, it is difficult, if not impossible, to evaluate definitively the validity of the hopes for the renewable resources. One can doubt that the renewable resources have the claimed potential, but one cannot prove that the potential is not there.

The Potential of Renewable Resources

One of the renewable resources, hydroelectric power, already has played an important part in electricity generation, accounting for almost 30 percent of U.S. electricity generation in 1948 and about 13 percent in 1978 (1). But the best sites have already been developed in the United States, new dams often face strong environmental objections, and there is at present little prospect of a major expansion in total output from hydroelectric sources.

Another of the sometimes cited sources of solar power, biomass, also seems implausible as a large contributor. Although waste products can be a useful local supplement to energy supplies, large biomass plantations would require roughly 250 square miles (1 square mile = 2.6 square kilometers) of land to provide the fuel to sustain 1 GW of electricity (*16*). It is unlikely that such a program will be adopted on any large scale in a world heading for food shortages. In any event, what biomass is available might more profitably be used directly as fuel rather than for electricity generation.

This leaves geothermal power, direct solar power, and wind power as seemingly the most promising, or at least most discussed, of the renewable sources of future electrical energy. First, let us consider geothermal power. Even though not strictly renewable, the energy pool from which it is drawn is so large that the caveat may not be very significant. It has been estimated that the heat stored in the top 10 kilometers of the crust of the United States is equivalent to almost 10^9 GW-year (*17*). Extracting the energy is another matter. Estimates of the rate of possible energy generation range from 2 to 400 gigawatts (electric) [GW(e)] (*17*).

A somewhat narrower range of estimates is given in a recent National Academy of Sciences (NAS) report (*18*). For the year 2000, the report projects a geothermal capacity of 7 GW(e) if we follow a "business-as-usual" pace but as much as 60 GW(e) with a crash program. In contrast to this favorable assessment, the Workshop on Alternative Energy Strategies (WAES) report, an international study project sponsored by the Massachusetts Institute of Technology, places no reliance on geothermal power for the remainder of the century (*19*).

The divergence of estimates in part reflects the site-specific character of geothermal energy. Until suitable sites are identified and their individual problems understood, the discussion is highly speculative. The present 0.5 GW(e) of geothermal capacity in the United States is all located in The Geysers region of California. A further 1.5 GW(e) is scheduled for completion by 1986, but the only announced locations (as of mid-1978) are also in The Geysers region (*20*).

The practicality of The Geysers site is clear, but its capacity is believed to be limited to an ultimate 5 GW(e) (*18*). If over the next few years geothermal explorers identify other suitable sites and if environmentally acceptable plans are formulated for utilizing them on the gigawatt scale (presumably a number of plants adding up to gigawatt totals), then one could begin to consider geothermal power as a significant national energy resource rather than a relatively minor local supplement.

Table 2. Estimates for electricity generation in the year 2000 (1978 generation = 252 GW-year).

Reference	Generation (GW-year) Low estimate	Generation (GW-year) High estimate
Ford Foundation (*5*)	385	850
Institute for Energy Analysis (*6*)	500	680
Ford Foundation–MITRE (*7*)	400−	500+
Electric Power Research Institute (*8*)	590	1040
Scenarios cited by the National Academy of Sciences (*9*)	275	925

The situation is the reverse with the solar generation of electricity. Here there are many potential sites, although the Southwest is preferred because of the higher solar insolation (an annual average flux at ground level of about 300 watts per square meter for the Southwest versus about 200 watts per square meter, or 0.5 GW per square mile, for the United States as a whole). The question reduces to developing devices or systems that are cheap enough to make solar-generated electricity economically plausible. There are two main approaches to the direct production of solar electricity: thermal boilers and photovoltaic devices.

The favored thermal systems use mirrors to reflect light to a boiler. For a system that converts incident solar energy into electricity with a 25 percent efficiency, the average annual output for the Southwest would be about 7 watts per square foot of collector; 1 GW of (average) power would require about 5 square miles of collector or 10 square miles total. The land use alone is not a major limitation. It would not be very difficult to reserve 1000 square miles of desert, and this would make a major contribution to electricity needs.

