Putting alternative sources of energy into perspective

Within the next 30 to 40 years, the U.S. will exhaust its reserves of oil and gas. What then? To what other energy sources is the U.S. likely to turn to fuel its energy-intensive civilization? What are the prospects for: Coal? Nuclear fission? Nuclear fusion? Solar? Wind? Geothermal? Shale oil?

R. A. BUDENHOLZER,
Professor of Mechanical Engineering
Illinois Institute of Technology
Chicago, Ill.

ZALMAN LAVAN
Associate Professor
Mechanics, Mech. & Aero. Engr.
Illinois Institute of Technology
Chicago, Ill.

UNTIL RECENTLY people gave little thought to how fast we are exhausting our limited energy resources. Although warnings had been sounded by a few farsighted individuals, little heed was paid to them until the Middle East oil embargo, striking like a clap of thunder, awakened the world to the impending danger. At present 75% of our energy is derived from oil and natural gas; the remaining 25% from coal, hydroelectric, nuclear and all other energy sources.

Since oil and natural gas are being depleted at an alarming rate and the demand for energy consumption is on the increase, we must seriously consider our future energy options. In 1850, 90% of our energy came from wood, water and wind power (renewable energy); in 1900, it was 75% from coal; now it is 75% oil and natural gas. The energy sources for the year 2020, are likely to be those that will be developed today.

Needs and resources

A total of 75 quads (1 quad = 10^{15}BTU of energy were consumed in 1973 (See Table 1). About 98% of this came from fossil fuels; of this, half came from oil, a third from natural gas, the remainder from coal. Use of this energy was divided almost evenly among the sectors of our economy: residential and commercial—21%; industrial—28%; transportation—25%; electric power generation—26%.

Our recoverable reserves of oil and gas (See Table 2) are dangerously low—about 30 to 40 years of present day consumption. In the years ahead, we will become increasingly dependent on foreign imports, which in turn will also dwindle. Even if these estimates are low, it would still be imprudent to consume these resources at the present rate; for once they are gone, they can never be replaced.

The outlook for coal is much more hopeful. At present consumption rates, there are sufficient proven reserves to last 600 years. This suggests we should intensify the use of coal. Yet, coal suffers from environmental handicaps. While it can be burned efficiently in large industrial and central-station boilers, much coal has too high a sulfur content to be used without expensive sulfur-removal equipment, equipment that may render its use uneconomical. Also, much must be surface mined under highly restrictive conditions that severely limit its attractiveness.

Coal isn't the *direct* solution for home heating and transportation. Heating can be supplied by: electricity produced from coal or nuclear fuel; synthetic gas obtained from coal; and direct use of solar energy. Transportation will continue to rely heavily on oil, which in turn will be derived either from shale and tar sand or from coal liquifaction and or gasification. If coal liquifaction and or gasification becomes prevalent, coal's lifespan, will be reduced from the 600 years to perhaps only 200 to 300 years. The U.S.'s energy options include: nuclear energy; hydroelectric and tidal power; oil shale and tar sand; synthetic fuel; geothermal energy; ocean thermal gradients; solar energy; and wind energy. Let's take a brief look at each.

The nuclear alternative

If generated at a 1973 rate, there is enough moderately priced uranium available to provide all U.S. electric power requirements for almost 100 years. The future price per pound of U_3O_8, however, is uncertain; but the trend is upward. With the breeder reactor, this supply could be extended some 70 fold, providing an adequate supply for over 6000 years. Even with a generation rate five times the 1973 rate (one not likely to be exceeded for years to come), there would still be enough uranium to last more than 1000 years if employed properly in breeder reactors.

Nuclear energy is used almost entirely to generate electric power. This power, however, can be employed to accomplish many tasks that would otherwise have to be done with fossil fuel. For example, electricity can heat and cool residences and even large commercial and industrial buildings. Moreover, if a heat pump is used, inherent losses in the thermal-electric cycle can be overcome; homes could be heated in winter with less expenditure of primary energy than for oil or gas. Cooling in the summer is accomplished with the same expenditure of energy as with present day air-conditioning systems. Before getting overly enthusiastic about electric energy for heating and cooling, though, recall that the total 1973 *electric* power generation was 6.25 quads, while the heating and cooling load was over 20 quads.

