ENERGY TECHNOLOGIES FOR MOUNTAIN DEVELOPMENT

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INTRODUCTION

Material development of services and goods available to mountain populations cannot be conceived of without considerably increasing energy availability. A good correlation is consistently found between energy consumption per capita and standard of living, whether measured across countries or between different regions of one country. It is now recognized that in addition to land, labor, and capital, energy is one of the essential inputs to the economic process.

Mountain populations throughout the world are known for their generally lower standards of living compared to the plains populations of the same countries. Energy required for communications, trade, and transportation, as well as the difficulty of obtaining the excess energy needed for mountain agriculture, all combine to make mountain development a slower and more difficult process than corresponding development in the plains. The impacts of energy technologies on development of mountain populations, with particular reference to health, food, cold stress, and small-scale industries, are described below. Two particular technologies--microhydel and biogas--have not been considered here since they are topics of two separate Chapters.

According to the best estimates, between fifteen and twenty million people live above 10,000 feet in the South American Andes, the Himalaya, and on the Tibetan plateau. Particularly extensive cultural and biological studies[1] have been carried out for two groups among these: Quechua Indians who live on the altiplano in the Nunoa District of south Peru, and the Sherpas who live in the Khumbu region of east Nepal. The Sherpas do not actually live on the Tibetan plateau, but just south of it, in the high-altitude valleys of the Himalaya. Information on the Quechuas mainly comes from the large, well-integrated project initiated, and for the most part led, by Paul Baker of Pennsylvania State University. Information on the Sherpas comes from diverse sources and has not been collected systematically, but complements the data on the Quechuas.

Both the Andean altiplano and the Tibetan plateau are essentially high altitude deserts, consisting of valley floors ranging from 10,000 to 15,000 feet in altitude separated by hills 2000 to 3000 feet higher. Neither area receives much rainfall due to high mountain ranges separating them from the tropical lowlands in their vicinity.

Health

The impact of energy availability on health of mountain populations is most pronounced at high altitudes. The three main forms of stress at high altitudes are restricted food supply, cold stress, and hypoxia. The last refers to decreased availability of oxygen reaching body tissues due to lower density of air at high altitudes. When individuals accustomed to lowland atmosphere travel to high altitudes, they may experience difficulties associated with hypoxia such as dizziness, fatigue, loss of appetite, headaches, and insomnia. For most persons, these symptoms disappear as their hearts, lungs, and circulatory systems adjust to hypoxia. However, adjustment of high-altitude populations to hypoxia is superior, mainly through biological adaptation. Their response to cold stress and restricted food supply is mainly cultural: learned behavior and technology.

In all high-altitude populations, children have been found more susceptible to cold stress due to their large body surface relative to body volume. Neonatal infants are the most susceptible since they are unable to regulate body heat loss by regulation of perspiration or vasoconstriction/dilation. The only way neonatal infants can maintain adequate body temperature is by raising their overall metabolic rate which leads to large energy demands by the body (Weldon and Hill 1983).

Cold stress coupled with hypoxia, resulting from low air densities, leads to high incidence of acute respiratory infection (ARI) in all ages and both sexes. Again, infants are the most susceptible. A survey in Jumla (altitude 7600 feet) revealed a very high incidence of ARI among infants; the total infant mortality was about 490 per 1000 live births, and of these, about 333 were due to ARI (Pandey et al 1983). Such mortality rates are among the world's highest. ARI was found to be the most important cause of mortality and morbidity among infants below one year of age.

Nutrition

High altitude populations also must cope with marginal nutrition. High altitude environments limit the quantity and quality of food crops just as they limit the types of vegetation. The adjustments by the Quechuas for low caloric potential of the environment have been extensively studied by Thomas from the University of Massachusetts, who has identified four specific strategies evolved in the Quechua culture for this purpose (Weitz 1981). First, the Quechuas rely on caloric resources that are well adapted to the environment and produce the most calories for the least amount of work. Second, the surplus resources (mostly animal products) are sold and exchanged for calorically rich products from other areas. Third, children are often assigned active tasks (such as herding) that would be calorically more costly for adults; and fourth, the tasks necessary for sustenance are organized so that large portions of time can be spent in sedentary activities. Even in herding, up to 75 percent of time may be spent in a stationary position.

The potato was originally domesticated in the Andes and has now become the staple food even among the Sherpas, constituting 30 to 44 percent of their adult diet. The rest is made up of cereals and some green vegetables in summer. A considerable amount of local beer made from rice or millet is consumed. About 80 percent of the diet is carbohydrates. In areas well connected to lowlands, such as Leh, an enormous amount of butter is purchased and consumed. About 70 percent of the cash flow at the Government Fair Price shop in Leh reportedly results from sale of various commercial brands of butter, though the shops are stocked with hundreds of other household commodities.