However, the cost would be excessive by present standards. For example, the Meinels, themselves pioneers in this field, estimate the cost of collectors, site preparation, and installation to be about \$50 per square foot (in 1977 dollars), exclusive of storage (*21*). This means capital costs of \$7 per average watt, neglecting storage, installation, and maintenance. Costs would be higher outside the Southwest. At this price, solar thermal electricity is too expensive to compete with coal or nuclear power. Other estimates put the costs lower, but nevertheless there appears to be a consensus that solar power towers of this sort are not economically practical at this time (*22*).

There is a greater spirit of enthusiasm for the prospects for photovoltaic systems (*22*). Nevertheless, a strong note of caution is suggested by the results of an extensive analysis of photovoltaic devices recently carried out by a study group of the American Physical Society (APS) (*23*). The overall conclusion of this analysis is that photovoltaic systems may eventually become a dominant technology in the United States, but that it would require 30 to 50 years to exceed 10 percent of our electricity production. For the nearer term, the study concludes (*23*, p. 19): "It is unlikely that photovoltaics will contribute more than about 1% of the U.S. electrical energy produced near the end of the century."

This is largely a matter of cost. At present, silicon plate cells cost about \$5 to \$10 per peak watt (*23*), or in the neighborhood of \$25 per watt averaged over the year in the Southwest (*24*). This cost is clearly prohibitive. However, with a reduction of price to about 50¢ per peak watt, which is considered a possible eventuality, the cost of the silicon modules will drop to about 45 mills per kilowatt-hour, and the total busbar electricity costs (for 16 percent efficient cells) to an estimated 80 mill/kwh (*23*). Although this is higher than the expected costs of competing sources such as coal, it is not out of the range of plausible acceptance, especially where it could be used to meet peak loads.

The APS study calls for a diverse program to find the optimum photovoltaic systems and to reduce the costs. People familiar with the miracles of the solid-state industry in electronics sometimes expect similar miracles in photovoltaic technology. However, solid-state electronics benefited from the advantages of miniaturization; any solar devices, on the other hand, must start with large areas to intercept the rather dilute sunlight. Thus it is unreasonable to expect a pace of improvement in photovoltaic systems which parallels the rate of improvement in computers.

Nevertheless, if we take the APS study seriously, there appears to be real promise in photovoltaic systems. The potential is almost open-ended, and, if the systems could provide 10 percent of our electricity, there is no obvious reason why they could not provide a considerably larger share of it, given some extra expenditure for storage. The timetables probably should not be taken too literally. The successful utilization of photovoltaic systems will require major innovations. They may come more quickly than anticipated or more slowly. There is no reason not to try to better the APS prediction of 1 percent photovoltaic electricity by the year 2000, but it would be imprudent to count on even that much. From the standpoint of some solar advocates, photovoltaic devices have the further social advantage of lending themselves to small units, divorced from large-scale utility systems; but this does not appear to significantly alter the overall costs (*23*).

The last renewable resource that I will discuss here is wind. Wind energy is also plentiful but dilute. The Department of Energy plans to build and test a giant windmill with a 200-foot blade span in North Carolina which will generate 2 MW(e) (*25*). Attaining this rated power requires wind speeds in the neighborhood of 30 miles per hour. If the average power were half the rated power, it would take roughly 1000 such windmills to provide 1 GW-year of electrical generation. Placed in an array with 2000-foot separation, these windmills would occupy about 140 square miles (*26*), although some other uses of the land might not be preempted.

It is difficult to take a large-scale program of this sort very seriously, at least until some success is achieved in siting the first gigawatt or so of windmill capacity and the actual environmental and aesthetic impact is observed. Undoubtedly, windmills can be useful in specialized, isolated locations, but the prospects for large-scale deployment appear uncertain.

Coal and Nuclear Power

The renewable resources represent great gambles, demanding, except for hydro power, expansions totally beyond their present levels. Coal and nuclear power, on the other hand, are already being used on a large scale, and plans for further expansion are well delineated. If we are willing to accept the perceived environmental costs, we probably could meet an additional electricity demand of 290 GW-year by the year 2000 with either of these sources. Matters would be made easier if we spread the burden between the two.

Table 3. Sources of projected additional electricity generation for the year 2000 (in gigawatt-years), according to alternative estimates by the Institute for Energy Analysis (IEA) (*6*) and the Electric Power Research Institute (EPRI) (*8*).