Nuclear energy can also generate hydrogen from water or make synthetic fuels from coal, to fuel the several forms of transportation now relying heavily on petroleum products. While nuclear capabilities are encouraging, there are many nuclear-power problems that need to be resolved. Some are technological, such as development of new reactors, fuel handling and containment problems; others are social. There is tremendous opposition by some environmentalists and others who believe nuclear plants to be unsafe. Whether their fears are justified or not, they may have the power to slow or even halt construction of nuclear plants. It would be unwise, therefore, to depend too heavily on this source of energy—even though, along with coal, it is almost the

TABLE 1. Sources of primary U.S. energy consumption in 1973—Quads (10^{15} BTU)

	Coal	Oil	Gas	Hydro[a] equivalent	Nuclear	Total	Percentage
Residential & commercial	0.36	7.03	8.00	N[b]	N	15.39	20.44%
Industrial	4.45	6.05	10.82	0.04	N	21.36	28.38%
Transportation	N	17.93	0.80	N	N	18.73	24.88%
Electric generation	8.70	3.43	3.92	2.90	0.85	19.80	26.30%
Total	13.51	34.44[c]	23.54	2.94	0.85	75.28	100.00%
Percentage	17.95%	45.75%	31.27%	3.90%	1.13%	100.00%	

[a] Thermal equivalent at 9600 BTU per Kw hr of electric generation.
[b] N = negligible.
[c] Approximately ⅓ of this energy was from imported oil

only viable long-range solution to our energy problem.

Hydroelectric power

Hydroelectric power is among the oldest forms of energy known to man and has been extensively exploited throughout the world. In the U.S. in 1973, hydroelectric power accounted for about 17% of the total electric energy output. 35% of the potential hydroelectric power in the U.S. (excluding Alaska) has already been developed. And efforts to develop many of the remaining sites have run into widespread opposition. Because of the increase in electric generation to meet future electric demand, look for a gradual reduction in the % of power from hydroelectric sources. It is definitely not a candidate to replace fossil and nuclear fuels; and can make only a limited contribution (perhaps 4-5%).

Tidal power

Tidal power is somewhat akin to hydroelectric power. It is, however, more limited and more expensive. Only one installation has been built to date, on the Rance River in France. This 240 MW project has not been competitive economically. Studies of Passamaquady Bay, one of the most promising sites in the U.S., show construction costs would be enormous, in no sense competitive with other forms of electric power generation. In sum, tidal power is an interesting but impractical idea that will at most make only a minor contribution.

Oil shale and tar sand

There is enough economically recoverable oil from shale to furnish our petroleum needs at present rates of consumption for about 35 years (See Table 2). If the more dilute shales yielding 10 to 25 gal/ton could be exploited, supply would be extended to about 170 years. The environmental problems, though, are severe. First, the extraction of oil from shale requires enormous quantities of water, not readily available where ore is abundant. Second, disposal of the rock from which the oil has been extracted is a monumental task that can only be accomplished with much money, time, and effort.

TABLE 2. Estimated U.S. Fossil Fuel Reserves—Quads (10^{15} BTU)

Fuel	Consumed prior to 1976	Recoverable with present technology	Ultimately[a] recoverable	Equivalent years of supply at 1973 rate of consumption
Oil	750	800	1100	20-30[b]
Shale Oil	Negligible	1200[c]	5800[d]	30-170
Gas	530	775	1030	30-40
Coal	860	4500	9000[e]	300-600

[a] Believed to be economically recoverable in the future.
[b] Without benefit of oil imports.
[c] In oil shales now believed economically recoverable.
[d] Including oil shales yielding 10 to 25 gallons per ton.
[e] Proven reserve (total estimated reserve is about 60000 quads).

A number of pilot plants using strip mining are presently underway. The largest (TOSCO) produces 700 barrels a day of oil from 1000 tons of oil shale. Production could reach 1 million barrels/day by 1985; the ultimate limit would probably never exceed 3-5 million barrels a day, mostly because of water shortages. (Present U.S. oil consumption is over 16 million barrels/day). Tar sands are more scarce in the U.S. than oil shale, and recovery is more difficult. Hence, no large extraction effort is expected.

Synthetic fuels

Synthetic fuels can be used as substitutes for liquid and gaseous hydrocarbon fuels. During World War II, they were used extensively in Germany and Sweden. Today, a sustained use of synthetic fuel can be found only in South Africa, due to political and economic isolation and abundance of cheap coal.