Almost all protein in Sherpa and Quechua diets is vegetable- based. The diets tend to be calorically adequate but deficient in protein. One biological consequence of inadequate caloric or protein intake is growth retardation. Among both Quechuas and Sherpas, physical growth is slower than among lowland populations. Skeletal growth and mineralization are slow; the growth spurt during adolescence is delayed until the early to mid-twenties. Retarded growth or small body size can add up to considerable caloric saving. Thomas has estimated that for the Quechuas, the retarded growth at adolescence alone (between the ages of 15 and 20) saves an average of 121 calories a day or more than 44,000 calories per year (Weitz 1981). This is equivalent to planting an additional 100 m^2 of cropland for each adolescent every year.

There is no consensus yet among experts as to how much of the growth retardation is a response to poor nutrition and how much is attributable to hypoxia; both seem to be implicated. Data from the Andean studies clearly suggests that slow growth is a developmental (not a genetic) response to high altitude conditions. Non-native children who migrate from sea level to high altitudes and remain there while growing up eventually attain the same large lung volume as high altitude natives. Lahiri of the University of Pennsylvania School of Medicine has reported that neonatal infants have the same lung volume at high and low altitudes but a difference appears at adolescence. In addition, he has shown that the high-altitude ventilatory response to hypoxia manifests itself only during adolescence and becomes irreversible by adulthood, again indicating developmental and not genetic adaptation (Weitz 1981).

The impact of altitude on survival begins even before birth. Because of the low amount of oxygen that diffuses across the placental membrane in the foetal system, all foetuses (even at low altitudes) develop in a hypoxic environment. The placentas of Andean women are larger in diameter, thinner, and weigh more relative to foetal weight, than for low-altitude populations. Even then, both fertility and birth weight are lower at high altitudes, both in the Andes and the Himalaya.

Several infectious diseases are not prevalent at high altitudes due to absence of disease vectors. All the same, hypoxia, poor nutrition, cold stress, and respiratory disease combine to significantly reduce survival rates. Only about 65 percent of Sherpas reach adolescence; the rate is roughly similar for the Quechuas. The cultural and biological adjustments cannot completely protect the high-altitude populations from the stress of their environments. The consequence, contrary to the popular assumption of unusual longevity and good health in mountain populations, is lower fertility, prevalence of respiratory diseases, and death at a fairly early age.

Architecture

The annual weather cycle in the high-altitude regions is characterized by comfortable summers and freezing winters. Summer daytime temperatures are about 25°C and winter nighttime temperatures are about -20°C. Large daily temperature swings are common due to thin and extremely dry atmosphere that facilitates radiation loss to the night sky.

Urban houses in Nunoa are constructed of adobe and covered with mud or plaster stucco. Rural houses are made with piled stone walls and thatched roofing. During the cold dry season, nighttime temperatures inside adobe houses average about 7°C. Rural houses offer little resistance to wind and cold, so the temperatures in rural houses fall below freezing during cold winter nights in Nunoa. In Ladakh, temperatures in rural peasant houses have been measured by Paul Mirmont to average about -10°C throughout winter[2].

Sherpa houses are built with thick stone walls that provide good protection from wind, particularly since windows are few and generally only on one side of the house. Most houses have two stories, with the ground floor serving as a manger and a stable. The family lives in one room upstairs, which is so large that much of the benefit resulting from the small heat and moisture gain from the ground floor is lost through the envelope.

In Ladakh, residential buildings are traditionally built two different ways. Ordinary houses are built with sun-dried mud brick walls about one-foot thick, with flat roofs consisting of timber joists supporting closely spaced willow branches which are then covered with about eight inches of mud. The other kind of residential arrangement found in Ladakh is the large monasteries, or *gompas*. These consist of tightly clustered rooms offering relatively small surface area to the exterior. Both the traditional homes as well as the *gompas* have very few windows. In poor peasant houses in the interior of Ladakh, the windows are covered with oiled paper which lets in some light without admitting the freezing wind.

In rural areas (e.g. Zanskar) of Ladakh one also finds a two-storied residential dwelling where the ground floor is a stable and manger for livestock, the second floor is occupied by people for their living activities, and the third level is used for storage of food and hay. Some of the Ladakhi peasant houses are built with mud walls without using prefabricated sun-dried mud bricks. The construction method consists of using woven willow shuttering for supporting the wet mud from both sides. As lower sections of the wall become dry and strong, the willow shuttering is moved up and more mud is added to raise the wall to the desired height.

The current standards for government buildings in Ladakh required by the Public Works Department in Leh are shown below:

Table 1. Specifications for PWD Buildings in Ladakh, 1985

ITEM	SINGLE STOREY	DOUBLE STOREY
Foundation	150 mm concrete then RSM* in mud mortar	150 mm mud mortar over 150 mm concrete
Plinth	RSM in mud mortar with corners in cement mortar	Same as for single story
Super-structure	RSM in mud mortar	or 2nd story must use sun dried brick and mud mortar.
Roofing	Ladakhi type. 100 mm thick mud *phuski* over alkathene sheet over 25 mm wooden planks over timber joists	Same as for single storey
Flooring	40 mm PCC**	
Finishing	Mud plaster both inside and outside the building and whitewash	
Cost/m^2 plinth area	Rs. 1185	Rs. 2260

Note the absence of any required insulation in walls and roof, any requirements for double glazing of windows, or weather stripping.