Primary source	IEA		EPRI	
	Low	High	Low	High
Coal	52	210	163	268
Nuclear power	169	188	208	277
Oil and gas	−26	−26	−49	−34
Hydro and geothermal power	44	44	18	30
Wind and solar power	11	11	1	1
Total additional	250	427	341	541

We are not immediately resource-limited either for nuclear power or for coal (Table 4). The available coal would suffice for hundreds of years, at the electricity generation rates projected for the near future. Even without breeder reactors or the recycling of spent fuel, estimated uranium resources are adequate for sustaining 400 large [1 GW(e)] reactors at a 75 percent capacity factor over roughly 45 years. This is enough to carry us well into the next century, and gives us some time before we must commit to the next succeeding phase. With breeder reactors, nuclear power is virtually unlimited, because the output per ton of uranium is increased roughly 50-fold and it becomes economical to use more expensive but more plentiful sources of uranium such as granite or seawater. (Fusion power would also be unlimited, but it is not yet possible to have any assurance of when, or perhaps even if, it will become available.)

At present, electricity from nuclear generation is less expensive than from coal generation. For example, in 1977 the busbar costs for Commonwealth Edison, an Illinois utility which makes extensive use of both nuclear power and coal, were about 10 mill/kWh less for nuclear power than for coal (*27*). An Atomic Industrial Forum survey concludes that in 1978 the nationwide average busbar costs were 15 mill/kWh for nuclear-generated electricity (the same as in 1976), 23 mill/kWh for coal-generated electricity (up from 18 mill/kWh in 1976), and 40 mill/kWh for oil-generated electricity (up from 35 mill/kWh in 1976) (*28*). In implied qualitative agreement, a group of coal companies advertised in the *Wall Street Journal* (25 May 1979) (*29*) that "Coal costs less than either oil or gas as a fuel for producing electricity. It may soon be cheaper than nuclear power."

Most projections for future costs still give nuclear power a slight edge. For example, in the Ford Foundation–MITRE Corporation study on nuclear power, the projected 1985 busbar costs in the Midwest are 24 mill/kWh for nuclear power, 28.5 mill/kWh for coal with scrubbers, and 27 mill/kWh for coal without scrubbers (in 1976 dollars) (*30*). However, regional variations, uncertainties in construction times and fuel costs, and revisions of design specifications probably imply cost changes which outweigh the 10 to 20 percent differentials in presently predicted costs. Thus, it does not seem possible to make a decisive choice between nuclear power and coal on the basis of cost alone.

Environmental and health issues provide another basis for choice. The large majority of authoritative studies give nuclear power a clear advantage, at least in routine operation. The results of a recent NAS study (*31*) are summarized in Table 5, in terms of expected fatalities associated with the production of 1 GW-year of electricity (excluding major radiation accidents). The Ford Foundation–MITRE Corporation study (*7*) reached similar conclusions, projecting 1 fatality per year for normal operations of a 1000-MW(e) nuclear plant and 2 to 25 fatalities per year for a comparable coal plant (*32*).

These estimates do not include the effects of possible reactor accidents. The most ambitious attempt to assess accident possibilities was the 1975 Reactor Safety Study, commonly known as the Rasmussen Report or WASH-1400 (*33*). This study concluded that the chances of a major reactor accident are very small, with an expected average fatality rate of only 0.02 death per reactor year, considering accidents of all sizes. However, it has been widely agreed that there are large uncertainties in the final probabilities presented in the Rasmussen Report.

In a reconsideration of accident risks, the 1977 Ford Foundation–MITRE Corporation study (*7*) concluded that the Rasmussen Report may have seriously underestimated the chances of reactor accidents (or conversely may have overestimated them). Its own worst-case assessment (*7*, p. 18) remained favorable to nuclear power:

> In the most pessimistic case, which we consider very unlikely, the average rate-of-loss could be as high as ten fatalities per year for a 1,000 MWe nuclear power plant. However, even in this extremely unlikely situation, the average fatalities would not exceed the pessi-

mistic end of the range of estimated fatalities caused by coal. Thus, on an average rate-of-loss basis, nuclear power compares favorably with coal even when the possibility of accidents is included.

At the instigation of Congress, the Nuclear Regulatory Commission organized a reconsideration of the Rasmussen Report, appointing for this purpose a panel headed by Harold Lewis of the University of California at Santa Barbara. The resulting Lewis Report (*34*) found aspects of the Rasmussen Report to criticize and aspects to commend, but its punch line settled nothing, stating (*34*, p. viii):

> We are unable to determine whether the absolute probabilities of accident sequences in WASH-1400 are high or low, but we believe that the error bounds on those estimates are, in general, greatly understated.

