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SMALL SCALE HYDROPOWER -
APPROPRIATE TECHNOLOGY FOR RURAL DEVELOPMENT IN LESSER DEVELOPED COUNTRIES

BY

STEPHEN R. HARPER
B.S.E., University of Central Florida, 1979

RESEARCH REPORT

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ABSTRACT

Less Developed Countries (LDC's) now have a total of about 2.8 billion people, or approximately 70 percent of the total world population.

World populations and current energy consumption are such that if all the world's countries came up to the U.S. per capita energy use, the world's consumption would multiply by a factor of seven. For the LDC's, energy development will be an increasingly important issue.

Hydropower technology is on the shelf, and available now, of proven feasibility both technically and economically, and presents a sound and rational energy solution from the environmental viewpoint. It is a technology which could be useful to the Less Developed Countries for the long term, irrespective of the shift from abundant low-cost fossil fuel options or the development of more exotic alternate energy technologies. With its continuing replenishment and nondepleting characteristics, it remains one of the most attractive sources of energy.

The nature of water resources includes a distributive element which makes it ideal for rural development. The apparent shift in development policy, from the traditional "top-down" industrialization approach to the "bottoms-up" reach the village approach, requires decentralized applications of energy resources attainable through development of hydropower in many regions of the world.

Distributed Small Scale Hydropower (SSH) systems offer excellent opportunities to augment energy supplies to many rural areas. Also, in a modest way the development of a community infrastructure, training of operating and maintenance personnel, and initiation of small scale agribusiness enterprises may be undertaken. Each of these activities could result in relatively major contributions to the improvement of quality of life.

SSH sites are found in abundancy in most mountainous regions and offer sensible possibilities for decentralized applications in LDC's.

Robert D. Kersten

Dr. Robert D. Kersten
Director of Research Report

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CHAPTER I

INTRODUCTION

The gap in standards of living between the Developed and Less Developed Countries (LDC's) continues to grow. Progress of the LDC's toward a better life has been slowed by the world-wide economic troubles that continue to result from the increases in oil prices. The OPEC economic squeeze brought new cries from the developing countries for technology to help develop their countries. The task of meeting the requirements of an energy-hungry world has never been more demanding than it is today. World population and current energy consumption growth rates are such that if all the world's countries came up to the U.S. per capita energy use, the world's energy consumption would multiply by a factor of seven (Palmedo, 1977).

For the developing countries, the choice of energy technology will have a more significant and long term impact than any other technological choice facing them. The challenge of supplying food, housing, health service and education for some six billion people by the year 2000 is the main engineering problem for the rest of this century (Cortes-Comerer, 1977).

The choice of energy (and other) technology influences a given society in several ways, such as demanding certain skills and education, by introducing certain usage patterns, by placing emphasis on conservation or oppositely on wasteful habits, and determining the scale of certain infra-structures. Particularly, for LDC's, the choice of energy (and other technology) can have a very strong influence on the kind of society emerging. The motivation for any development effort should be either to satisfy basic needs, such as food, shelter and human life conditions, or in particular, when basic needs have been provided, to improve standards, e.g., by providing more material goods or intellectual "goods", improving working conditions, improving educational opportunities and increasing public participation in decision-making.

What constitutes "desirable development" is often a difficult question, and will vary from one country to another, depending upon their internal aspirations and the way in which those aspirations are influenced by comparisons with more industrialized nations. It seems clear, however, that economic development in terms of real disposable income and the way in which this translates to the availability of goods and services is an essential part of any development plan (Thomas and Jawaharlall, 1979).

Policy Shift

In the mid-1970's, amidst threats of nonaligned governments and international conflicts, the Developed Countries took renewed interest in foreign aid policies. In 1976, at the Nairobi U.S. Conference on Trade and Development, Dr. Henry Kissinger outlined

U.S. proposals to increase technology transfer, manpower training, and research.

The ensuing surge of development efforts brought to the third world countries much bright, shining, expensive machinery. However, the realities of village life do not always lend themselves to sophisticated 20th century technology. There are numerous examples of technology transfers which were failures. Pieces of electrical equipment sit idle due to the lack of three phase power in certain regions. Machinery lies unused after the first mechanical failure, due to the lack of some simple maintenance or for the need of spare parts.

Utilization of capital intensive technology only tends to widen the gap between the rich and poor and increase foreign dependency rather than self reliance. Emphasis must be placed on "many small steps" . . . "on adopting what we already know is better" . . . not on buying the latest big machine (Grubbs, 1979).

The basic motives of the development effort are being reviewed, and the trend seems to be towards decentralized, low cost projects capable of indigenous production and support. Renewable energy resources, which in the past have not had a chance to compete with low cost fuel generation schemes, are receiving primary attention. It is recognized that dependence on renewable resources constrains a society to its natural limits and increases its stability. Energy planning is reflecting a more wide-spread realization that the westernized, wasteful society is not necessarily the solution for the LDC.

A closer look is being taken at the site specific cultural and economic factors, with emphasis on local participation to promote creativity and realization that self reliance is indeed possible. Public, private and international agencies seem to be turning to a "from the bottom up approach".

Appropriate Technology

The phrase "appropriate technology" is coming into more common usage. Since technology traditionally has connoted technical "hardware", there was a tendency for people to stress this aspect of "appropriate technology" at the expense of a more all-encompassing meaning.

One of the most important aspects of "appropriate technology" which must be emphasized, is its social and political dimensions. Relating this to LDC's, it is clear that attempts to improve the standard of living and the quality of life in such countries require more than just technological hardware artifacts. Introduction of modern capital intensive technology into an LDC requires approval and/or cooperation of the political power structure and it is this element which historically stands to gain the most benefits from such technology transfer. It is this same power structure which often does not have the haziest idea of the benefits of simple technologies in meeting the needs of their people.

The question then is, what current energy technology would be most useful to many LDC's for the long term? The technologies most of the world needs are those based on indigenous energy and human resources of the respective countries. The technology should be low in capital cost, small in scale, simple to maintain and operate, and, if possible, involve a renewable resource. It seems evident that small scale hydropower (SSH) mini and micro packaged hydro units is included in that technology.

An approach which stresses rural development programs is ideally suited (from an energy standpoint) in many LDC areas to SSH. The nature of the water resource itself includes a distributive element which makes it ideal for rural development.

Modest energy production could enable implementation of rural development programs aimed at increasing food production, preventing unemployment and urban sprawl through labor-intensive projects, offsetting population growth by development, and augmenting the role of health and education.

Hydropower technology is on the shelf, of proven feasibility both technically and economically, and presents a rational energy solution from the environmental viewpoint. It is a technology which could be useful to the Less Developed Countries for the long term, irrespective of the shift from abundant low-cost fossil fuel options or the development of more exotic alternate energy technologies. With its continuing replenishment and nondepleting characteristics, it remains one of the most attractive sources of energy. SSH sites are found in abundance in most mountainous regions and offer sensible possibilities for decentralized applications in LDC's.

CHAPTER II

HISTORY OF SMALL SCALE HYDROPOWER

Through the reaches of time, the nature of technology used to meet man's basic life-needs has depended on many of the same factors. The socio-economic, technical, religious, and philosophical doctrine of each specific cultural stage determined the nature of its technological tools. The technology available, in turn, helped to shape the existing and emerging societies.

The major technological choice has always been that of power, especially motive power. For it is the nature of the prime mover, wity its wide varying dimensions, that determines the size of units of wood, metals, or other materials used by craftsmen and laborers.

Prime movers separate technological history into five stages, the first two revolving about the use of manual and bestial labor. Work efficiencies in these stages were extremely low, and life often required working constantly just for survival. The beginning of the third stage is marked by the introduction of small scale hydro systems, usually applied to the constantly recurring burden of corn grinding.

The most primitive water mill is of the Norse horizontal-type which probably originated in the hilly regions of the near east as far back as 65-100 B.C. The mill utilizes a vertical shaft or axle bore at its lower end, and a small horizontal wheel composed of a number of scoops or paddles (see Figure 1, Forbes, 1956). The first literary references to hydropower are found in a Greek epigram dating to the 1st century B.C., in a poem by Antipater of Thessalonica (Forbes, 1956):

> Cease from grinding, ye women who toil at the mill; sleep late, even if the crowing cocks announce the dawn. For Demeter has ordered the nymphs to perform the work of your hands, and they, leaping down on top of the wheel, turn its axle which, with its revolving spokes, turns the heavy concave Nisyrian mill-stones.

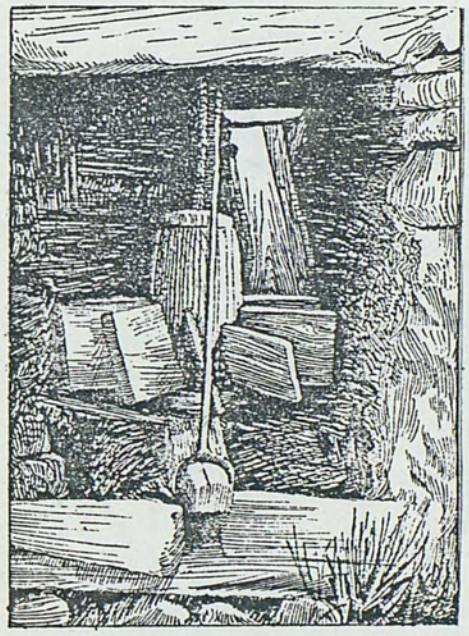

Figure 1. A water mill of the Norse type used in Shetland until recently. The blades were lifted clear of the stream by the rope.