* RSM - Rubble Stone Masonry

** PCC - Plain Cement Concrete

RELEVANT TECHNOLOGIES

Various renewable energy technologies suitable for high-altitude mountain settlements are described and explained in the sections below.

With intense sunshine available 340 days each year in Ladakh and other high-altitude regions of the Himalaya, solar energy is an effective and inexpensive energy resource. Solar radiation reaches the earth's surface at sea level with an intensity of about 1000 watts/m^2 under a clear sky at noon. At high altitudes, the intensity is somewhat higher since there is less scattering and absorption of solar energy in its passage through the atmosphere. Solar radiation has an equivalent temperature of about 6000°C. This means that it is possible in principle to achieve any temperature up to this maximum by suitably concentrating sunlight. In practice, temperatures much above 1000°C are not practical owing to materials problems. Even below this temperature, the capital costs of capturing solar energy can be quite high. However, the cost of capturing a unit of solar energy rapidly decreases with the temperature at which the energy is needed. The lowest useful temperature for solar energy use is about 30°C, for heating buildings.

Passive Solar Architecture

Traditional Ladakhi buildings have large thermal inertia owing to their massive earth construction. The buildings can be modified to capture solar energy during the daytime and absorb part of the captured energy in the building elements without overheating the building during the day. This heat is released into the building at night. Modifications of the traditional Ladakhi architecture can make use of their naturally high thermal mass. Broadly, design of a solar-heated building follows two strategies: First, the building has to be modified so that it captures solar energy from low-altitude winter sun; and second, the building envelope has to be insulated so that it retains the energy thus captured.

In addition, provision of various heat-rejection methods to avoid overheating, combined with skillful use of thermal mass, keeps the building comfortable all year. Specific approaches for the above two strategies are described below.

Solar energy is suitably captured in a building by either using a *trombe* wall or by Direct Gain design. A *trombe* wall consists of a south-facing wall painted black on the outside with a vertical sheet glass cover on the outside, about 10 cm away. Sunlight shines through the sheet glass on the black wall. Ordinary glass is transparent only to short-wave radiation (visible and infrared components of sunlight) and is opaque to long-wave infrared radiation emitted from the heated black surface. Thus, the black surface cannot easily reradiate its heat to the cold exterior environment. Most of this heat passes by conduction into the wall. If the wall is thermally massive, the heat is stored in the wall and slowly released to the interior of the building. If rapid heat gain to the building interior during daylight hours is desired, the *trombe* wall can be made either of low thermal mass, such as corrugated galvanized iron/asbestos sheets, or can be provided with vents at its top and bottom which allow cool air from the building interior to be sucked into the space between the wall and the glass, heated by the hot black wall surface and returned to the building interior by vents at the top of the wall. Pieces of lightweight plastic film backed with a wire mesh may be installed at the top and bottom vents to ensure that no reverse flow of air takes place during the night through the vents. In the absence of these valves, the warmer air from the building interior is sucked into the *trombe* wall cavity from the top vents at night, cooled by the cold glass sheet, and is returned to the building interior from the bottom vents. The plastic films block this reverse flow since the reverse pressure presses them against the wire mesh, and seals the valve. During forward flow operation, the films gently flap in the jet of air, free from the wire mesh, to allow forward flow of air.

Low mass or vented *trombe* walls are best suited for buildings occupied and used only during the day, such as offices or schools. Unvented high mass *trombe* walls are desirable for buildings occupied at night, such as houses, dormitories, and hotels. The amount of heat captured using vented *trombe* walls can be accurately calculated for a wide range of design parameters (Akbari and Borgers 1979; Borgers and Akbari 1984). The results given in these papers have been subsequently verified with careful experiments conducted independently in Australia and the U.S.A.

Direct Gain design consists of having large areas of south-facing wall made of single or double glazed windows. A large amount of sunlight enters the building interior through the glazing and warms up the building. During the night, occupants move to other parts of the building where heat loss is relatively low. Direct Gain design is attractive where the glare of direct sunlight and possible loss of privacy in part of the building will be acceptable. Another inexpensive solution for solar heating of buildings is attaching a sun-space to the building. The sun-space is a south projecting part of the building that is enclosed on four sides (east, west, south, and top) with glass. Air from the heated sun-space can be convectively moved to cooler parts of the building to warm them.

Insulation in the building envelope prevents loss of heat from the building to the environment. In fact, insulating and weather stripping are the two most effective measures to keep buildings warm in winter. These should be implemented before attempting any scheme to capture solar energy for space heating; all the exterior surfaces of the building should be insulated. This can usually be done without modifying the traditional architectural style, and without use of expensive material.

An attractive solution demonstrated in Leh by C. L. Gupta (1981), Helena Norberg-Hodge (1979), and by Paul Mirmont is to build double-walled building envelopes with space between the two wall layers packed with straw. The roof is also insulated with 20 cm straw added between the willow branches and the top mud layer. This improves the insulation value of the walls from the traditional value of $0.7 m^2\text{-}^\circ C/watt$ to $3.2 m^2\text{-}^\circ C/watt$. In addition, if the ordinary wooden plank door is replaced with a sandwich panel door containing 5 cm thick rigid polystyrene foam, the resistance to heat loss of the entire envelope can be further increased by a factor of 2.5.

