RENEWABLE ENERGY IN ISOLATED FRONTIER AREAS

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ABSTRACT

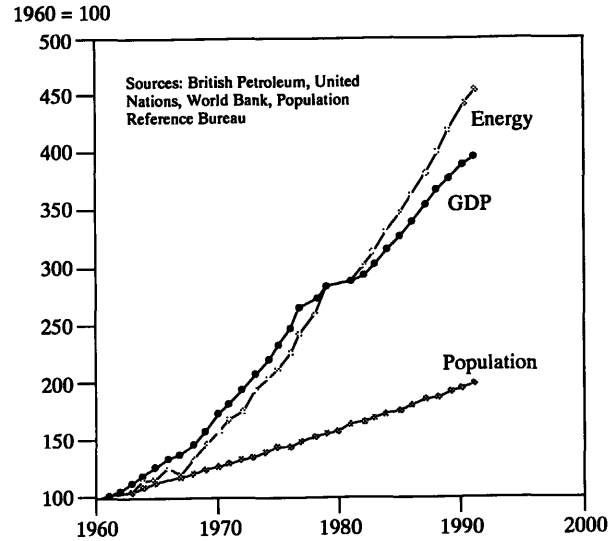
After recapitulating the importance of electricity to the well being of nations, this paper provides a comparison between different power supply technologies in frontier areas which are remote from central grids. After defining the characteristics of several renewable power technologies, we attempt to provide some guidelines to the selection and suitability of these techniques in remote, rural areas. Particular attention is paid to the utilization of geothermal energy by itself or in combination with other renewable technologies. The value of renewable energy is briefly discussed from the point of view of environmental quality and its economic benefit (i.e., its externality cost).

ENERGY AND THE WEALTH OF NATIONS

It can be demonstrated that the rate of energy utilization in developing countries is directly related to the amount of energy consumed by them. Figure 1 shows the relationship between the Gross Development Product (GDP) of developing countries and the amount of the energy they consume (Lenssen, 1993).

The ability to harness chemical or mechanical energy in the service of society increased the standard of living of industrialized societies by more than two orders of magnitude, as compared to those in the pre-industrial, pre-animal-domestication societies. For example, the total annual energy consumption in the U.S. is approximately 80 quads (80 million billion BTUs) at present. This is about 400 times the amount of calorific energy that could be expended on useful mechanical energy by adults of working age in the U.S., assuming a normal work week. In other words, there are on average about 400 energy slaves, in the form of automobiles, electrical and mechanical devices which contribute to the high standard of living that the U.S population currently enjoys.

Electricity provides approximately one third of the energy slaves which helped create the wealth of developed nations and which ensures the high standards of living that members of those nations enjoy. Availability of electricity for industrial, agricultural and other economic activities has been largely responsible for the rapid increase in that economic



Growth in Energy Use, GDP and Population, Developing Countries, 1960-91

Figure 1

well being. The same is true for developing countries. For example, the per capita electricity consumption in China increased from 8.2 kWh in 1950 to 299 kWh per year in 1980, a growth rate of 12.7% per annum, accompanied by a growth in the per capita GDP from $300 per annum to $1135, representing a 4.5% annual growth rate in the same time interval (Huang, 1993).

ENVIRONMENT, HEALTH AND THE CHOICE OF ENERGY

The 1992 Earth Summit called attention to the fact that indiscriminate use of fossil energy can cause an irreparable harm to the global environment. This harm would be expressed primarily in global warming, as much as 4.5 deg C by the end of the 21st century. Global warming could cause major changes in the agricultural productivity of vast regions of the earth, a substantial rise in the level of oceans which would inundate island and coastal areas, and other catastrophic events.

Countries which were signatories to the Earth Summit pledged to significantly reduce carbon dioxide emission to the atmosphere, such that the total global emission by the year 2000 would be no greater than that in 1990. Emission of carbon dioxide to the atmosphere amounts to about 1.2 kg per kWh produced from coal burning; the CO_2 emission drops to about 0.9 kg/kWh if oil is utilized, and to about 0.4 kg/kWh if natural gas is employed. Although the earth is rich in fossil fuel resources, it is evident that new supply additions in the future must rely more heavily on demand-side-management and alternative energy resources than in the past, if the increase in global warming is to be arrested (Gore 1993, Romm and Lovins, 1992). The alternative resources include geothermal, wind, biomass and solar, if global warming is to be reversed.