For perspective on this inconclusive statement of the group finding, it is of interest to note Lewis's own personal evaluation, made in congressional testimony (*35*):

> . . . I generally feel that the risk is small and that it is the potential for a large and *unfamiliar* event that so frightens people that the risk tends to be exaggerated. The demonstrated risk of coal mining, the risk of war over oil (which seems frighteningly real to me these days), the risk (nay, fact) of a decline in our economy—all these are worse.

The NAS document (*31*) also finds strong and weak points in the Rasmussen Report. It offers its own (*31*, p. 57) "illustrations of how one may be able to draw useful conclusions—if only in the form of rather extreme bounds" from the (pre-Three Mile Island) nonoccurrence of "accidents releasing significant radioactivity." Depending upon which of two illustrative assumptions is adopted concerning the implications of the (then perfect) record, the report suggests that one would anticipate less than 23 cancer deaths per reactor-year or less than 1.1 cancer deaths per reactor-year. These numbers are presented as illustrative upper bounds and are not to be construed as rough estimates of expected averages. The NAS report further suggests, in a footnote (*31*, p. 57), that the upper bounds "would not be seriously changed" if one considers the longer record, including Three Mile Island.

Aside from the NAS footnote, these studies and statements preceded the Three Mile Island accident in March 1979, an accident susceptible to a wide range of interpretations. The anticipated medical consequences are relatively minor, especially when compared to the public concern. The total exposure to the public has been estimated by federal agencies to be up to about 5000 person-rem (*36*). From extrapolation of the known effects of radiation at high dose levels, such an exposure is conventionally assumed to have the potential of causing about one eventual fatal cancer (*37*). This translates, for 30 GW-year of nuclear power in 1979, to 0.03 fatality per GW-year. This is strikingly, but irrelevantly, close to the estimate of the Rasmussen Report and far below the Ford Foundation-MITRE Corporation worst-case estimate or the NAS report upper bounds.

On the less sanguine side of the coin, the accident disabled a reactor, probably for several years, and demonstrated important deficiencies in reactor equipment, in operator response, and in communications both before and during the accident. Above all, it raised in the minds of many people the specter of a much worse accident which might have occurred at Three Mile Island and which still might occur elsewhere.

In light of this, it is essential that corrective steps be taken to decrease the chances of further accidents, at any level of seriousness. But, despite the shock of the accident and the attention it received, there appears to be no reason to conclude that the overall safety picture has changed appreciably. The indications remain that the total risks are less than those of coal, if one focuses on total casualties rather than on individual dramatic events. Just as the main transportation hazard (per passenger-mile) remains automobiles, not commercial aircraft, the main energy health hazard (per gigawatt-year) remains coal, not nuclear power. In fact, in grim irony, it appears probable that the chief adverse health effects of the Three Mile Island accident will stem from the slowdown of nuclear power and the consequent increase in the use of coal.

There remain two long-term problems to consider: the disposal of nuclear wastes and the possible effects of carbon dioxide (CO_2) from the burning of coal. The first of these is a matter of considerable frustration to much of the scientific community. It appears clear to many that nuclear waste disposal is a readily solvable problem. A widely held view is cited in the NAS study (*31*, p. 110):

> In conclusion, it may be noted that several evaluations of the waste-disposal problem by groups with access to considerable expertise but not associated with the development of nuclear power have concluded that it is possible with presently available technology to dispose of wastes so as to pose only a negligible threat to the health of future generations.

The reported optimism stems from the relatively small volume of the high-level

Table 4. Coal and uranium resources in the United States. Estimates are from (*1*). The indicated coal resources are demonstrated reserves; the indicated nuclear resources (U_3O_8) include "probable" and "possible" potential resources (at $50 per pound or less) but exclude "speculative" resources. The uranium ore requirements are calculated on the assumption that there is no recycling of nuclear fuel.

Resource	Supply (tons)	Tons per GW-year	GW-year of resources	Years at 300 GW-year per year
Coal	4.4×10^{11}	4.0×10^{6}	1.1×10^{5}	350
U_3O_8	3.8×10^{6}	2.7×10^{2}	1.4×10^{4}	45

Table 5. Estimated annual fatalities resulting routinely from the generation of 1 GW-year of electricity, in coal-fired and nuclear plants. The estimates are from (*31*) and include the complete fuel cycle excluding reactor accidents.