Subsequent improvements in the thermal integrity of the buildings would consist of changing windows from single pane to double pane and decreasing the subsequent improvements in the thermal integrity infiltration of outside cold air into the building with weather stripping. A fairly comprehensive reference for solar heating of buildings is found in Mazria's book (Mazria 1979).

Solar Hot Water

In Tibet as well as in Ladakh, water scarcity is a problem due to inadequate precipitation. In Leh, water is available to city residents in winter at only four public water taps. Hot water is a luxury due to the high cost of fuel. A majority of the population reportedly go without a bath for several months at a stretch. It is relatively inexpensive to provide hot water with the use of solar energy. Batch-type solar water heaters can be fabricated costing no more than Rs. 1400 per unit to yield 40 liters of hot water each day. One such design by TERI is being tested in Leh. At lower altitudes, relatively warmer winters mean even lower costs for solar water heating.

Solar Energy for Food Preservation and Production

Despite harsh weather, a few fruit orchards are cultivated near the Indus River, where water is available. Peaches and apples grown locally are available only for immediate local consumption. It is possible to use solar energy for operating agricultural dryers so that food products can be stored beyond the harvesting season. Several designs can be found in the survey by Lawand (Lawand 1975).

In the course of one poultry research project conducted among the Quechuas in Peru, the reason for the low rate of weight gain by young chicks at that altitude was identified to be the low ambient temperatures particularly during the cold nights. A solar-heated chicken brooder using exclusively local skills and materials was developed and successfully field-tested. (Benard et al 1981). The brooder consists of a sun-space which receives considerable solar energy during the day. Heat from the sun-space is absorbed in an inexpensive, phase-change, thermal storage unit during the day. The chicks stay away from this hot part of the brooder during the day and spend most of their time in a shaded area; during the cold night, they huddle close to the thermal storage unit. The design is adaptable to any sunny cold climate, typical of high-altitude mountain regions.

Solar-Assisted Biogas

It is known that gas yield from biogas digesters decreases by a factor of approximately two for every 10°C drop in the digester temperature. In China, biogas digesters effectively shut down during the sub-zero winter. It is possible to warm small quantities of water inexpensively in shallow solar ponds. This warm water when used to make the slurry for the biogas digester raises the temperature of the digester and consequently its gas output considerably. V. V. N. Kishore of TERI has been experimenting with this technique for biogas digesters of Chinese design (known as Janata design in India) and these will be tried in Haryana and Jammu. N. K. Bansal of the Indian Institute of Technology, New Delhi, has been conducting experiments with KVIC design biogas plants which consist of enclosing the entire dome in a transparent plastic shell, effectively forming a sun-space around the biogas digester. These technologies are not suitable for extremely cold climates of high-altitude regions such as Ladakh and Tibet; they will be useful in lower altitude mountain regions.

Improved Space Heating and Cookstoves

During winter, it is common to use hard coke-fired space heaters in Ladakh, at least among those who can afford fuel. Since hard coke costs are high, use of this space heater (*bukhari*) translates into a fuel cost of Rs. 3 per hour. The *bukharis* have not been designed using modern engineering knowledge and probably their efficiency can be improved by 50 to 100 percent with only a marginal increase in cost. TERI is presently developing more efficient *bukhari* designs.

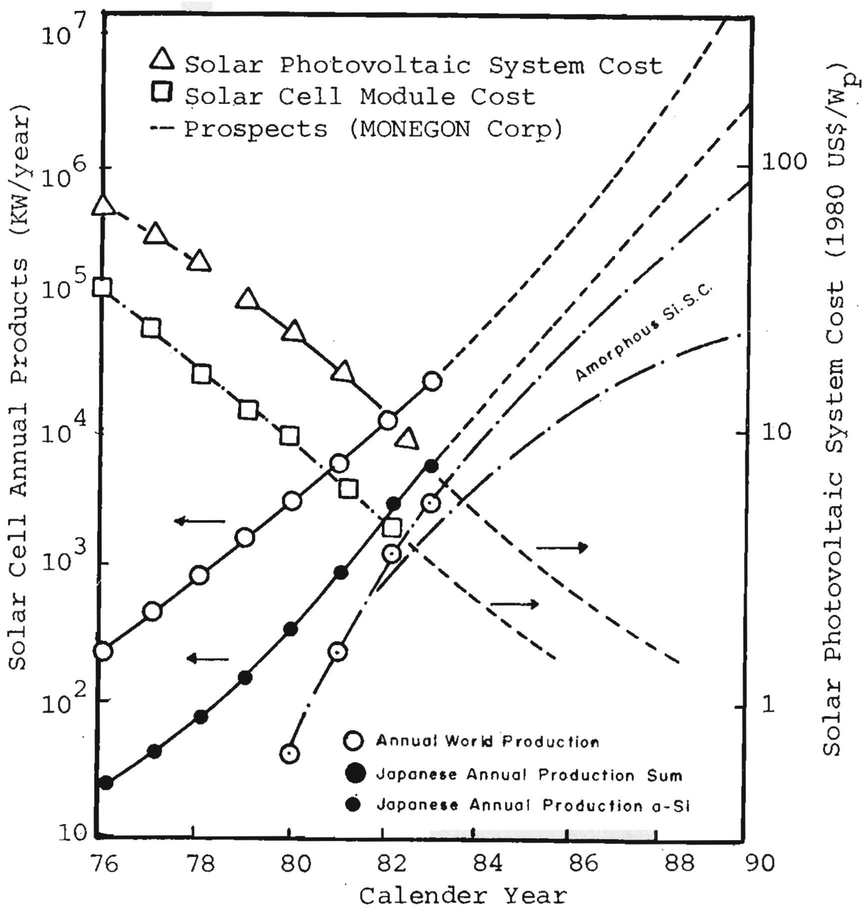
Cookstoves made from oil drums have recently become popular in Ladakh. They have extremely elaborate and ornamental designs and cost up to Rs. 6000. Their energy efficiency, however, has not even been tested. Preliminary inspection leads one to suspect low efficiency (about 10 percent). It seems likely that it could be improved significantly with a little effort.