The externality cost of fossil fuels (i.e. the cost of mitigation of the damage caused by a given fuel), is not taken into account in the conventional analysis of electricity production cost per unit of energy produced. That cost depends upon the fuel. Thus, the cost of global warming or preservation of the human habitat, should be a factor of major importance in evaluating alternative energy paths. This paper assumes, a priori, that alternative energy paths are always preferable to those based upon fossil fuel energy in power production.

The Public Service Commission of Nevada (PSCN) estimated the externality costs associated with different fuels is as shown in Table 1. These externality costs include the various pollution components associated with each of the fuels considered, including CO_2, carbon monoxide, methane, nitrous oxides, sulfur oxides, reactive organic gases and particulate matter.

Fuel Type	$/kWh
Coal	.05
Oil	.031
Natural Gas	.023

Table 1. Externality costs of different fuels, Nevada

These externality costs deal only with direct environmental impacts of the specific fuels and do not include the external military or political costs associated with securing some fossil fuel costs (Romm and Lovins, 1992). Those latter costs could greatly increase the true national costs of the fossil fuels, but are paid out of other pots of money, such as the defense department, and are therefore not included in the true cost of fossil energy.

Absent clear regulatory requirements, electric utility planners generally ignore the externality costs associated with the specific fuels that are selected for the next plant to be constructed. Ignoring externality costs of fuels would tend to aggravate the perilous state of the global environment. This undesirable approach to energy supply could be reversed if governments would impose some uniform taxes on energy supplies, which reflect the environmental costs of the pollutants, as well as the other societal costs of providing fossil energy. Such a tax would encourage the abatement of pollutants or their displacement by alternative energy sources, and by demand side management. In 1991 the European Community proposed the imposition of a uniform tax of $100 per ton of carbon emitted into the atmosphere. That proposal has not been adopted to date, because of the lack of support for it by the U.S Congress.

An example of the external cost of energy utilization is provided by the World Health Organization which asserts that respiratory infections are now the leading killer of children under five, accounting for more than 3.5 million deaths annually (Lenssen, 1993). Likewise, it is estimated that acid rain in China, a heavy coal user, now affects more than 14% of the country's population.

Internalizing the external costs of energy supply would lead to a better allocation of economic resources (Friedrich and Voss, 1993) and would accelerate the development of demand-side management and alternative energy resources. Reduction of energy losses associated with long transmission lines in rural regions may become a significant contributor to increasing the overall efficiency of power generation. Development of small, alternative energy resources, when locally available, may become an important factor in reducing the amount of pollution associated with increase in the power supply additions as well in the unit cost of electricity provided.

DECENTRALIZED VERSUS GRID-CONNECTED ELECTRICITY

Remote regions may find that a local supply of electricity, despite its inherent inefficiencies, may be more cost effective than the extension of long, costly transmission lines to the region. In some isolated areas and islands, local supply, although more expensive than grid-connected electricity at short distances from the source, is the only viable solution to electrification. Experience in India has shown that decentralized energy technologies based on local resources can be a viable alternative to rural electrification (Sinha and Kandpal, 1991).

Low load factors and long transmission and distribution lines, coupled with high transmission and distribution losses make many rural electrification programs economically unattractive. Average load factors in parts of rural India, for example, may be as low as 6% to a high of 16%. According to Sinha and Kandpal, the losses of power between a central power plant and the finally distributed power to the consumer in rural India is often as much as 40% of the power produced at the power plant.

Because of these factors, local supply of electricity may be the most effective in remote areas, even though the apparent unit cost of electricity may be substantially higher than that paid by customers in a densely populated region which is well served by central power plants. Renewable energy sources such as biomass, geothermal, wind and solar may be the appropriate sources of power in the smaller, less dense or remote areas which cannot be effectively served by the central grid.

Abundant sources of alternative energy are available in various parts of the world. "Big is Beautiful" was the unstated motto of Western power planners, in designing power additions in the Northern hemisphere. Economies of scale favored large central plants. Costly high voltage, low loss transmission lines paid for themselves because they carried large loads and operated at high capacity factors. Furthermore, emissions to the atmosphere were considered a secondary factor, not taken into account until about a decade ago. "The solution to pollution is dilution", was the unstated motto, i.e. tall enough smoke stacks will distribute the pollution over a large enough area, making the concentration of pollutants small enough that its effects could be ignored. Hence, development of cleaner alternative energy resources, which are amenable to smaller, distributed networks, lagged behind those that were large and relied on fossil fuels.