The use of the Norse mill gradually spread northward, eastward, and westward. It could produce up to one-half horsepower but could only be made to work with small volumes of high-velocity water, thus its use was restricted to hilly rather than valley regions.

No The Norse mill inspired the Vitruvian mill, engineered in the first century B.C. by the Romans. The Vitruvian mill utilized gearing and a vertical undershot wheel to achieve better speeds and efficiencies. These wheels were capable of developing up to three horsepower which allowed for a wider variety of applications (see Figure 2, Forbes, 1956).

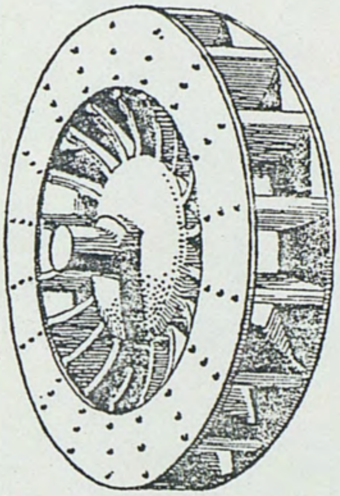

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Figure 2. Model of an undershot Roman water wheel from Venafro, near Cassino, Italy. It is reconstructed from impressions left in lava that had flowed over the mill. Scale 1/30.

yes The use of gang labor methods utilized during Roman times, however, seemed to suppress the use of the water wheel, and it was not until the fall of Rome that hydropower technology began to spread.

yes The use of the Vitruvian mills spread rapidly northward and eastward in the Fifth and Sixth Centuries to France, Germany, England, Spain, Wales and other European countries. Meanwhile, the horizontal Norse wheel was spreading in use to China, Syria, Lebanon, Romania, Greece, Denmark, Norway and Sweden.

yes The public-works minded Spanish Moslems had a great interest in dams and helped to advance the current day technology a great deal. The Monastic orders of 10th Century Europe also had much to do with the spread of water wheel technology, so that by 1100 A.D., the water wheel was well established in the rural societies of many cultural regions. The wheel was being used for grinding, sawing, pumping water and air, hammering, spinning, and a multitude of everyday labor tasks (Ermenc, 1978). 980 b

no The Doomesday survey of William the Conqueror (1086 A.D.) recorded 5624 water mills in rural England. It is estimated that at this time there averaged 3-4 mills per mile of English stream (Hyde, 1978).

yes Towards the end of the Middle Ages, the transition from the undershot to the more efficient overshot wheel further expanded the capabilities of water power systems (see Figure 3, Stowers, 1957).

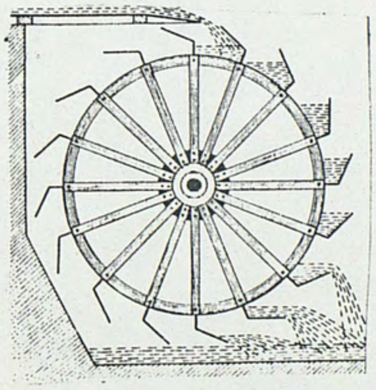


Figure 3. Typical overshot water wheel with side-shroudings removed. C 1600.

Yes By 1300 A.D., use of water power technology had expanded for such uses as rag pulping for paper, hide beating, silk spinning, mining, and improved grinding, hulling and sawing.

No Thirteenth century Russian literature describes governmental decrees concerning the uses, construction, and ownership of water mills. Despite political problems associated with the feudalism of the times, Russian "engineers" were able to keep abreast of European technology, and utlized water power in much the same manner as the Europeans.

Yes By the Sixteenth century, hydropower had become the center of everyday life, and was taken for granted much as today's electricity is. New towns were planned and built with respect to the power potential of specific streams. Emphasis was placed on local industrial applications, and each town generally had at least two or more mills.

Yes The Seventeenth century showed some research and improvement of water wheel efficiencies. Water wheel technology was in such common usage as to allow for such diverse applications as jewel and cosmetic trades. The number of water wheels in Europe was reckoned in the tens of thousands, and their construction had become the refined art of the "Millwright".

No In South America, water wheel technology had become widely employed in gold and silver mining. In Potosi, South America, after the mines had played out the easier ore veins, large dams were built to provide the additional mining power needed. One of these dams failed in 1626, wiping out 126 of 132 water mills, and killing 4000 people (Smith, 1971).

Yes The mid-Seventeenth century brought the pilgrims to the Americas and with them the overshot water wheel technology of the times. By 1647 in Saugus, Massachusetts, a metal mill was producing up to 8 tons of merchant iron bars per week (Ermenc, 1978).

yes Much progress was made in hydropower research during the eighteenth century, most notably the work of John Smeaton, who accurately compared the efficiencies of overshot and undershot wheels, and initiated the use of metals in water wheel construction (Rouse, 1963). A great increase in floating mills was noted, and water wheel technology found new uses in providing arms and powder, glass manufacturing, coining and printing (Stowers, 1957).

No Euler, in 1754, developed the theory of reaction machines, and expressed the first basic relationship of reaction turbines (Rouse, 1963).

Yes The nineteenth century brought log-scale advancements in hydropower technology with the development of the turbine (see Figure 2 4).

No The sixth census of the United States gives the number of various mills in use in 1840 (see Table 1). An 1885 census reported over 900 mills along the 100 mile long Merrimac, turning out such household products as cutlery and edge tools, brooms and brushes, furniture, paper lead, clocks, washing machines, fertilizers, gunpowder, agricultural tools and a wide variety of

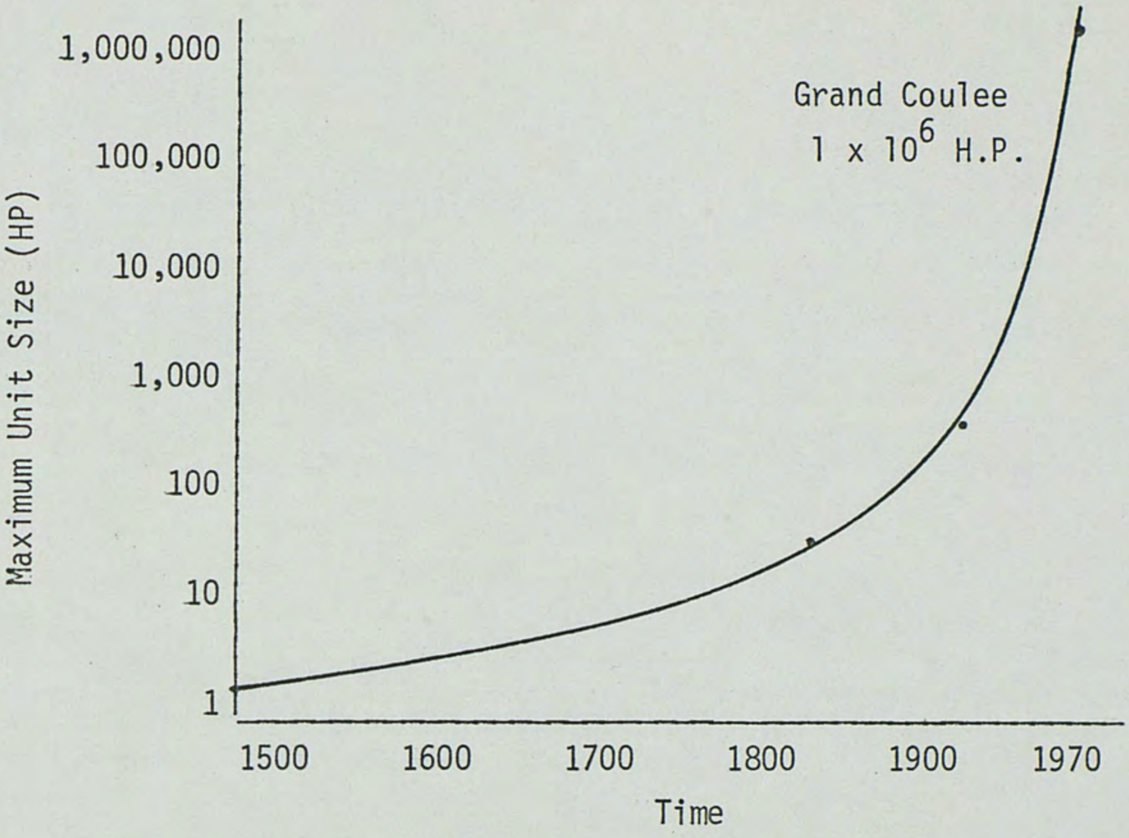


Figure 4. The progress of waterpower technology.