Photovoltaics

There exist several techniques for direct conversion of sunlight into electricity. The most successful of these is the silicon solar cell. Other technologies (e.g. Gallium Arsenide, Photoelectrochemical cells, etc.) are not yet mature enough for practical field applications. A silicon solar cell essentially consists of a wafer of pure silicon which has been purposefully doped to alter its electronic characteristics.

Silicon photovoltaic cells were first commercially developed and used for space applications. At that time, they were extremely expensive and thus could only be used for supplying electrical power to satellites and spacecraft. The prices of photovoltaic cells have declined sharply since 1970 as a result of concentrated efforts in this direction undertaken mostly in the U.S.A. Photovoltaic modules are rated in terms of maximum power they produce when exposed to solar radiation that has passed through one standard atmosphere of air. (Since passage through the atmosphere attenuates sunlight, the solar spectrum is characterized as AM 1, AM 1.5, AM 2, etc., giving equivalent air mass through which sunlight may pass before it reaches the observer.) The common way of rating photovoltaic modules and cells is in terms of Watts-peak (Wp). A cell rated at 1 Wp would thus produce one watt of power when exposed to AM 1 radiation incident normal on its surface. In 1970, photovoltaic modules cost US$ 150/Wp. This cost rapidly came down to US$ 50/Wp in 1976 and afterwards has shown an equally dramatic and rapid decline. Annual photovoltaic production measured in terms of kW/year has shown an exponential increase since the early 1970s. In 1976, the production was about 300 kW/year and in 1984 it was about 30,000 kW/year. More details are shown in Figure 1 (Hamakawa 1985).

Of course a photovoltaic cell, module, or system rated at a given power does



Growth of world and domestic annual production of solar cell modules and transitions of module cost and system cost.

Figure 1

not produce that power 24 hours a day. It does not even produce that much power during the daylight hours since the energy incident on the panel is a function of length of the atmosphere through which the sunlight is attenuated and decrease in radiation flux due to non-normal angles of incidence.

An important advance in further decreasing the cost of silicon photovoltaic modules has been the maturing of technology for amorphous silicon (a-Si) PV cells. Amorphous Silicon has a coefficient of photon absorption about 40 times larger than crystalline silicon. This allows for amorphous silicon cells to be extremely thin. (The optimal thickness for crystalline silicon cells is 70 um. In practice, the cells are about 300 um thick for mechanical strength. In contrast, a-Si cells have a thickness of 0.5 um.) There are about 60 percent losses involved in preparing silicon wafers from cylindrical ingots of pure silicon. Though these can be considerably reduced by producing silicon ribbons directly from molten silicon using the Edge Defined Growth technique, polycrystalline silicon cells still need 600 times more pure silicon than amorphous silicon cells of the same area.

The amorphous silicon cells are prepared by directly depositing a very thin film of a-Si on a metal substrate. In 1985, Sanyo Electric Company of Japan announced that they had made a-Si cells with the conversion efficiencies shown in Table 2.

Table 2. Conversion Efficiency of a-Si Cells

AREA	CONVERSION EFFICIENCY
1 cm^2	11%
100 cm^2	9%
600 cm^2	7%

Sanyo has developed a microfabrication technology for producing a-Si solar cells that is completely automated and uses laser-scribers for evaporating sublayers of an a-Si cell assembly. This is a completely dry process and is expected to operate continuously.