There is enough moderately priced uranium available to provide all U.S. electric power requirements for about 100 yrs. With the breeder reactor, this could be extended to over 6,000 yrs.

Current estimates of synthetic fuel costs are $2.50-4.00 per million Btu. This should be competitive with oil at $15 to 20/barrel. President Ford has called for one million barrels of synthetic fuel per day by 1985; the Energy Resource Council estimates only 350,000 barrels/day will actually be produced.

Coal gasification is obtained by chemical reaction between coal, oxygen (or air) and hydrogen (or steam). Coal liquification is a similar process. Neither are expected to substantially reduce oil imports before the turn of the century.

Geothermal Energy

Geothermal energy occurs in underground reservoirs containing either steam, hot water, hot brine, or dry hot rock. The use of hot water is mostly limited to heating. Steam reservoirs are directly suitable for use in conventional electric-power-generation plants—e.g. the Geysers Plants in California (presently generating 500 MW).

Despite optimistic claims, geothermal energy has severe environmental problems. The steam contains undesirable gases such as hydrogen sulfide, ammonia, boron, fluorides and even mercury. In hot brine installations, corrosion would be a problem; and disposal of wastewater difficult. Also, dissolved minerals may clog up wells as steam is released from the brine.

With dry hot rock, energy is tapped by injecting water into the rock and bringing it back as hot water or steam. Although this form of geothermal energy is thought to be the most abundant, no plants have yet been installed.

Geothermal energy will be economical only in areas where hot water or steam can be tapped from the ground at relatively small depth. In Iceland (pop. 215,000), 40% of the total energy use goes to heating; about 60% of this is geothermal. In the U.S., exploiting economical geothermal sites might be able to furnish ½ to 3% of the total electric generation needs, with 1% being the most likely estimate. While this is helpful, geothermal power can not be considered a viable alternative to coal or nuclear energy.

Ocean thermal gradient power

Even more impractical is the idea of using ocean thermal gradients for generating power. Idea: use the difference in temperature between the water at the surface and at depths of half a mile. In the tropics, surface water is about 80°F; at lower depths, 40°F. Carnot-cycle efficiency for a plant operating between these two temperatures would be 7.4%. With the appreciable temperature difference to affect the necessary heat transfer, and with turbine, pump, and flow losses, actual efficiencies could hardly exceed 3 to 4%. While the cost of fuel is zero, the enormous size of heat exchangers would be all but prohibitive. Add to this the need to anchor the plant, secure it against storms, and transmit generated power to the mainland and one begins to grasp the economic and engineering odds involved. This method of power generation will have difficulty progressing beyond the drawing board.

Wind power

Windmills have been used for centuries and are a very practical means of performing such mechanical tasks as pumping water, grinding grain, and even generating electricity. The amount of energy in the wind over the U.S. is enormous; but it is quite dilute and varies in intensity with geographical region, topography, season of the year, time of day, height above ground, type of ground cover.

A recent study by Westinghouse and Public Service Electric and Gas Company indicates that a wind power installation at a favorable offshore site in New Jersey, operating in a fuel-displacement mode, would be economically justified at a capital investment cost as high as $1258 per KW.

By evenly spacing one huge wind-generator tower (200kw) for every square mile over an area of 300,000 sq. miles of the Great Plains, 500 million megawatt-hours of power could be generated per year—at an average generation rate of 57,000 MW. When one considers that each tower would be 850 ft high and have 20 wind turbines, each with a 50 ft (15.m) diam. blade, it is not difficult to see the enormous problems.

Although some estimate 19% of the electric power demand in the year 2000 can be supplied by wind power, the future of wind energy is uncertain. One obstacle: the intermittent nature of winds, a situation that would require some means of energy storage for a continuous supply of electric current. Accordingly, wind power is unlikely to be used as anything other than a *supplement* to other forms of electric generation. In this capacity it could save much fuel by feeding electric current into an existing electric power system at a rate wind conditions permit.

Solar energy

The solar energy striking the land area of the U.S. is over 3 x 10^{19} BTU/yr—enough to supply 300 times the total energy requirements for the year 2000. Difficulty: this energy is dilute, intermittent. In talking of solar energy, we must consider three areas: placing solar collectors on individual houses for space heating and cooling, and hot-water heating; constructing giant solar farms to directly convert solar energy into electricity via photovoltaic cells; and building central-station solar collectors to convert the sun's energy into steam, then the steam into electricity.