RENEWABLE SOURCES OF ELECTRICITY

Abundant sources of alternative energy are available in various parts of the world. These include hydro, biomass, geothermal, wind and solar. Energy substitution, or demand-side management offers an important supplement to supply additions, especially in the case of geothermal. The following describes the different sources of energy, with a discussion of advantages and shortcomings of each.

Biomass

Biomass (plant matter) accounts for about 15% of world energy use and 38% of energy use in developing countries (Hall et al, 1992). Biomass, primarily in the form of agricultural and industrial waste, burned to fuel conventional steam turbines to produce electricity has been in use for many years. Biomass is often characterized as "non-polluting" despite the large emission of carbon dioxide and other pollutants, because the amount of CO_2 emitted in the combustion process equals the amount absorbed from the atmosphere during the growth of plants and photosynthesis of atmospheric CO_2.

In developing countries, growing biomass for energy in an environmentally sensitive manner, can provide livelihood for farmers and pay for restoration of land. Large scale biomass production as a crop will be limited to regions of high rainfall or abundant resources of fresh water. A common example of biomass conversion into electricity is the burning of bagasse, the left-over residue of sugar cane, in a conventional steam boiler plant. Likewise, the residues of growing of corn, wheat, rice and other field products provide a large mass of residue suitable for electricity production.

Approximately 9000 MW of biomass-based electric power is installed in the U.S., as a result of incentives provided by the government to private cogenerators who are considered Qualifying Facilities. Biomass plants have hitherto tended to be small (because of the dispersed nature of the feedstock), low pressure (because of decreased unit costs of boilers at low pressures) and low efficiencies, in the range of 14-18% in California, compared to about 40% for a modern coal plant. As a result, biomass units in the U.S. have to rely on low-, zero- or negative cost of the biomass fuel to be economically operated (Williams and Larson, 1993). It is expected that with the advent of biomass-integrated gasifier/gas turbines (BIG/GT), unit costs of electricity production will dramatically decline in the near term, even for smaller power plants, bringing it down to about 5 cents per kWh for the total cost of generation, in 1993 dollars. The actual cost will be higher when various other external costs are taken into account, such as financing costs, interest during construction and profit (if constructed by private investors). Typically, a privately owned facility must charge between six and seven cents/kWh (in 1993 dollars) to be minimally profitable.

Biomass-based power generation enjoys the advantage of being capable of load following, with power output that can be increased or decreased with demand. Wherever available, biomass offers substantial advantages because of its flexibility of supply. A large quantity of biomass matter may be available in agricultural communities during the relatively short season following the harvest, such as after the processing of sugar cane, but become scarce during the growing season. Adequate planning is needed for assurance of a continuous supply of the biomass, to ensure a steady output from the power plant.

Wind Power

The great advantage of wind power is that it can be constructed in small modules, has a relatively low environmental impact, and involves a fundamentally simple technology. The chief shortcoming of wind power is that it produces power only when the wind blows. Wind power supply typically reaches its peak in the evening or night time in many areas. The typical availability factor of wind turbines has been in the range of 15-20%, due to the vagaries of wind.