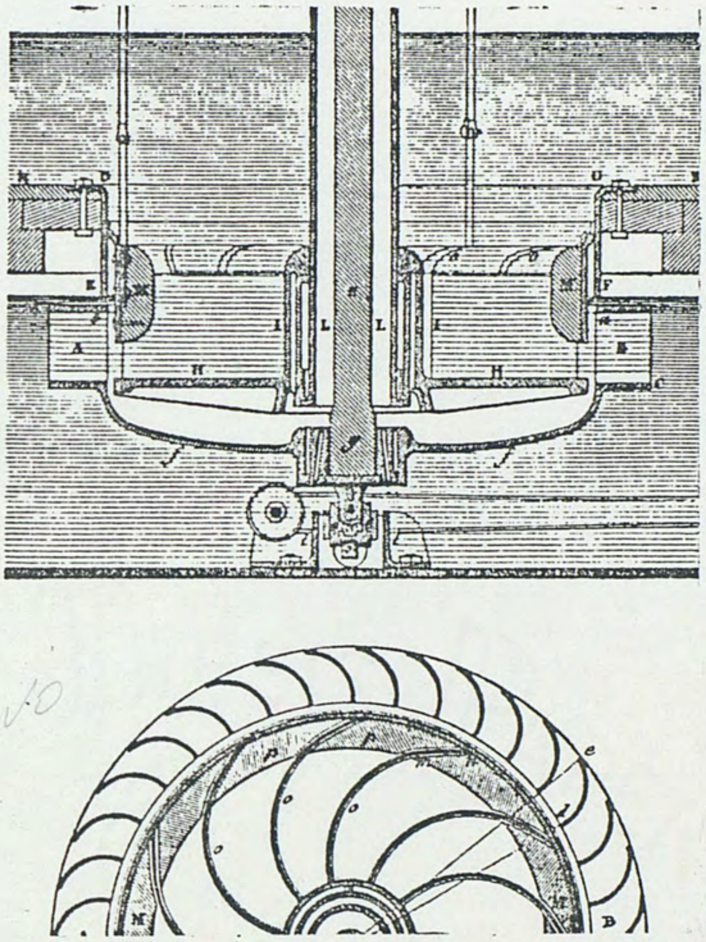
other useful products (Ermenc, 1978). The number of mills counted in service at that time totaled 60,518.

yes The first hydraulic turbine worthy of the name was developed through the successive efforts of two French engineers, Claude Burdin, a professor at L'Ecole des Mines, and his student, Benoit Fourneyron. Burdin was a theoretical man, whose work inspired the practical genius of Fourneyron to produce a successful experimental turbine unit in 1827. Fourneyron eventually built more than 100 turbines, mainly of the free efflux type (see Figure 5, Rouse, 1976).

TABLE 1

COMPENDIUM OF THE SIXTH CENSUS - WATERMILLS IN 1840

State	Mills					
	No. of Flouring Mills	Barrels of Flour Manufactured	No. of Grist Mills	No. of Saw Mills	No. of Oil Mills	Value of Manufactures ($)
Maine	20	6,969	558	1,381	20	3,161,592
New Hampshire	3	800	449	959	9	758,260
Massachusetts	12	7,436	678	1,252	7	1,771,185
Rhode Island			144	123		83,683
Connecticut	7	15,500	384	673	57	543,509
Vermont	7	4,495	312	1,081	20	1,083,124
New York	338	1,861,385	1,750	6,356	63	16,953,280
New Jersey	64	168,797	509	597	21	3,446,895
Pennsylvania	736	1,193,405	2,554	5,389	166	9,424,955
Delaware	21	76,194	104	123		737,971
Maryland	189	466,708	478	430	9	3,267,250
Virginia	764	1,041,526	2,174	1,987	61	7,855,499
North Carolina	323	87,641	2,033	1,056	46	1,552,096
South Carolina	164	58,458	1,016	746	19	1,201,678
Georgia	114	55,158	1,051	677	6	1,268,715
Alabama	51	23,664	797	524	16	1,225,425
Mississippi	16	1,809	806	309	28	486,864
Louisiana	3		276	139	50	706,785
Tennessee	255	67,881	1,565	977	26	1,020,664
Kentucky	258	273,088	1,515	718	23	2,437,937
Ohio	536	1,311,954	1,325	2,883	112	8,868,213
Indiana	204	224,624	846	1,248	54	2,329,134
Illinois	98	172,657	640	785	18	2,417,826
Missouri	64	49,363	636	393	9	960,058
Arkansas	10	1,430	292	88	1	330,847
Michigan	93	202,880	97	491		1,832,363
Florida Territory			62	65	2	189,650
Wisconsin Territory	4	900	29	124		350,993
Iowa Territory	6	4,340	37	75		95,425
District of Columbia	4	25,500	4	1		183,370
TOTAL	4,364	7,404,562	23,661	31,650	843	76,545,246



NO

Figure 5. Fifty horsepower Fourneyron turbine, 1832.

yes Boyden (1844) recognized that an additional artificial head could be created if the tailrace velocity were reduced, and by 1855 patented a suitable diffuser for application to Fourneyron's turbine.

yes The turbine demonstrated superiority to the water wheel in all respects. It could utilize lower as well as higher heads, and developed better than twice the power at ten times the speed of the conventional water wheel.

No By 1838, news of Fourneyron's success had reached the U.S. and some were installed according to his original specifications. It was soon recognized, however, that the Fourneyron turbine suffered from the divergent, outward flow produced by the guide vanes (Rouse, 1976).

No In 1838 to compensate for this, Samuel B. Howd patented an inward flow turbine, and again in 1842 an outward flow design he felt superior to Fourneyron's. In 1844, Uriah Boyden also designed an outward flow turbine which, accompanied by his flow diffuser, achieved a 78% efficiency rating (Rouse, 1976).

No Changes came very quickly. Blacksmiths and foundrymen found the turbines easy to make and profitable, and many new improvements and patents ensued.

No Many times, the "new" turbine would assume the name of its builder or improver. Most notable in this respect is the work of James Francis, Chief Engineer for The Proprieters, a group of manufacturing companies on the Merrimac River. Equipped with the patents of Howd and Boyden, he built in 1847 a center vent turbine which used a conical approach, inclined guide vanes and tailrace diffuser (see Figure 6, National Center for Appropriate Technology, 1979). Although his first turbines had low efficiencies, in several short years, his designs were tested to have up to 80% efficiencies (Rouse, 1963).

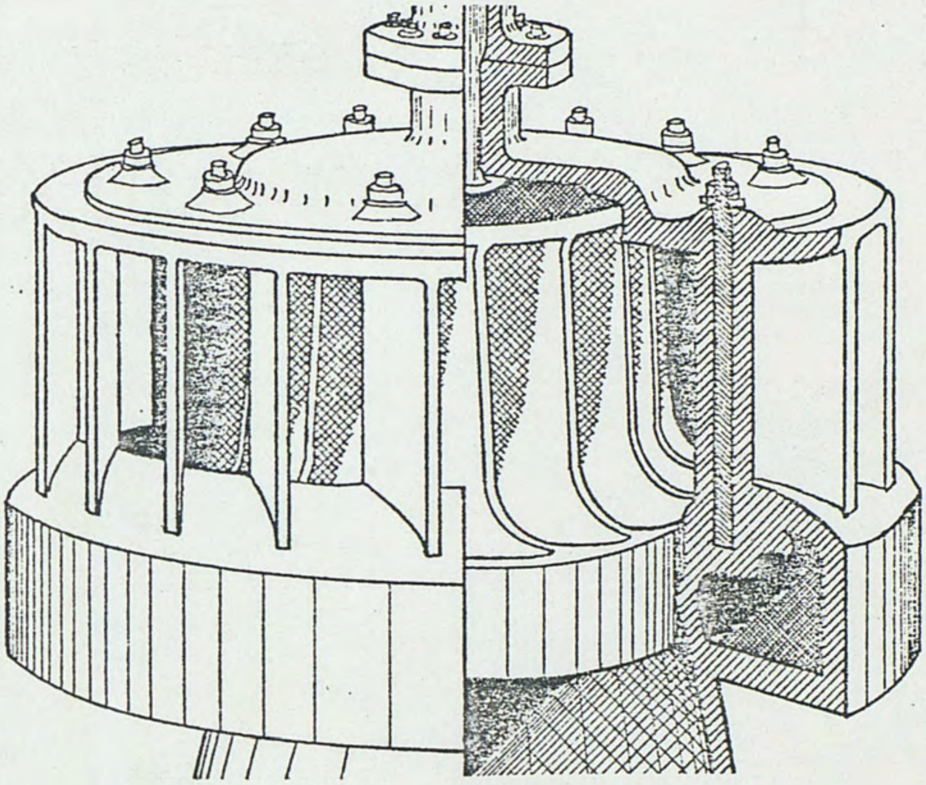


Figure 6. Francis turbine runner.

No Francis and Boyden continually refined their designs, and with the help of trial and error work done by John B. McCormick, formed the forerunner of the mixed flow unit.

Yes In the western U.S., where large heads were available, attention turned to impulse type turbines. The most common impulse wheel is the Pelton wheel, which utilizes split buckets to discharge the jet flow. Pelton tested a wide variety of impact buckets and patented his split-bucket design in 1880 (See Figure 10, Rouse, 1976).

yes Most important to water power technology during this century was the development of the electric generator. One feature of supreme significance was that power could now be transmitted over long distances. The size of hydropower units increased greatly, and in the late nineteenth and early twentieth centuries, large dams for hydroelectric facilities began to appear.

yes Since 1900 more dams have been built than were already standing up to the turn of the century. Turbines were increasing in size and by 1925 tens of thousands of turbines developing up to 500 horsepower were working throughout the world. By 1950, large projects capable of producing thousands of horsepower were becoming quite common throughout the world (see Table 2).

yes Twentieth century improvements in turbine designs also include the development of the propeller type turbine, generally used for large installations of up to 50 MW. The fixed blade propeller turbine appeared to give the answer to the problem of low head generation at high speeds. The Kaplan turbine of 1925 varies the propeller blade angle to achieve better part-load efficiencies.

yes A new design of the impulse turbine was presented by Eric Crewson, Director of Gilkes, in 1920. The impact of his development was that a jet of larger diameter could be applied to a runner of the same mean diameter as the Pelton wheel, giving higher speeds without great efficiency losses (Wilson, 1956).

yes Water turbine governors changed vastly during mid century and are now high-capital, sophisticated pieces of control equipment.