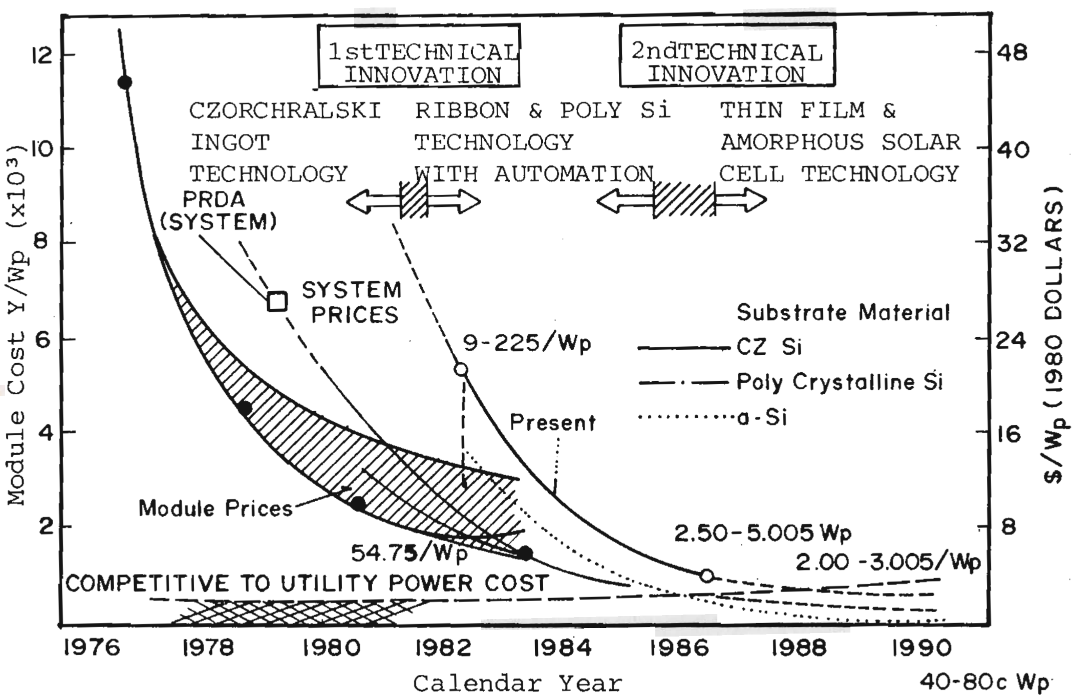
Amorphous-Silicon cells have so far had relatively low efficiencies (about 6 percent) of photovoltaic conversion compared to polycrystalline a-Si cells (typically 12 percent or more). Various innovations have successfully pushed the efficiencies up as indicated in the above table. A-Si cells also have tended to deteriorate rather rapidly when exposed to direct sunlight. Thus the applications of a-Si cells have almost extensively been in desktop calculators (these calculators, though called "solar calculators", will not last long if operated in direct sunlight). Japanese researchers were able to stabilize a-Si with respect to exposure to direct sunlight only in 1985. Toyota has announced that its best line of cars will have their tops coated with a-Si cells which will power the instrumentation, charge the battery, etc. Sanyo has also produced experimental a-Si roof tiles and tiles for exterior walls of buildings, which could power all the appliances inside the building. These recent advances indicate that a-Si technology is likely to completely overtake polycrystalline ribbon technology in the near future. The cost transition of solar cell modules and of photovoltaic systems with various technological innovations is shown in Figure 2, also from Hamakawa (Hamakawa 1985). The estimated point of transition where photovoltaic power system costs, would favorably compare with utility (thermal) power costs is expected to be between 1986 and 1989.

A considerable amount of high-temperature processing is needed to obtain ultra-pure silicon which leads to such a large consumption of energy in the production of crystalline silicon cells that the payback period for the energy invested in the production is about 10 years, assuming continuous daily operation of the cell. Since 10 years is approximately the lifetime of the photovoltaic system, it does not seem attractive to invest energy in photovoltaic systems. A-Si cells, however, use 600 times less silicon per unit area and hence, despite their slightly lower efficiency, energy payback periods for a-Si cells are about one year.

In remote mountain areas, the cost of transmission and distribution of power can be very significant. A transmission and distribution network is a fixed cost that depends more on the distance from the grid line and less on the total energy demand for small load centers. Photovoltaic system costs are, on the other hand, directly proportional to the energy demand, and more or less independent of location. A study done at TERI indicates that state-of-the-art photovoltaic power systems become cost-effective compared to grid-connected electric power supply for electrification of small mountain villages (peak load 40 kW; daily energy demand 500 kWh) located more than 10 km from the existing grid lines. These conditions are satisfied for the majority of unelectrified mountain villages. For villages with less demand, photovoltaics are cost-effective even at distances less than 10 km from the grid lines. For larger villages and towns where the electricity demand is higher, grid-connected power systems remain cheaper than photovoltaics for distances greater than 10 km from existing grid lines.

Electricity Production and End-Use Efficiency

For various demographic and topographic reasons, the transmission and distribution of electricity is expensive in mountain regions. With the sharply declining prices of photovoltaic systems, their use has already become cost effective in remote villages. Electricity produced with hydropower can be inexpensive in principle. However, persistent cost and time overuns make hydroelectric power sometimes enormously expensive. The four MW minihydel projects on the Indus River at Stakhna near Leh will cost about Rs. 120 million. The cost thus translates to Rs. 30 per watt of installed capacity. The dam, however, will produce 4 MW of power only during summer. During the sub-zero winters, the flow in the Indus river decreases



Cost transition of solar cell modules and photovoltaic systems with prospective technological innovations.

Figure 2

considerably and the power output is expected to drop to only 2 MW. Thus the cost for annual average capacity is Rs. 40 per Watt installed. This is comparable to the costs expected for large photovoltaic installation before the end of this decade.