Cause	Fatalities per GW-year
Coal	
Accidents, mining	0.8
Accidents, transportation	1 to 2
Total	2 to 3
Pollution, new plants with lime scrubbers	0.007 to 17
Pollution, old plants, 3 percent sulfur coal	3 to 170
Total coal: 2 to 170	
Nuclear power	
Nonradiation accidents (mining)	0.4
Radiation, occupational	0.3
Radiation, public	0.2
Total radiation	0.5
Total nuclear: 0.9	

wastes, the substantial reduction in activity after a few hundred years, the possibility of using wasteforms of high integrity, and the possibility of long-term isolation deep underground (*38*).

However, until the government decides on which of several acceptable paths to pursue, it is fair to say that we have no plan for the disposal of the wastes. Although some scientists may attribute this failure primarily to administrative ineptitude or to the attempt to find a perfect plan when perfection is not necessary, the public and nuclear critics remain skeptical. Just as the assertion that there is a vast geothermal potential will be viewed with skepticism until greater progress is made in identifying and exploiting it, the claim that there are many ways of solving the waste-disposal problem will be doubted until at least one specific plan is implemented.

Coal has its own waste-disposal problems, particularly the CO_2 unavoidably formed in the combustion of fossil fuels. It is estimated that the worldwide use of fossil fuels is already causing a 0.2 percent annual increase in the atmospheric CO_2 concentration (*7*). If there is a continued growth in the worldwide use of fossil fuels, it is feared that the CO_2 concentration could eventually rise by an amount sufficient to cause a significant increase in the global temperature. Although neither the rate of CO_2 retention in the atmosphere nor the potential climatic effects are well established, the CO_2 problem has raised a cloud over future heavy reliance on fossil fuels, particularly coal, because there is so much of it. Thus, even though the United States could embark on a substantial expansion of coal usage, such a policy could prove to be dangerous if the action were emulated worldwide or if high usage continued for many decades. It is to be hoped that the CO_2 problem will be better understood before any dangerous increase is achieved.

The Special Problems of Nuclear Power

Nuclear power occupies a unique place among energy sources. In recent years it has been the largest single contributor to additional electricity generation (Table 1). It is economical, and leading studies of comparative health effects favor nuclear power over coal. Furthermore, nuclear power generation has thus far had a very good safety record in terms of actual radiation exposures incurred by workers and the general public. Nevertheless, there are serious calls for a moratorium on nuclear power, which long antedated Three Mile Island.

These calls are so vigorous and after Three Mile Island have gained such political momentum that no consideration of the future use of nuclear power can ignore them. An important underlying component in the long-standing opposition to nuclear power has been succinctly described in the Report of the British Royal Commission on Environmental Pollution (*39*, p. 191):

> Nuclear power provides a dramatic focus for opposition in some countries to technological development and we have no doubt that some who attack it are primarily motivated by antipathy to the basic nature of industrial society, and see in nuclear power an opportunity to attack that society where it seems likely to be most vulnerable, in energy supply.

Nuclear power provides a uniquely vulnerable target for this attack, in part because of an uneasy association in people's minds between nuclear weapons and nuclear power. Further, much of the public incorrectly believes that nuclear radiation is new and mysterious and that large amounts of radiation are being introduced into the environment by the nuclear power program.

Of course, far from being new, nuclear radiation has been present since the formation of the earth, and all species, for better or worse, have evolved in a terrestrial environment of radioactive minerals and cosmic rays. It is no longer mysterious, having been intensively studied over the past 50 years in animal experiments and through detailed analyses of instances in which humans have been exposed to above-normal levels of radiation. Nuclear power adds little to the preexisting radiation levels. The average radiation dose in the United States is about 80 millirem per person per year from natural causes, and people in Denver average about 130 millirem; medical treatments account for an additional average annual radiation dose of about 70 millirem per person, with wide variations among individuals (*40*). In contrast, in the absence of accidents, the average dose to the general public in the United States from a considerably expanded nuclear power program would be about 1 millirem per year (*41*). The maximum dose received by a person living near Three Mile Island was under 100 millirem, and the average dose to the 2 million people within a 50-mile radius was less than 2 millirem (*36, 42*).