TABLE 2

HYDRO-ELECTRIC POWER DEVELOPMENT IN SELECTED COUNTRIES, 1927-1950

Country	Power-station capacity (MW)			Increase on 1927 (per cent)
	1927	1933	1950	
Algeria	Nil	-----	111	-----
Austria	243	642	1,250	410
Belgium	Nil	-----	24	-----
Brazil	373	-----	1,536	310
Canada	4,590	5,191	9,212	86
Chile	85	-----	387	355
Finland	164	288	667	300
France	1,490	2,700	4,739	220
Germany (including Saar)	945	1,269		-----
Germany (West)			3,398	-----
Greece	6	6	34	466
Iceland	Nil	-----	30	-----
Japan	1,305	3,684	7,549	475
New Zealand	45	298	633	1,300
Norway	1,420	1,740	3,008	117
Portugal	7	-----	138	1,900
Spain	746	1,250	-----	-----
Sweden	1,000	1,156	2,566	256
Switzerland	1,380	1,882	3,057	320
United Kingdom and Irish Republic	186	-----	793	325
United States of America	8,744	11,208	19,733	125

After 1950, with the advent of large thermal and hydropower stations, rural electrification and better transportation systems led to a world-wide decline in the use of small scale hydropower, especially in the industrialized nations. Only recently has interest been rekindled in its use for rural electrification and small scale industries. Thus, the use of small scale hydropower as a prime mover has gone through a complete cycle of existence, and may again be on the upswing.

CHAPTER III

THE POTENTIAL IMPACTS OF SSH SYSTEMS IN LDC'S

Quality of Life

As noted earlier, the motivation for an energy development scheme is to increase the overall quality of life. For the rural developing community or village, the life quality issue of greatest importance is generally that of food provisions.

Estimates of malnourished persons in the third world range from 550 million to over 1 billion. Population projections suggest that by the year 2000, the world-wide need for farmlands will have increased by 1 billion acres. Further, against these new lands must be balanced the loss of existing agricultural lands due to factors such as urbanization, industry, salt water intrusion, erosion and over-cultivation.

The major thrust of new agricultural land development involves the transport and use of water. On one extreme, the pumping power provided by a small scale hydro system could irrigate the dry lands, on the other it could relieve flooded wetland conditions. The availability of irrigation water from pumped storage ponds could feasibly allow double or triple crop harvests, since it could provide water that is normally not available during dry seasons of the year. Possibilities include shallow well pumps or even short distance transport of water to dry regions. Proper water conditions not only help the basic nature of plant growth, but more importantly, they allow the use of nitrogenous fertilizers and pesticides which increase the farmer's crop yields.

Increased production levels can lead to increased nutritional levels and worker productivities. Resulting surpluses can be marketed to help pay for power and other agribusiness equipment.

Small irrigation developments can also lead to provision of a dependable domestic water supply and treatment works, which would serve to reduce outbreaks of water borne diseases. Other sanitation measures enacted through SSH power could include showers and latrines, food refrigeration, and improved health care technologies and programs. The resulting increased level of health could further raise worker productivity and life expectancies.

Energy production on the rural scale serves several educational functions. Increased communication with the outside world, such as radio, news reports, nighttime reading, and leisure entertainment can be important transitions, depending on the level of development sought. The importance of leisure entertainment was attested by the 1963 General Electric survey team: "Power plant was worth 100 policemen" (General Electric, 1963). The G.E. survey team witnessed that the showing of films at night greatly reduced local criminal activities by relieving the monotony of boring nights.

NO The offshoot of development efforts related to small scale hydro implementation will most likely include educational system improvements. The economic development could result in increased educational opportunities and development.

NO Recent evidence in China, Egypt and Costa Rica indicate that educational and economic levels also have an inverse effect on population growth (Cortes - Comerer, 1977). It is generalized that birth rate is linked with girls' education levels and village attitudes.

NO Locally, increased education can lead to the development of an indigenous infrastructure, with labor-intensive projects aimed at better utilization of indigenous resources and promotion of a positive attitude towards self sufficiency. A small scale hydro system can provide the impetus for such self-organization in a small way, by requiring timely maintenance and the delegation of certain responsibilities, such as lubrication, cleaning, monitoring, etc.

y On the environmental side, due to the non-polluting nature of hydropower, the development of SSH projects leads to a decrease in the potential impacts of other energy sources. It has been predicted that the emissions from the development of traditional industrialized energy sources could result in catastrophic air pollution episodes (Wark and Warner, 1976). Finally, modest energy sources enable the better undertaking of the basic processes (e.g., sawing, milling, grinding, etc.), that lead to an increase in production efficiency, and reduction in drudgery resulting in a higher quality of life and enhancement of real economic growth.

Economic Development

One cannot identify quality of life exclusively with the economic factors such as per capita income and gross national product, since many important non-economic factors are also involved. Nevertheless, it is clear that substantial economic growth is needed within the LDC group. Furthermore, it is obvious that in order to significantly lessen the economic gap, the LDC's will have to sustain long term real economic growth at annual rates higher than those prevailing in more developed countries. Such economic growth will clearly require increases in energy consumption. Estimates show that the LDC's would have to sustain economic growth rates of 5-7% for as long as 75 years or 10-12% for 25 years to close the present socio-economic gap (Thomas and Jawaharlall, 1979).

It is important to note that the value of this economic growth is highly dependent on the equal distribution of income and preservation of political freedoms.

SSH systems can have both a positive and negative impact on developing countries' economic growth. On the positive side, they ultimately result in a reduction of food, energy and other imports. However, since rapid economic growth is usually a function of centralized industrialization, the decentralization effect of SSH systems tends to slow growth. SSH can help the development effort in both the rural and the industrialized sectors of the LDC's. The provision of electricity in rural sectors will generate a demand for goods and services which can be met by industries and workers from the industrial areas. This cooperation will help lead to an increased national stability and further self reliance, and a multitude of other benefits.

If engineers and scientists are to be maximally effective in helping to solve the development problem in advanced, as well as emerging nations, they must further their understanding of how to work with the social, economic and political processes, both in the rural as well as industrialized sectors.

It seems that emphasis on the transfer of SSH technology is consistent with the recent developmental policy shift from goods to people, resulting in a general "quality of life" improvement in the LDC's. Not only do SSH systems fit well into the distributed rural development process, they can also be applied to centralized locations with good success.

Project Scale

The scale of an energy project, especially in the developing country, has a direct bearing on many socio-economic factors and the future life-style of the local population. The costs associated with the civil works of large systems may exclude them from use by the poorer societies. In many cases, even the costs of electrical hookups can exclude some families from service. Electricity cannot profoundly affect the economics of developing nations unless it is extremely cheap, i.e., available to all equally. Often the acquisition of even a small amount of capital can be an insurmountable task. However, the "many small steps" approach offers a direct advantage here. Small amounts of capital, which may be more available, can be used in a positive manner, as "building blocks" towards an overall goal.

The size of a project can also restrict the choice of technology utilized. A brief comparison of various energy technologies available versus scale is presented in Table 3 (Kersten and Harper, 1980).

Notice that hydropower is unique among the power generation schemes in that it is not technologically restricted by scale. Small projects using water flow as a direct source of energy can be attractive in economic terms even where there is no possibility for large scale development.

Project scale also affects such issues as environmental quality and public safety. Large scale systems, especially in the case of hydropower, present much greater safety risks than small systems.

TABLE 3

PRESENTLY AVAILABLE ENERGY TECHNOLOGIES VS. SCALE

Technology	Scale			
	Large ≥ 100 MW	Small 10 ≤ MW ≤ 100	Mini 1 ≤ MW ≤ 10	Micro MW < 1
Nuclear	*			
Coal	*	*		
Oil	*	*		
Gas	*	*		
Fossil Engine		*	*	*
Solar Thermal		P		
Solar Photovoltaic				*
Solar Biomass		P		
Wind		P	P	*
Hydro	*	*	*	*

P = in pilot plant stage

* = Technology proven and available

CHAPTER IV

ENERGY DEMANDS IN THE RURAL LDC

Many of the rural societies of the Lesser Developed Countries are isolated from the centralized electrification schemes in their countries, or cannot afford to pay for the electricity when it is available.

The World Bank has estimated that about 12% of the rural LDC poor were served by electricity in 1971. But fewer small villages were electrified than larger, and only a small percentage of villages actually "served" had hookups (Cecelski, 1979). The vast majority of domestic energy needs have been and continue to be supplied by traditional sources, such as wood, agricultural residues, and dung. This energy use pattern has several socio-economic and environmental implications worth considering.

The form in which energy is used is often closely related to the tasks it is designed to perform. The use of the traditional fuels as a major energy source suggests that the majority of energy used is for meeting basic needs, i.e., cooking, lighting, and space heating.

Not only are the traditional fuels highly inefficient themselves, but as they become more scarce, the time spent collecting them increases. Often one or more members of a family must spend each entire day in search of fuel.

The use of traditional fuels has environmental consequences, also. Widespread deforestation is becoming a major problem, compounded by massive erosions as in the hills of Nepal, where the need for expansion of agricultural lands has caused the farmers to clear and terrace the hillsides, which are then washed away by heavy monsoon rains (National Academy of Science, 1976).