The alternative for hydroelectricity is generation with diesel engines. Efficiency of diesel generation decreases by three percent with every 1000 feet increase in elevation. The diesel generators in the 1 MW power house near Leh operate at best at 70 percent of their rated capacity. The cost of transporting diesel to high altitudes is also significant, as is the cost of transmission of distribution network over rugged terrain. The Power Development Department of Jammu and Kashmir State has estimated that the cost of electrical energy from its diesel generating stations for Leh was Rs. 4.10/kWh in 1982-83. The cost of electricity supplied to remote areas like Zanskar was much higher: Rs. 10/kWh. The diesel has to be trucked to Leh and stored in underground reservoirs for the winter since the road to Srinagar is snowbound and closed by mid-November. End-use efficiency of electricity thus becomes extremely important, not only to the residents of Leh (for whom the billing rate is about Rs. 0.65/kWh) but to the utility which bears the cost of subsidy. All electric-resistance heating is forbidden in Leh (except at hospitals for sterilization, etc.). Since the electricity is available only for five evening hours, almost all consumption is confined to lighting.

The demand has grown faster than the generation capacity and the supply voltage is usually in the range of 140 to 180 volts. This low voltage makes it impossible to use fluorescent lamps which normally are five times more energy-efficient than incandescent lamps. If everyone switched to fluorescent lamps there would be a 2.5-fold drop in electricity consumption and a twofold increase in the light produced. However, there are obvious management and organizational problems which must be overcome in implementing such a massive switch.

Waste-Heat Recovery

Diesel generation also produces twice as much heat as electricity. This heat is presently all dumped into the atmosphere. Several companies in India manufacture equipment to capture waste heat from diesel electric generators with ratings larger than about 500 kW and make it available for various low temperature applications (temperatures of less than 120°C). The amount of waste heat thus recovered is equal to about 60 percent of the electrical energy being produced. No such equipment is presently in use in Ladakh to the author's knowledge. It is economically attractive to capture this free heat, and use it for process industries such as food preservation or canning, which would give rise to local employment and income generation.

Wind Power

Winds flowing over mountainous terrains are strongly influenced by the terrain geometry, and it is commonly possible to identify passes and channels where the wind is funneled naturally. Wind power is thus highly site-dependent. Detailed monitoring of local wind characteristics is essential for identifying sites for wind power generation, or before writing off any mountain district as having no potential for wind power generation. The wind power potential in the Indian Himalaya remains almost totally uncharted at present. The lowest cost per unit of installed capacity for wind machines is rated at about 50 kW with a diameter of about 15 meters. This is somewhat different from the initial expectation of about 10 years ago that economies of scale would continue to make wind power cheaper as the rated power of the wind machines increased. It is fully expected that with better understanding of the low - velocity, high - turbulence aerodynamics, and with the development of better fatigue-resistant materials for wind turbine blades, the lowest wind turbine cost (per kW of rated capacity) would gradually shift to larger wind turbines in the rotor diameter range of 20-30 meters.

A wind farm of 50 kW-rated wind turbines with a total installed capacity of 6 MW would currently cost about Rs. 120 million. Fairly attractive terms of payment are available from manufacturers for installing such wind farms where only 25 percent of the payment is to be made on installation with the rest of the amount to be paid over the next seven years. The annual payments are tied to the actual annual energy output from the wind turbines. If the wind turbines produce less energy in a given year for any reason, the owner pays a proportionately smaller amount to the installers, the difference being made up by an insurance company.

The U.S.A., West Germany, and Sweden have developed large wind turbines rated at 2 to 3 MW over the last 10 years. Both the West German and the U.S. programs have presently been closed down due to technical difficulties, or lack of funds. The Swedish research program with two large wind turbines at Nasudden and Maglarp continues to operate.

Underground Refrigerated Storage

In most high-altitude regions, electric power is not available continuously and often is not available at all. This leads to problems in keeping a supply of refrigerated vaccine on hand in hospitals and for public heating purposes. Inexpensive refrigeration, if available at these locations, can also be used for storage of vegetables and other food products. The extreme cold of the high-altitude winter season and the large thermal mass of soil can be used to design underground low-temperature storage facilities which do not use any electricity. In Ladakh, TERI is designing a low-temperature storage facility for the Leh District Hospital where vaccine would be stored approximately 10 meters under the soil surface. Detailed numerical simulations of heat conduction in the soil indicate that at these depths the annual temperature swing is from +8 to -8^{o+}C, which makes the facility suitable for storage of BCG/Typhoid and DPT/DT/TT vaccines. (If these vaccines freeze, their proteins are denatured and the vaccines have no medical effectiveness after thawing. Storing them above ground in winter quickly leads to their getting frozen solid and renders them useless.) Underground storage facilities due to the large thermal mass of soil between the storage area and the ground surface, provides a more or less uniform storage temperature year-round that protects the vaccines.