Such numerical information has only limited impact, especially because of the credence given by the media to rather far-fetched charges about radiation. For example, the *New York Times* gave serious attention to the suggestion that the lower Scholastic Aptitude Scores in the late 1960's were due to radiation from bomb test fallout (*43*), and television news devoted considerable time to the suggestion that deaths among cows near Three Mile Island within a few weeks of the accident might have been associated with the accident. Until greater discrimination is shown by the media, the public inevitably will be confused and alarmed.

An important component of any rational consideration of our energy future is a comprehensive comparison of the health hazards of all sources of electricity generation. Such a study has been prepared by Dr. Herbert Inhaber of the Atomic Energy Control Board of Canada (*44*). One of his results is standard—that coal has considerably more adverse health impact than nuclear power. A more surprising conclusion reached by Inhaber is that wind power and solar electric power are also more dangerous than nuclear power, because of the need to handle large amounts of material and the need for backup power which is assumed (seemingly arbitrarily) to come from coal.

The uncertainties in both the accounting procedures and the actual numbers are great, and Inhaber's conclusions have been vigorously challenged (*45*). However, at the least, the Inhaber study has the merit of pointing up the need for comprehensive comparisons and for the reminder that all activities, even the use of solar power, have some risks. It is a regrettable failure on the part of the U.S. government that there is apparently no federal agency charged with preparing and publicizing hazard comparisons for different energy sources, on a continuing basis. Fragments of the needed information are available from numerous sources, but it would be highly desirable for these to be combined into a unified, comprehensive annual report. Initially such reports would undoubtedly suffer from uncertainties, questionable interpretations, and ambiguities. However, were the reports mandated on an annual basis, in time we would develop a useful starting point for policy-makers who must choose between different energy alternatives.

Without such data it is easy to lose sight of the fact that all energy sources have dangers. For example, seven people were killed in a gas explosion in Philadelphia about 6 weeks after the Three Mile Island accident (*46*), a far more serious toll than the conventionally predicted single cancer death from Three Mile Island. Yet it would be considered unreasonable to contemplate a moratorium on gas. Part of the difference in reactions stems from the fear that Three Mile Island might have developed into something far worse, but part stems from a lack of any readily available guide on comparative risks.

This is not to say that nuclear power is without problems. The lessons of Three Mile Island must be implemented, and the indecision over nuclear waste disposal must be resolved. But this can most effectively be accomplished in a climate in which the need for nuclear power is accepted. If the fate of nuclear power itself is in balance, the resolution of specific issues will be distorted and distracted by the broader fight.

Should a nuclear moratorium be imposed, the damage to our potential for electricity generation will depend upon its duration. If prolonged, there may be a diminution in our nuclear expertise, as scientists, engineers, and technicians either leave the field or fail to enter it. Then, should later energy shortages provoke a swing in the pendulum of public opinion with a demand for rapid development of nuclear reactors, it will be more difficult to accomplish the desired nuclear expansion in a safe and orderly fashion. This argues for steps to assure the continued stability of the nuclear industry, perhaps through federally guaranteed reactor orders, made in anticipation of future utility needs.

Conclusions

If we are to lessen our dependence on imported oil during the remainder of the century, we must intensify conservation efforts and turn for a greater fraction of our energy needs to three domestic sources—coal, renewable resources, and nuclear power. These options hold for the energy economy as a whole and, with a somewhat different balance among the sources, for electricity generation.

Coal has obviously been proven to be practical, and, if we are content to postpone decision on the CO_2 problem while ameliorating the other emission problems, it can surely make a major contribution to future electricity generation. Nuclear power is efficient, is probably slightly more economical than coal, and, depending upon whether one heeds the proponents or opponents, is either environmentally benign or a ticking environmental time bomb. Geothermal power and the various forms of solar power draw upon almost unlimited resources, but their practicality as major contributors is yet to be demonstrated. We probably do not know enough at this moment to make a fully rational choice from among these alternatives, and we certainly lack the national consensus to implement any crisp choice.