The majority of energy used in rural LDCs' small scale industries is also from traditional sources. Wood, charcoal and agricultural products are burned in furnaces and open fires in the soap, textile, metals, and foods industries. In some cases, the use of these fuels can be "appropriate" such as in Ghana, where massive timber harvests leave up to 70% as waste usable for domestic and non-domestic uses, providing nearly half of the entire nation's needs (Powell, 1978). However, electricity in most cases provides a much better alternative. It is much more adaptable to agricultural functions ranging from pumping water to fertilizer production and other small scale agribusiness. Electricity not only supplies the needed energy, it also frees the manhours spent in search of fuel to allow for use in other productive means. This time can be spent expanding farmlands, harvesting crops, and preparing seed beds. Benefits are also compounded by increased production and processing efficiencies. Domestically, electricity can improve the efficiency of the basic processes such as cooking, heating, and lighting by using more efficient equipment.

The domestic and residential energy consumption rates of several rural poor countries are given in Table 4 (Revelle, 1978). The proportion of total rural energy used for commercial vs. non-commercial purposes varies from country to country, and, due to the nature of the fuel sources used, data are highly speculative. Estimates of fuel wood consumption can vary up to factors of ten or more, and determinations of heat contents derived from mass quantities of organic matter are sketchy at best. However, it is generally believed that domestic uses of energy outweigh commercial uses, comprising from 50% (rural and urban) up to 80% of the total energy used in rural areas.

The difference in total energy consumption and production for several LDC's is depicted in Figure 7. Notice that most of the countries' already low consumption far outweighs their production. The need for energy is evident for commercial as well as domestic applications. Introduction of a new energy source should be effected to serve an equitable benefit, that is, to increase the quality of life for many, rather than a select few. SSH can help some, however, it is not the total answer (Muiga, 1979).

It is clear, however, that a significant improvement in this deficit is attainable through hydropower development. Table 5 (Hubbert, 1969) shows the world's water power potential by regions. Also shown is the amount which is presently developed in each region. The total world potential is 2,857,000 MW, of which only 152,000 MW (little more than 5%) has been developed.

TABLE 4

RURAL ENERGY DEMANDS (KWH/DAY/CAPITA) FOR SELECTED LDC'S

	India (1)	China, Hunan (2)	Tanzania (2)	Northern Nigeria (2)	Northern Mexico (2)	Bolivia (2)	Bangladesh (6)
Human Labor	0.77	0.74	0.74	0.71	0.87	0.82	0.77
Animal Work	1.16	1.07	----	0.15	1.51	2.12	1.16
Fuel Wood	3.32	15.88	17.48	11.91	11.25	26.48	1.08
Crop Residues	1.35		----	----	----	----	1.91
Dung	0.77		----	----	----	----	0.66
Coal, Oil, Gas and Electricity	0.27	2.38	----	0.02	22.98	----	0.31
Chemical Fertilizers	0.26	0.39	----	0.06	6.18	----	0.16
TOTAL ALL SOURCES	8.25	20.46	18.22	12.85	42.79	29.43	6.02

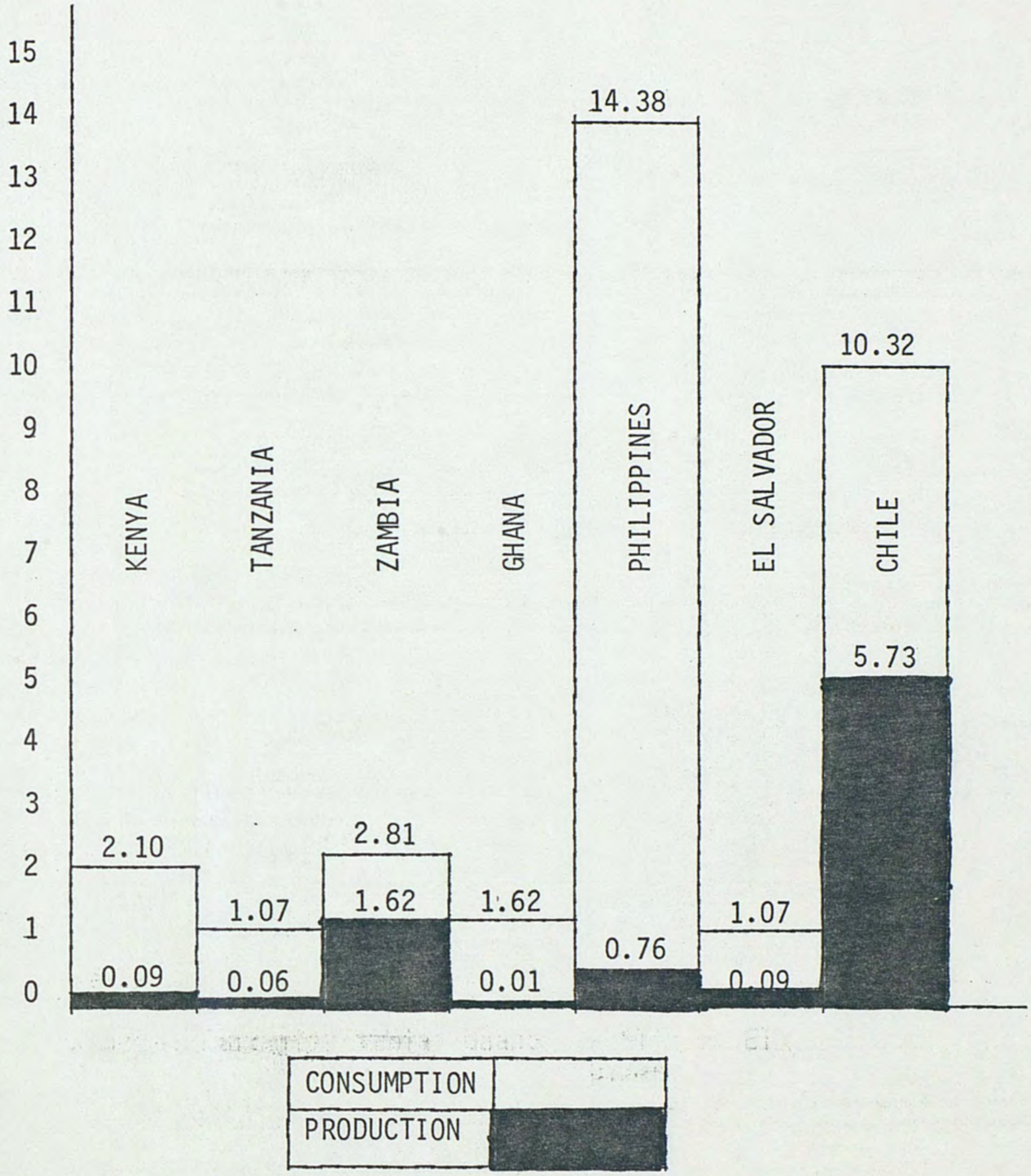


Figure 7. Selected LDC's energy consumption and production in millions of metric tons of coal equivalent.

TABLE 5

WORLD WATER-POWER POTENTIAL

Region	Potential (10^3 MW)	Percent of total	Development (10^3 MW)	Percent Developed
North America	313	11	59	19
South America	577	20	5	
Western Europe	158	6	47	30
Africa	780	27	2	
Middle East	21	1	--	
Southeast Asia	455	16	2	
Far East	42	1	19	
Australasia	45	2	2	
USSR, China and satellites	466	16	16	3
TOTAL	2,857	100	152	

Notice that high potentials exist in Africa and South America, both fossil-fuel deficient continents. Africa has a potential for 780,000 MW and South America has 577,000 MW.

If we look at the growth of total world hydropower resources through time, we see the typical logistic "S" curve (See Figure 8).

We are presently in the log phase of this growth, with much room for future improvement. Hubbert (1969) predicts that the world should come close to a near-ultimate utilization of its hydropower resources by the mid- to late-twenty-first century.

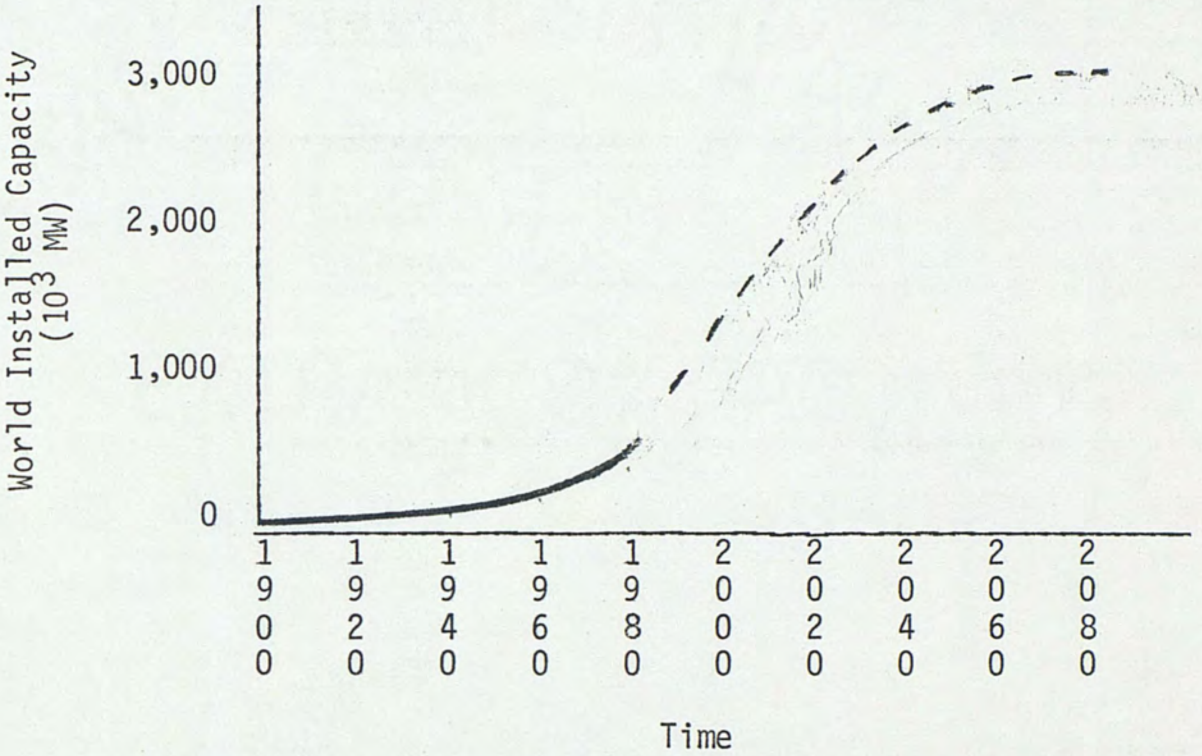


Figure 8. World hydropower installed potential with time.