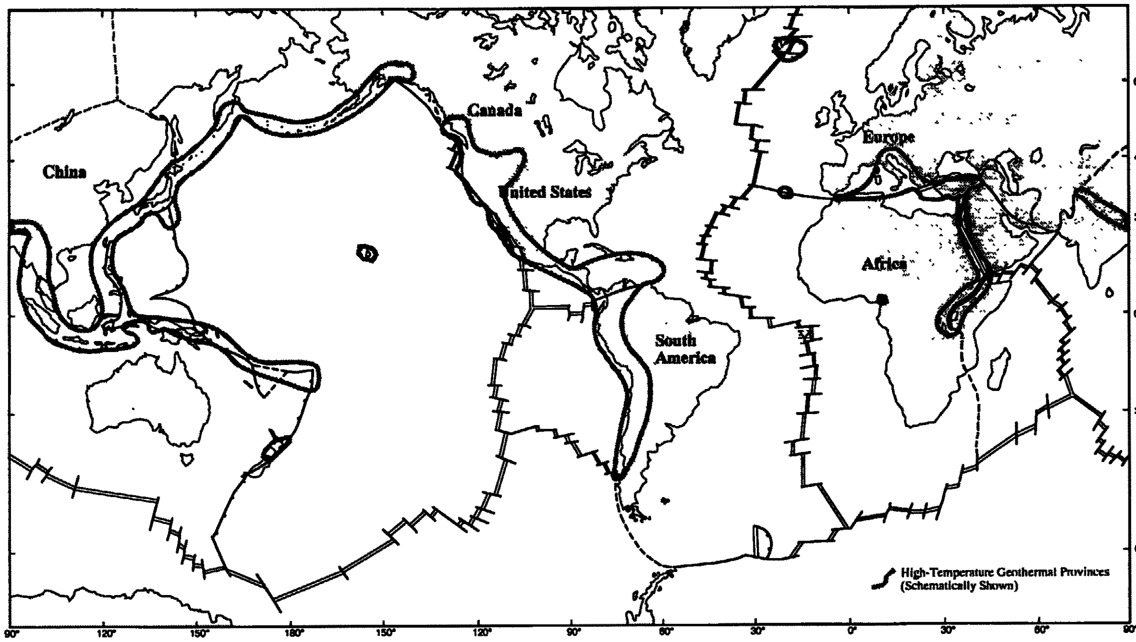


Figure 2. Geothermal regions of the world

With the advent of more flexible wind turbines which can operate at a wider range of wind speeds, it is anticipated that wind power availability may increase to 25% in good wind areas. Likewise, the cost of wind-based power plants is continually declining, and is now already in the range of $800-1000 per kW of installed capacity.

The major shortcoming of wind power is its irregularity. It can therefore be a valuable addition to a grid only if the region already has a reliable baseload source of power, and where the wind contributes only a small fraction of the total power needed. Alternatively, battery storage can augment the availability of wind power in remote areas. The cost of battery storage can exceed the cost of generation.

Solar Power

Solar power enjoys the advantage of tracking the increase in electric demand during the day (assuming cloudless weather). Like wind power, it suffers from low availability, which is about 25% of installed capacity. Solar-thermal electricity could be produced in 1992 for about 9.3 cents/kWh in large installations (Johannson et al., 1993). It is anticipated that with further research, the cost of solar-electric power would ultimately decline to about 6 cents/kWh (in 1992 dollars). The cost of solar power may double, if the cost of battery storage is added to the cost of generation (Entingh et al., 1994).

Photovoltaic power generation enjoys the advantage of simplicity, but suffers from the high cost of electricity that is generated with it at present , which is estimated at 25-35 cents/kWh in 1992 (Johannson et al., 1993). Continuous supply of solar -based power electricity is possible, if battery storage is utilized. However, the cost of such an installation may increase the cost of solar power to more than twice the above cited figure (Entingh and others, 1994). Despite its high cost, photo-voltaic power generation can offer a significant contribution in remote areas which are far from an interconnected grid. Furthermore, being available during peak demand, solar power may justify the high costs associated with it even in some grid-connected systems. Keeping in mind the very high losses that are often associated with grid connected electricity in remote areas, the cost of photo-voltaic power may not be exorbitant.

Demand-side-management, using solar energy, is already employed in a number of countries which are rich in solar energy. For example, in both Israel and Cyprus, a high level of utilization of solar hot water heaters is practiced by individuals, by virtue of time-of-use pricing of electricity which encourages the use of solar heaters during peak demand, usually when the sun shines brightly.

Geothermal Energy

Anywhere on the earth's surface, temperatures of rocks increase at a rate of 25-35 deg C per km of depth. Temperature gradients may increase much more rapidly, as much as 500 deg C per km, along geologic plate boundaries and their adjacent areas (see Figure 2), where volcanic activity has occurred in the past one million years or so. In areas of low-, or moderate-temperature gradients (less than 60 deg C per km), such as Europe and Eurasia, geothermal waters are already being pumped for direct heat applications such as space heating and greenhouse operations on a major scale. It is estimated that over 11,000 MW thermal were in use by the end of 1989 on a worldwide basis, and that this rate would double by the year 2000 (Palmerini, 1993).