Vegetables are traditionally stored in Ladakh in pits six feet deep, and covered with about a foot of soil. The vegetables stay fresh for several months and do not spoil due to freezing or overheating. The Council for Administration and Rural Technology (CART) of the Government of India is presently interested in developing scientifically designed underground vegetable storage units for Ladakh based on the above principle.

Both the technologies described above use the natural swings in ambient temperature to provide low temperature storage facilities, whereas other alternatives would need a considerable amount of electric power and fairly sophisticated control equipment. At lower altitudes in the mountain areas (e.g. Srinagar) sometimes the summer temperatures are sufficiently high that air-conditioning is required in critical areas (operation theatres, satellite communication facilities, computer centers, etc.). It has been demonstrated that in this case also it is not only technically feasible but also economically cost-effective to capture the sub-zero cold of the winter months to freeze a large mass of wet soil underground. During the summer months when cool air is needed for air-conditioning, this frozen mass of soil can be used to absorb the indoor heat in place of relatively costlier electric air-conditioning (Francis 1985).

RESEARCH AND DEVELOPMENT NEEDS

Paucity of data is the first difficulty faced by any research or development program on renewable energy in the mountain regions. Renewable energy potential is a highly site-specific variable. The India Meteorological Service already has several weather stations throughout India which record hourly solar radiation, temperature, wind speed, relative humidity, etc. There are very few stations of this kind in the mountain areas. In Ladakh, there is only one station and that data is normally available only to the Indian Air Force. A series of such weather stations need to be scattered throughout the mountain regions to enable planning for exploitation of renewable energy potential.

The technology of passive solar heating of buildings is now well understood and there exists a large body of practical experience in Europe and North America on this subject. This information is all in the public domain and several books and research papers have already been published on this topic. It is important that this knowledge be transferred to the mountain population. Most of the mountain population is poor and their dwellings are not designed and built by construction professionals such as architects, engineers, and building contractors. These ordinary people have to be provided with guidelines in their local languages which will explain in simple terms how new dwellings can be constructed or their existing houses modified to capture and retain solar heat. Demonstration buildings also have to be erected which will prove the concepts to the local population.

The CEC (Committee of European Communities) has presently funded a small project in Ladakh with Paul Mirmont,[3] which has constructed 15 passive solar houses in villages surrounding Leh. The incremental costs for these houses, (over the cost of the standard design) is only Rs. 5000. The CEC project also envisages printing of manuals in Ladakhi and Tibetan languages which will explain the passive solar design concepts in simple terms. This work needs to be expanded considerably throughout Ladakh and other high-altitude mountain regions. It would be essential to create a resource center (a kind of energy extension service) which would provide advice and plans for solar building. Since cold stress is one of the three main health problems facing high-altitude mountain populations, efforts to introduce passive solar architecture on a wide scale will surely have a significant impact on health and survival. Government Public Works Department specifications for buildings should be modified to specify levels of insulation, window areas, and double glazing on windows as well as weather stripping as part of government building requirements.

Due to high costs of fuelwood, coal, kerosene, and diesel, solar hot water is probably already cost-effective in most high-altitude mountain regions. Without detailed radiation and weather data, it is difficult to quantify the cost of solar hot water at any specific site. However, it is likely that solar hot water would not only be cost-effective due to extremely clear skies for most of the year, but its use would be very desirable since a large part of the population reportedly goes without bathing throughout winter.

Solar chicken brooders and greenhouses for extending the vegetable growing season beyond summer need to be experimented with and disseminated widely. Experiments with subsoil drip irrigation and horticulture under controlled atmosphere (under polythene sheets) to prevent excessive water loss also need to be investigated.

In low-altitude mountain regions, biogas digesters almost stop producing methane in winter. Solar energy can be used either via shallow solar ponds or with sun-space enclosures to keep the biogas plant functioning throughout winter. More research needs to be conducted on both these methods and results disseminated.

Photovoltaics are already cost-effective in most of the mountain region since the cost of transmission and distribution networks is extremely high. The existing photovoltaic panels made in India have low efficiency and a short life (about two years in Ladakh) and thus are not cost-effective. The quality of indigenously produced panels has to be improved to international standards so that this technology can be used widely.

Most of the electricity produced in the high-altitude mountain regions is developed from diesel engines. It is very inexpensive and cost-effective to capture a part of the heat exhausted by these engines and use it for various intermediate temperatures (80°-130°C) applications. Several companies in India already manufacture equipment to capture part of this heat equal to about 60 percent of the electrical output for diesel gensets rated larger than 500 kW. This technology needs to be disseminated widely, and also heat recovery units for smaller rated diesel gensets need development.

The end-use efficiency of electric appliances in high-altitude mountain regions becomes particularly important since the cost of electricity is very high. In mountain areas where electricity is used mostly for illumination purposes, a switch from incandescent lamps to fluorescent lamps seems economically attractive even if it involves investments in voltage stabilizers to ensure a reasonably high voltage supply to the fluorescent lamps.

Traditional domestic appliances using fossil and wood fuel such as *bukharis* and *chulhas* are generally quite inefficient and can probably be significantly improved with little effort. Introduction of pressure cookers throughout high mountain areas seems desirable both from the point of view of improved energy efficiency as well as forest conservation.

ENDNOTES

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