Well into the 21st century, the U.S. will have to rely mainly on fossil and nuclear sources. The fossil component will come mostly from coal, with some coming from shale oil.

Solar heating of houses has been demonstrated and is already economically competitive with electric power in certain areas. By, the year 2000, estimates the federal Energy Research & Development Admin. (ERDA), one-third of all houses will use solar heating to some extent. While solar heating has an efficiency of 30 to 50%, solar air-conditioning is much less efficient.

As for building vast *solar-electric* central stations, the key problem there is that photovoltaic cells, developed for the space program, are very expensive. While their price has already dropped from $600 to $30/watt, reduction by another factor of 100 is required to make the cells competitive.

Use of *solar energy to generate steam* can be accomplished by concentration devices. The "tower power" seems to be the winning concept, and demonstration plants are being planned. Here the problem is to produce large amounts of high-quality equipment at sufficiently low prices.

A major problem with solar energy (as well as wind energy) is energy storage. Without storage, the conventional network will have to furnish the entire power load when called for. While several storage ideas have been advanced, successful large-scale systems other than pumped storage are not available as yet.

ERDA estimates that by 1985, 1% of the national energy will be provided by the sun; and by 2000, possibly 7%. These figures are not unreasonable; solar energy for space and water heating alone can account for this.

If solar energy is to assume an even larger role, it must be used to produce electric power. Yet unless nuclear power is wholly unacceptable for environmental or safety reasons, solar power, we believe, will be unable to compete economically. Electric power costs from solar energy could be as much as 10 to 15 times greater than from direct-fired coal or nuclear energy.

In view of the high-cost of building solar-electric central power stations, and the many environmental and reliability problems associated with them, even in the sunny southwest, solar power will be limited to no more than 15 to 20% of electric capacity. This is much lower than the 25% suggested by ERDA for the entire U.S. for the year 2020.

Outlook for the future

Until at least 2000, the main energy sources will remain fossil, nuclear and hydroelectric; synthetic fuels, solar, geothermal and wind energy are the only alternatives likely to be used as a supplement. Total energy consumption in the year 2000 is projected to be 150 quads as compared to 75 quads in 1973 (Table I). This 150 quad figure is about midway between the pre-1973 projected figure of about 180 quads and the technical fix scenario figure of about 120 quads suggested as a difficult but achievable goal by the Energy Policy Project of the Ford Foundation.

Projected growth rates between 1973 and 2000 assume there will be impressive improvement in automobile fuel economy; homes and other buildings will be better insulated and more energy efficient; and extensive conservation methods will have been implemented in all sectors.

In the year 2000, *supplementary* energy sources are expected to provide only about 11 quads out of a total of an estimated 150. While this seems small, (it equals ¼th the total U.S. energy consumption of 1960), it represents a saving of 5 million barrels/day of oil. Most of this saving comes from *solar energy* (9 quads); and the remaining two quads, from *geothermal* and *wind power.*

Key role for fossil and nuclear

While every effort must be made to develop alternative sources of energy, their contribution before 2000 A.D. will be very limited. Well into the next century, the U.S. will have to rely mainly on fossil and nuclear sources. The fossil-fuel component will undoubtedly come mostly from coal, with some being supplied by shale oil.

Beyond the year 2000, where will our energy come from? We can only speculate. But we believe the bulk of our electric power will be supplied by nuclear power and coal, with the breeder reactor carrying an increasing share of the load. If fusion power can be accomplished and made economically competitive, it will gradually assume its share of the load and may eventually become the major source. Should neither the breeder reactor nor fusion power prove feasible, solar and wind power could become the major energy sources—but probably at very high cost. One thing appears certain: with wise planning, diligent research, and the proper incentives for capital investment, a way can be found to meet our future energy needs. Exactly what this way will be, no one can foretell. ▽

R. A. Budenholzer, a CalTech PhD, joined the IIT faculty in 1940. He helped found the American Power Conference in 1952 and has been its director since then. In 1968, he was awarded the ASME George Westinghouse Medal for distinguished achievement in the power field.

Dr. Zalman Lavan is professor of Mechanics, Mechanical & Aerospace Engineering at IIT. He has worked in fluid mechanics, heat transfer, and thermodynamics, and more recently has specialized in solar and other energy-related areas. He holds MS and PhD degrees from IIT.