Electricity production from geothermal energy has been in use along the world's geothermal belts (Fig. 2) for the past 80 years. At present, about 6000 MW of geothermal power are in operation, with power plants varying in size from 300 kW to 135 MW each. The temperature of the geothermal reservoirs tapped for power production vary from as little as 90 deg C to nearly 400 deg C.

Efficiency and cost of geothermal energy plants used for power production vary greatly with reservoir temperatures. At temperatures higher than about 170 deg C, the simpler flash technology can be utilized. Flash technology involves tapping the high temperature liquid resource at some depth below surface, letting it flash into a mixture of steam and boiling water in the borehole, and then separating the steam from the boiling water at the surface. The steam, under pressure, is conducted into a turbine to generate electricity (Fig. 3). The separated boiling water is usually reinjected into the subsurface. When the temperature of the geothermal fluid is lower than about 175 deg C, not enough steam is produced when the well is allowed to flash. In that case, the binary technology is utilized.

In the binary power plant (Fig. 4), a pump is inserted in the well at depth. The hot water is pumped in a liquid state into a heat exchanger on the surface. A low boiling-point fluid, such as hydrocarbon, is utilized to as the heat transfer medium. The working fluid is made to boil, generating high pressure gas which makes the turbine turn. The hydrocarbon is then compressed again into a liquid, and the cycle is repeated. Because of the utilization of a lower boiling point fluid, the binary system permits the extraction of a greater amount of heat from the geothermal liquid, reducing the amount of liquid necessary to produce a unit of electricity. However, because of the greater complexity of the binary system, the capital cost of binary power plants tends to be approximately 1.5 to 2 times that of flash systems.

The overall capital cost of geothermal plants, like those of hydro projects, tends to be greater than that of a fossil fuel plant of comparable size. This is because in the case of a geothermal system it is necessary to drill wells and provide gathering lines, in addition to construction of the power plant itself. However, on a levelized lifetime costs, geothermal power projects are price-competitive with the most inexpensive fossil plants, even without regard to the externality costs that should be imputed to the latter. This is because with geothermal plants, as with hydro, there is no need to buy fuel from an outside source at a cost which is likely to escalate with inflation. The operation and maintenance of geothermal projects typically increase over time at a rate of one third to one half that of the inflation rate.

Usually, geothermal wells will decline with time at a very steady, exponentially decreasing rate, which may vary to an insignificant number over time. As a result, geothermal plants have proven to be highly reliable baseload plants, with very little change in output from summer to winter.. This makes geothermal power highly valuable as a steady-output base load source of electricity, which is both a blessing and a problem.

In the U.S., geothermal plants have availability factors which range from 88% to 98%. If liquid cooling is feasible, the difference in out put between day and night, or summer and winter, are negligible. Air cooling is practiced when water cooling cannot be practiced. If air cooling is deployed, a substantial difference in output can take place between day and night and between summer and winter. This difference in output could amount to as much as one third. The output is higher when the air temperature is lower, and lower when the air temperature is higher.

In industrial countries and in large, centrally-connected grids, the variation in demand of electricity between day and night is accommodated in different ways. The grid manager will bring additional capacity on line, or order excess capacity to be shut down, as changes in demand take place. This is also the way in which he deals with the sudden increase in electricity availability from variable output renewable resources. This applies to wind-power in particular. However, since wind-based power in any grid provides only a minuscule power of the total system, there is no need for storage. Likewise, the increase in power output at night from an air-cooled geothermal plant is readily absorbed in a large power network, by reducing the output from fossil-fuel-based power plants.

In frontier areas which are not connected to a central grid and where demand varies greatly from day to night, the near-steady output from a geothermal plant may not provide the necessary power at the midday peak, if the system is designed to provide an average load only. If integrated into a larger system of diverse electricity sources, this constancy of supply will pose no problem. However, if geothermal power is to serve as the major source of electricity, what should its design capacity be? If geared to the night-time base load, it will not serve the needs of the community during peak load hours. If geared to peak load demand, the plant would have excess capacity at night which might have to be left unutilized. In some cases, this problem of uneven demand may be solved by charging the customer with a fee for electricity which is a function of the timer of use. For example, farmers may be content to operate their well pumps at night only, if the cost of the power during the off-peak night time hours is substantially less than that during the mid-day peak-hour price.