Once supplied with electricity, what will happen to the energy use pattern of rural people will be difficult to predict. Energy increases can lead to accelerated use and waste by extending the range of services available, based mostly on increases in personal economic income. If incomes rise, the purchase of appliances could well result in an exponential demand growth function.

However, the more efficient use of energy atainable through these appliances could tend to offset the demand growth. In the rural and poor areas, energy demand has been shown to decrease in the short run, if it changes at all. In the long run, however, energy use will undoubtedly rise, but to what degree is uncertain. It has been estimated that, in order to secure an adequate life with some opportunity for improved health and well being, total consumption for the world's LDC's will have to at least triple (Cecelski, 1979).

When estimating the electrical demand that will be generated by a specific community development, the use of past data is not recommended. A better approach would be to predict the specific uses that the SSH system will serve. Locally or regionally, specific estimates can be derived for commercial and residential uses, to give per capita consumption.

These demand projections will be highly dependent on the level of development that is sought or achieved. Based on income, various residential and commercial appliances may or may not be used. A social classification system can be derived, based on these appliances, and their uses, as seen in Table 6.

Class I development can be described as incipient, with very limited personal income. This class would be associated with the provision for the most basic of needs.

Class II development would be just a step above Class I, including possible communal purchases of a meal grinder, refrigerator, more lights, more water pumps, and a more efficient stove, etc.

TABLE 6

RESIDENTIAL DEVELOPMENTAL CLASSIFICATION SYSTEM BY APPLIANCES

Appliance	Class I	Class II	Class III	Class IV
Light Bulbs	*	*	*	*
Meal Grinder		1	*	*
Water Pump	1	2	2	2
Refrigerator		1	2	*
Heater			2	*
Fan			2	*
Hot Water Heater			1	*
Radio	2	*	*	*
Television			1	*
Cooking Device		1	*	*
Washing Machine				2

* May be found in every home unit

1 May be a communal unit

2 May be communal or sparsely distributed

Class III development is typified by a widespread availability of the basic appliances and the appearance of some of the " creature comfort" appliances. Community funds may be available for the building of showers with hot water, a film projector or television set.

Class IV development can best be described as "sub-industrialized", that is, the basic creature comforts are evident in every home. The use of labor saving devices and a wide variety of industrial tools starts and spreads in this stage.

Each class of development can be associated with range of per capita demands, based on the appliances used and the following factors: Community Cooperatives and Local Industry

Community Cooperatives

In Class II or III development, every home may not have a refrigerator, freezer, or hot water heater. However, community cooperative ventures such as communal showers, freezers, etc., may exist. Such demands must be distributed over a larger population to arrive at a reasonably accurate per capita figure.

Local Industry

Based on the level of development, certain small or medium scale industries will exert electrical demands, also. The same type of classification system as above can be arrived at for the rural industrial sector. The many electrical demands for Class IV industry would be difficult to list. For Classes I, II and III, Table 7 may be representative.

These uses are of course just examples, for each development effort will be site specific. For a given community, this type of sensitive evaluation, accompanied with the power ratings and average use-hours per tool, can help assure that a proper size unit

TABLE 7

INDUSTRIAL DEVELOPMENT CLASSIFICATION
SYSTEM BY TOOLS

Tool	Class I	Class II	Class III
Water Pump	*	*	*
Shop Drill		*	*
Skill Saw			*
Saw Mill		*	*
Table Saw			*
Radial Saw			*
Lathe			*
Drill Press			*
Lift Crane			*
Air Compressor			*

has been chosen. A classification system such as this would fit nicely into a national/regional development plan, whether for SSH or any other small scale energy development. Based on the appliances and tools chosen for Classes I and II, the following ranges of electricity demands were arrived at:

Class I,II - up to 100 KWH/Capita/Year
Class III - 100 to 1000 KWH/Capita/Year
Class IV - greater than 1000 KWH/Capita/Year

For instance, for Class II development the following home units may exist:

1. Seven persons per family, 1000 person village
2. Three light bulbs, 60 watts each
3. One radio, 50 watts, per 100 people

The following community appliances may be present:

1. Two water pumps, 1000 watts each, per village
2. One meal grinder, 200 watts, per village
3. One refrigerator, 350 watts, per village

The following small scale industrial tools may be used:

1. Shop drill, 150 watts, two per village
2. Timber saw, 2000 watts, per village

Based on these tools and appliances, the total demand is calculated as follows:

Light Bulbs: 180 watts x 1200 hrs/yr ÷ 7 persons = 30.9
Radio: 50 watts x 1200 hrs/yr ÷ 100 persons = 0.6
Water Pumps: 2000 watts x 600 hrs/yr ÷ 1000 persons = 1.2
Meal Grinder: 200 watts x 500 hrs/yr ÷ 1000 persons = 0.01
Refrigerator: 350 watts x 1800 hrs/yr ÷ 1000 persons = 0.6
Shop Drill: 300 watts x 25 hrs/yr ÷ 1000 persons = 0.01
Saw Mill: 2000 watts x 120 hrs/yr ÷ 1000 persons = 0.24

TOTAL: 32.71 kwh/cap/yr, or 3.73 watts/cap/yr

Package unit sizes for each class would probably be around (per 1000 people):

Class I - 1-10 KW
Class II - 10-100 KW
Class III - 100-1000 KW
Class IV - 1000 KW and up

Again, these ranges are mere generalities, the need for site specific studies is evident.

The 1963 study on rural power systems by General Electric suggests that a minimum of 50 KW would be required per village installation (2,000-3,000 people). They recommend excess capacities for future growths, and suggest that local hydro is the most appropriate equipment for power generation. Their survey concluded that there is a definite need for package production of 75-100 KW units for rural applications.

CHAPTER V

yes SMALL SCALE HYDROPOWER - SYSTEM NEEDS

No + The many factors associated with the in-house production of, and installation and maintenance of hydropower equipment require careful consideration. Care must be taken to match system needs with the site specific resources and needs of each locality, while attempting to optimize economics with the production or purchase of a standard size unit. Regional studies incorporated into a national energy plan would greatly aid in deciding upon the best unit size necessary for each country or region.

No + Indigenous Production of Packaged Units

The electrical demand that will be exerted and its uses such as lighting, space heating, irrigation pumping, commodity processing, sanitation and communications must all be examined for present and future development levels, as seen earlier.

No Based on the forecasted electrical demands, a specific size (KW, HP) generating unit can be chosen. The type of turbine unit best suited for this size will depend on the physical-hydrologic constraints, such as head, flowrate, and general topography.

Local physical conditions can be grouped to form a regional plan, with each region having relatively homogeneous conditions, thus allowing for the possibility of local production of a number of standard size units of the same turbine type. For instance, a very mountainous region would provide numerous sites for high head, low flow generation, and a number of impulse turbines could be produced in this region. In regions of high flow, low head, a shop can be set up to produce a number of propeller type turbines.

The production of small scale hydro by local small scale industries would be very desirable. A small scale industry such as SSH would benefit the local population through better employment opportunities, and a more equitable income distribution. They are also beneficial on the national scale as they tend towards decentralization and help to create investor opportunities and capital formation.

A "small scale industry" is generally defined as having somewhere around ten employees, one-person management, and limited capital. Small scale <u>turbine</u> production could fit into this category, but if generators, penstocks, and other electrical equipment are also to be produced, SSH production would probably not conform to the traditional "small scale" definition.

Production of packaged hydropower units would probably be best classified as "medium" scale industry. The possibilities for a rural industry still exists, but the wide range of technical expertise required probably excludes a one man supervisory structure, and the acquisition of substantial capital might be difficult.

Full scale production, especially initially, would tend to be highly capital intensive, due to the wide range of services (mechanical, electrical) needed, and the nature of the tools and skilled labor needed. More feasible for the rural setting would be a small scale assembly plant. Small scale industry could certainly handle the assembly of pre-sized, pre-machined, pre-wound parts for a packaged unit. In this case, one skilled person could probably manage the operation, and at a much reduced overhead. The success of each small scale assembly plant would revolve largely around the managerial skills and energetic drive of the manager, who probably will own the business. He must have the ability to handle not only the technical, economic, and social problems, but he must also be able to coordinate his activities with various sectors of the regional, or national infra-structure in meeting their overall development goals. He also must deal with materials supply and scheduling, vocational training, marketing and other non-technical tasks. The scope of skills and manpower required, however, is not beyond the resources of many of the lesser developed countries.

The costs involved with the production or assembly of package units will depend on the local availability of tools, materials and skills, and transportation costs.