Under these circumstances, the most sensible course is to pursue all options. Should we abandon nuclear power for solar power, as some urge, we may be writing a prescription for disaster, both economically and politically. In a world in which oil is becoming a scarcer and scarcer commodity, one cannot dismiss the possibility of stumbling into a war over oil, if the promise of solar power is false or slow to realization. The warning from Chancellor Helmut Schmidt of West Germany is pertinent (*47*):

> . . . I will point to the great danger that if nuclear energy is not developed fast enough, wars may be possible for the single reason of competition for oil and natural gas.

Of course, this view may be alarmist. Nevertheless, we should remember that Hiroshima came in a war which stemmed in significant measure from competition for natural resources in Southeast Asia, with oil as a crucial factor.

In conclusion, if we keep a constructive and balanced perspective, the availability of alternatives for electricity generation can be a source of strength rather than the present source of confusion. The 21st century may see a decisive commitment to fission energy, solar power, fusion, or coal. For the immediate future, however, no such commitment is possible. Our best hope lies in the vigorous exploration and exploitation of each of the possible options, establishing the further roles of each through experience and objective analysis.

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48. The viewpoints presented in this article developed during a period in which I was engaged in extensive discussions and collaborative writing with Prof. F. H. Schmidt, and I acknowledge with appreciation my indebtedness to him. I also thank Prof. J. Rothberg for helpful discussions.

Melanesian Prehistory: Some Recent Advances

J. Peter White and Jim Allen

Speculation about the history of the inhabitants of New Guinea and adjacent islands to the east, the whole area generally referred to as Melanesia (Fig. 1), began with its early European discoverers and was continued into the mid-20th century by linguists, physical anthropologists, artifact collectors, and others (1). Scientific archeology in Papua New Guinea began in 1959 (2), and research during the following decade (3) established long-term artifact sequences in the central highlands and on the south Papuan coast. Subsequently, greater attention has been given to economic change and development. A Pleistocene occupation and the local development of intensive horticulture over the last 9000 years has been defined in the highlands, and on the south Papuan coast the growth of maritime-oriented coastal economies and exchange networks has been documented. In the eastern islands, movement of materials over long distances is found in the earliest dated sites, which were occupied by horticulturalists. We review these data here. We do not review data for areas or periods where, in our view, an integrated prehistory cannot yet be written, although research is being done in those areas (3, 4). Almost no archeological research has been undertaken in Irian Jaya (5).

Summary. Human occupation of New Guinea had begun 50,000 years ago, but islands further east were settled only in Recent times. In part of the New Guinea highlands, wet and dry horticultural systems began by 9000 years ago. Local intensification is evident until the present, but only the most recent major crop (sweet potato, which has been grown in the region for less than 300 years) is documented. On the south coast, exchange systems and economies locally diversify over the last two millennia. In the Melanesian islands, exotic materials were moved 3000 kilometers 3000 years ago, but whether traders or colonists were involved is not yet clear. The prehistory of the area is proving more complex than was believed even a decade ago.

Only about 60 professional archeologists, including graduate students, have worked in the area, the majority within the last decade. Thus, an unusually high proportion of data and interpretation remains in unpublished papers, letters, and verbal communications. We have drawn on our knowledge of these, but refer to published reports wherever possible.

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Early Inhabitants

The oldest definite archeological evidence for human occupation of the main island of New Guinea is scattered wood charcoal dated to 26,870 ± 590 years (sample ANU-191) associated with some flaked stone artifacts at Kosipe, Papua (6). The site lies within a series of mineralogically distinct volcanic ashes from Mt. Lamington, 140 kilometers distant; the Kosipe dates are confirmed by a fuller sequence of ashes nearer the source (7). A date of about 30,000 years is claimed (8) for burned wood and some impacted stones on the margins of a peat swamp near Mt. Hagen. A human cause is likely, but further details are not available. The Kosipe site is above 1900 meters altitude. Hope and Hope (9) have argued that its location is explicable in terms of the 50,000 km^2 of mountain grasslands which crowned the cordillera above 2200 m during the Pleistocene; these grasslands may have supported some now-extinct megafauna that would have been a favored prey of hunters. Some Late Pleistocene megafaunal remains known from the Highlands (10) occur in the same layers as artifacts at the Nombe site (11), but kill sites have not been discovered, and all occurrences to date are below 2000 m.

Fig. 1 (facing page). (A) Melanesia, showing main islands. (B) Eastern New Guinea (Papua New Guinea) and the Bismarck Archipelago showing sites. Altitudes are given in meters.

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