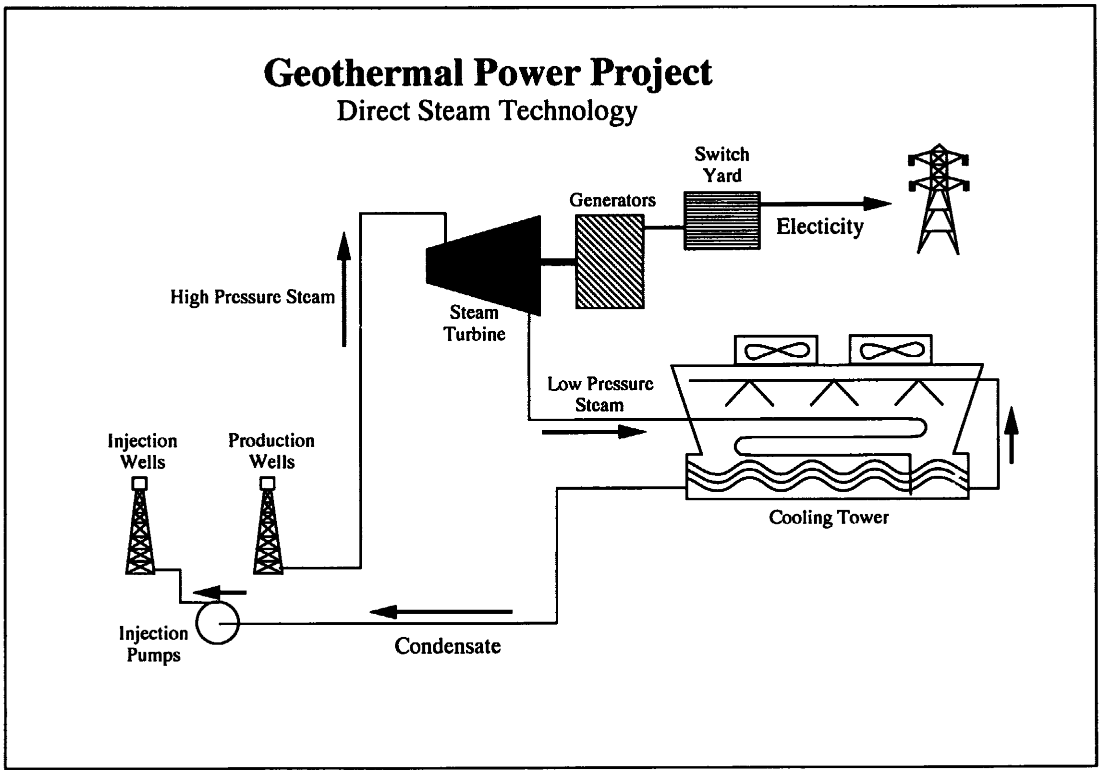


Figure 3

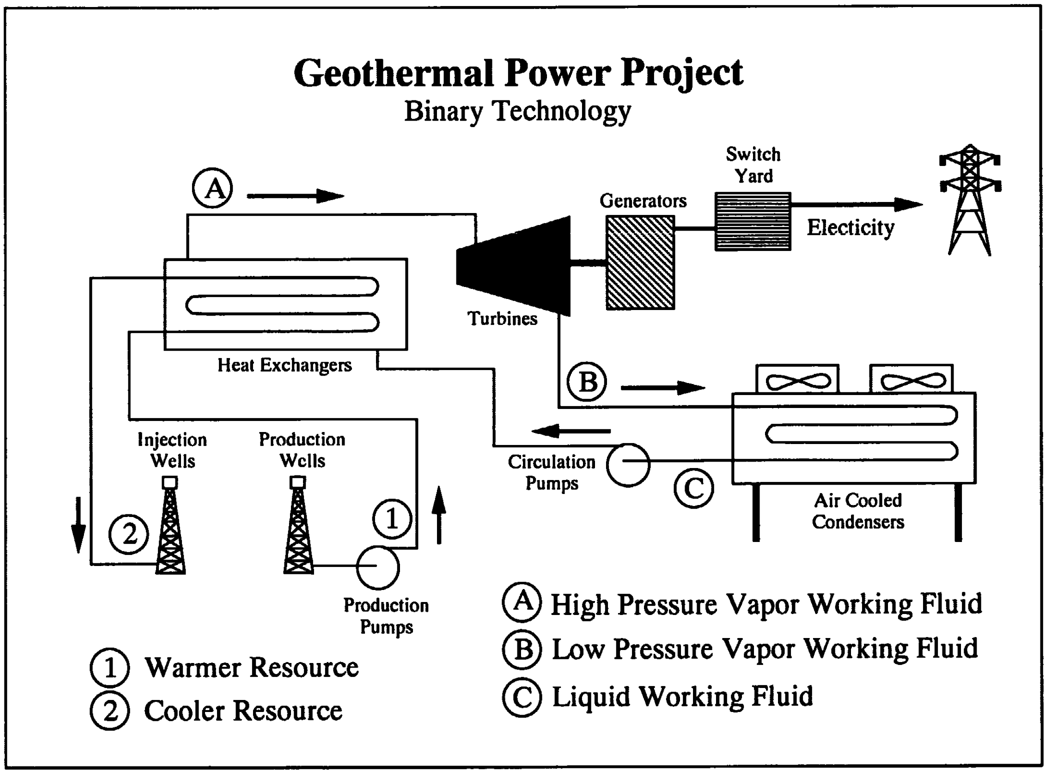


Figure 4

With present day technology and assuming a high load factor, moderate sized geothermal plants (10-50 MW) can produce power at a cost of 5-7 cents per kWh if flash technology can be utilized, and at about 6-9 cents per kWh, if binary technology is deployed. The above cost numbers are based on a utilization factor of 80% or better. The cost numbers above do not take into account such additional items as interest during construction, taxes, insurance, startup costs, banking fees and profit. Entingh and other provide detailed cost estimates for geothermal plants in the 100 kilowatt to one megawatt range (Entingh et al., 1994). For their modal system of 300 kilowatts they come up with a geothermal power cost of 11 cents/kWh, levelized in constant 1993 dollars.

DIVERSITY OF POWER SOURCES AS A COST CONTROLLING MECHANISM

In frontier areas which have a geothermal potential but where connection into a grid is not feasible, the development agency faces two alternatives: Either overbuild the geothermal plant above the average capacity required, to meet most or all of the peak demand, thereby resulting in a lower overall capacity factor, and hence higher unit costs of electricity, or construct a hybrid plant. The hybrid plant may consist of a combination of geothermal, as a base load supplier, and a biomass plant as a peak load source. Alternatively, if any hydro potential exists in the area, utilize the hydro as the source for peaking power. Finally, but least preferably, use a fossil fuel plant as a standby peaking power supply source.