Yes

Indigenous Support

Although there is a general lack of mechanically trained individuals in the rural LDC setting, village people show the capacity for learning enough to maintain their equipment. This has been evidenced where diesel or gasoline engines have been installed for power generation in India and several South American countries (General Electric, 1963). Of course, simplicity of technology greatly aids in this respect, and if regional production is enacted, the necessary expertise will be close at hand.

Small scale hydro systems tend to be low maintenance, especially if the system is designed with LDC skills in mind. A rural, small scale system would probably only require once or twice yearly simple maintenance, such as lubrication and cleaning of trash racks, etc.

Y

Electrical Transmission Service

Y Many of the developing countries have established voltage and frequency standards, usually 220 volts at 50 cycles. Rural electrification, even in highly isolated plants, should also reflect this standard.

NO Three phase generation is recommended for costs and transmission ease. Transmission lines can represent a major portion of the capital cost involved, and should be minimized, if possible. Since D.C. transmission requires larger cables than A.C., D.C. generation, with inversion to A.C. before transmission, is recommended.

y A water turbine, depending on its generator, can produce either A.C. or D.C. power, as desired. Since power demand will fluctuate both daily and seasonally, some type of regulation is generally required. Either the excess power must be stored or used, or the flow of water and thus the turbine output must be regulated. This regulation requirement largely helps determine whether A.C. or D.C. current is to be produced.

In producing A.C. current, the flow of water must be regulated because A.C. cannot be directly stored, especially in isolated plants. Production of D.C. requires no flow regulation, as excess power can be stored in batteries.

Since flow regulation requires expensive governor and valve shut-off devices, its use is not recommended in LDC's. Instead, the turbine should run according to the flow it has available, with storage provided for use during low flow periods. Here the unit is designated for peak load conditions, and the excess energy produced during low demand periods can be stored for such a time as it may be needed, such as during low flow, dry weather periods.

Seasonal Storage

Storage of energy is a necessity in many LDC's due to seasonal precipitation variations. In India and other southeast Asian nations, for example, monsoon rains produce high flows for four months of the year, and very low flows for the remainder of the year.

There are many ways to store energy, either by direct electrical storage, or by converting it to some physical form which can be used at a later date. Possibilities include battery banks, pumped storage systems, compressed air storage, hydrolysis of water for hydrogen, and heat storage (National Academy of Science, 1976).

The storage system of choice will be site specific, and highly dependent on the amount of storage needed, the availability and cost of specific technologies.

Selection of Feasible Sites

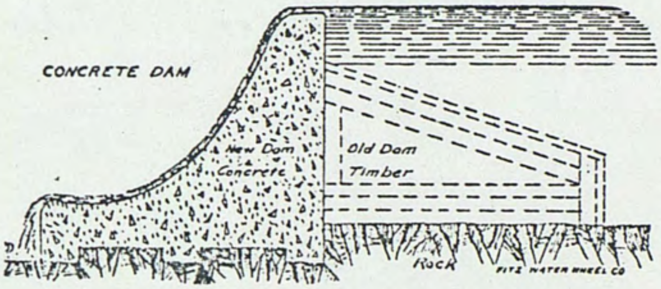
The selection of appropriate sites for installing package-type units in LDC's is dependent on the following factors:

1. Topography - slopes, streams, depressions
2. Hydrology - rainfall, runoff rates
3. Proximity to demand
4. Social acceptability

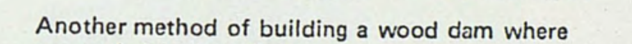
Specific design details differ for high and low head schemes. High head (greater than 10 meters) schemes are generally "run-of-river", where no dam is required to produce the needed head. Instead, water is drawn into a pipe at a high elevation and discharged at a lower elevation after being run through a turbine. High head schemes are much more efficient than low head schemes, equipment is smaller, and unit costs are much lower.

Low head (greater than 1 meter, less than 10 meters) schemes can also be "run-of-river" if large flowrates are available. Usually, however, a small dam is built to provide additional head. If a dam will be required the site must be chosen very carefully with respect to foundations and flooding. The best location for building a dam is where a broad valley narrows with steep sides and a firm base. The best bases for building dams are granite or basalt layers, the worst are sands or porous rocks, and fissured bedrock. Construction should be of indigenous, readily available materials. Wood, clays, stones, etc., are all acceptable (See Figure 9, National Academy of Science, 1976). If concrete is readily available, its use is highly recommended, even if some steel must be imported.

For high head schemes, the major topographic constraints revolve around the length of penstock pipe required and the problems anticipated in laying it. Consideration must also be given to the discharge of water from the turbine unit, especially the erosion potential.



To anyone familiar with the handling of concrete, this makes a very neat and permanent means of obtaining water storage. It is possibly the best and most shapely structure which can be used. The old wood dam need not be removed.



Another method of building a wood dam where greater height is desired.

Figure 9. Dams for use with small heads.

Available Power

After assessing that conditions are topographically suitable, hydrologic resources must be examined. The available power from any water resource is dependent on the head available, the volume flowrate, and various mechanical efficiencies and losses. For a given power requirement, there are many combinations of head (H) and flowrate (Q) which will work. As a rule of thumb, the power available can be expressed as:

$$\text{Power (KW)} = \frac{Q(\text{cfm}) \times H(\text{ft})}{709} \times \text{Efficiency factors}$$

At a potential site, head is maximized for efficiency, and the flowrate needed can then be computed from the above relation. The flowrate calculated is a minimum needed to keep the power supply constant, or provide the excess needed for storage, as reflected in the initial size choice.

Notice that the head (H) used in this calculation is the net head, which differs from gross head, in that it accounts for all losses incurred through friction in pipes, elbows and bends, and turbine discharge requirements.

$$\text{Net Head} = \text{Gross Head} - \text{Head Losses}$$

Head losses include friction losses, which can be calculated from basic fluid mechanics principles or from nomographs supplied by pipe manufacturers. Impulse wheels may require that the turbine be set above tailwater level, thus also losing some of the available head.

NO The efficiency factors used in the power calculation are based on conversion losses, particularly in three stages. The first is the efficiency of the turbine itself in withdrawing the kinetic energy from the flowing water. Efficiencies vary for different types of turbines and water wheels as shown in Table 8 .

TABLE 8

TURBINE AND WATER WHEEL EFFICIENCIES

TURBINES	EFFICIENCY
Reaction	80%
Impulse	80 - 85%
Crossflow	60 - 80%
WATER WHEELS	EFFICIENCY
Overshot	60 - 75%
Undershot	25 - 45%

NO The second efficiency loss occurs in transmitting the turbine power to the generator through belts or gears - generally 5% or lower.

NO The third loss occurs in the generator. Generators have typical kinetic to electrical conversion efficiencies of around 80%.

The overall system efficiency factor used in the power calculation is a product of the three factors. Overall system efficiencies, from water flow to electrical output, generally range from 50 to 70%.

CHAPTER VI

"APPROPRIATE" SSH TECHNOLOGY

go to 53

Hydraulic Turbines

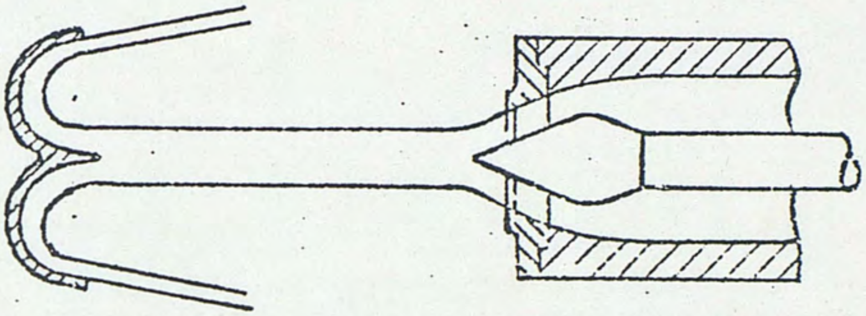
Basically there are two types of hydraulic turbines, impulse or reaction turbines. Impulse turbines differ from reaction turbines in that they utilize only the kinetic energy of the water, while reaction turbines also utilize pressure energy.

Impulse turbines applicable to high head, small scale hydropower generation include the Pelton and Turgo impulse wheels and the crossflow turbine unit.

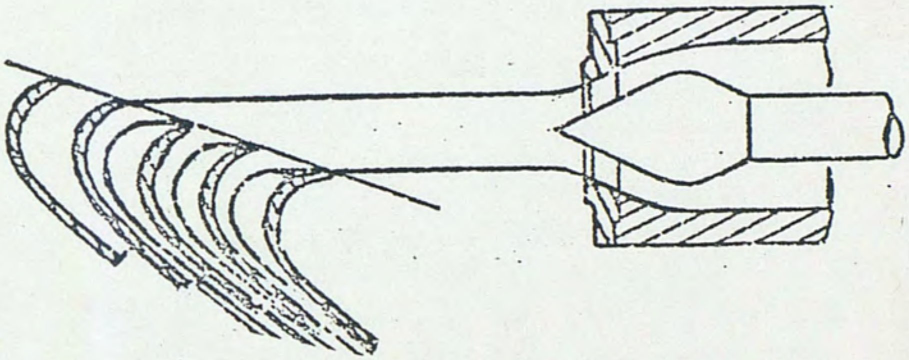
Pelton and Turgo impulse (See Figure 10) wheels utilize jet streams to strike specially shaped paddles, causing the wheel to spin. They are best adapted to high head, low flow situations.

Crossflow units (See Figure 11) use radially fixed blades under high or low head conditions, even as low as 1 meter. The crossflow unit manufacturer claims that it maintains a high efficiency over a wide range of heads and flowrates (Ossberger, 1979).