REFERENCES

Entingh, D.J., E. Easwaran, L. McLarty, 1994, Small Geothermal Electric Systems for Remote Powering, presented at the U.S. Department of Energy Geothermal Program Review, San Francisco, April 28, 1994.

Gore, Al, 1993, Earth in the Balance, Penguin Books, USA

Hall, O.H., F. Rosillo-Calle, R. H. Williams and J. Woods, 1992, Biomass for Energy: Supply Prospects, in: Renewable Energy, Island Press, Washington D.C.

Huang J.P., 1993, Electric Consumption and Economic Growth, June 1993, Energy Policy Journal.

Johansson T. B., H. Kelly, A.K.N. Reddy, R.H. Williams, 1993, Renewable Fuels and Electricity for a Growing World Economy, in: Renewable Energy, Island Press, 1993

Kats, G., 1992, The Earth Summit, Opportunity for Energy Reform, June 1992, Energy Policy Journal.

Lenssen, N., 1993, Providing Energy in Developing Countries, in: State of The World-1993, A Worldwatch Institute Report.

Palmerini, C.G., 1993, Geothermal energy, in: Renewable Energy, Island Press, 1993.

Romm, J. B. and A. B. Lovins, 1992, Fueling a Competitive Economy, in: Foreign Affairs, Winter 1992/1993

Sinha C.S. and T.C. Kandpal, 1991, Decentralized v grid electricity for rural India, Energy Policy, June 1991.

Williams, R.H., and E.D. Larson, 1993, Advanced gasification-based biomass power generation, in: Renewable Energy, Island Press.