Reaction-type turbines utilize more pressure head than velocity head. The runner is placed directly in the flow stream and the blades are turned by water flowing over them, rather than striking them. Reaction units are generally of higher speeds than impulse type turbines, and are applicable to the entire range of available heads.



PELTON WHEELS

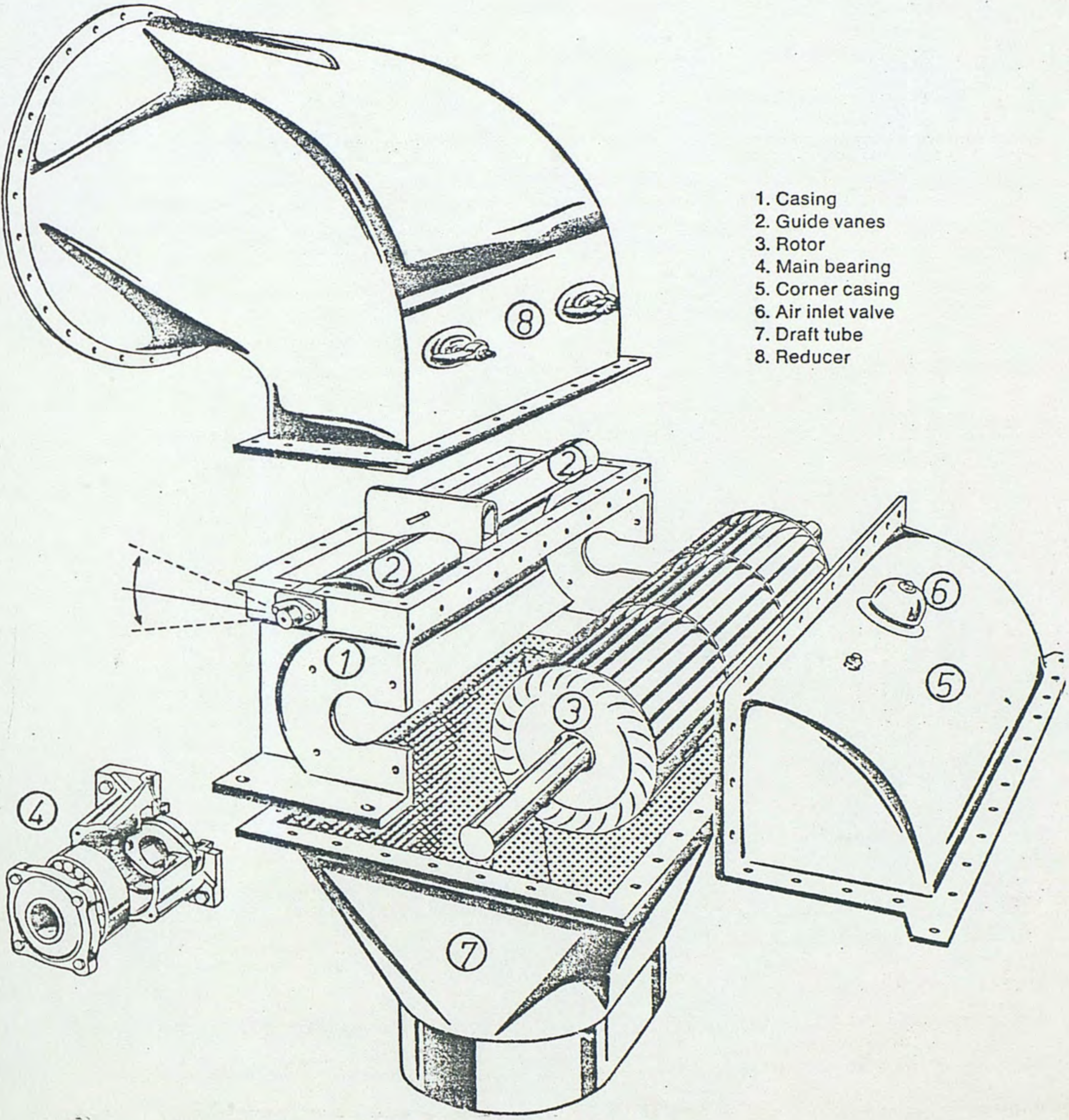


TURGO IMPULSE WHEELS

Figure 10. Pelton and Turgo impulse turbines

Reaction turbines are classified as either Francis type or propeller type. The Francis runners are like the propeller type, except that they have a band located circumferentially around the runner at the discharge end (See Figure 6).

The propeller type turbine resembles a ship's screw placed in a tube. The number of blades is usually substantially less than for the Francis type designs. Propeller turbines can be installed vertically or horizontally. For horizontal installations,



1. Casing
2. Guide vanes
3. Rotor
4. Main bearing
5. Corner casing
6. Air inlet valve
7. Draft tube
8. Reducer

Figure 11. Crossflow turbine unit

care must be taken to keep the water pressure the same across the runner inlet.

Water Wheels

Since water wheel technologies have existed since the dawn of civilization, their simplicity is obvious. Water wheels are most suited to delivering mechanical power, since their slow speeds generally exclude them from generating electricity without extensive gearing.

The mechanical power available can be transmitted through gears, for such uses as pumping, milling and grinding, and many other uses similar to those of the nineteenth century.

State-of-the-art water wheel technologies are of the classical overshot or undershot type (See Figure 2 and Figure 3), with specially designed blades or buckets. They are typically 15 feet in diameter or greater and operate for heads ranging from one to thirty feet.

Efficiencies of water wheels themselves range from 20-75%, and further losses occur in the necessary gearing systems. In many cases, water wheel technologies may tend to be more "appropriate" than turbine-electric projects. That is, the goods and services that accompany or preclude the use of electricity may not be available or affordable. In these cases, such as low level Class I or Class II development, water wheels offer excellent opportunities for helping to carry out the basic processes previously mentioned.

Commercially Available Package Units

Pre-manufactured, assembled or un-assembled micro hydropower turbine units are available through private companies in many countries of the world. They usually are shipped as a unit mounted on a base requiring bolting onto a pre-manufactured foundation, water and electrical hookups. Many times the manufacturer will supervise the installation of the unit. However, one of the main advantages of the package unit is its simplicity of installation. With a good set of instructions, relatively inexperienced personnel should be able to set up the unit and put it in operation.

The Barber hydraulic turbine company of Ontario carries a line of "micro" (up to 25 KW) and "mini" (100-600 KW) Hydel units as a standard package (See Figure 12).

The unit utilizes a Francis type runner (which minimizes civil works due to low discharge velocities) to provide cavitation free operation at efficiencies of 85-88%. Heads utilized vary from 10 to 25 feet (3-10 m). They are equipped with synchronous generators which are designed to be driven at 1200 rpm to provide 60 Hz, 3 phase output at 600/347 volts. The generator is air cooled and self ventilated, which are desirable qualities. Also provided for the generator are a brushless exciter and voltage regulator devices. The unit also comes equipped with a governor and associated flow control devices. Barber estimates that it could require up to a year from start to finish to install a 100 KW or greater unit.

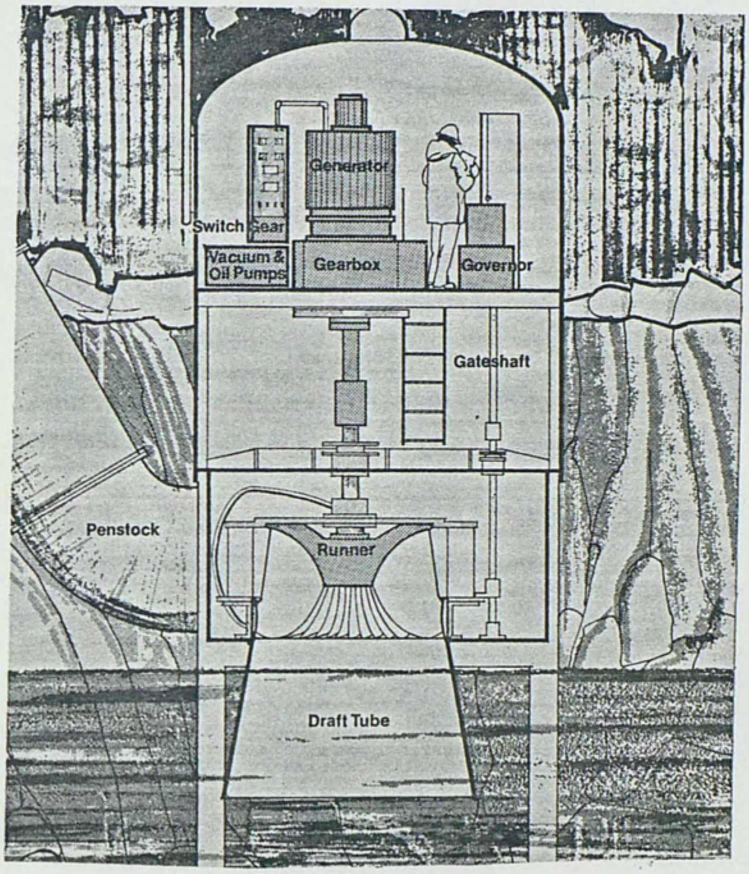


Figure 12. Section through Mini-Hydel power generating station under design development.

Gilbert Gilkes and Gordon, Ltd., of London, provide small scale hydropower turbines ranging from 1 to 1000 KW but do not provide a packaged turbine-generator unit. They have installed many units in more than 50 countries, including Indonesia, Bolivia, Sri-Lanka, Guatemala, Ecuador and many other LDC's.

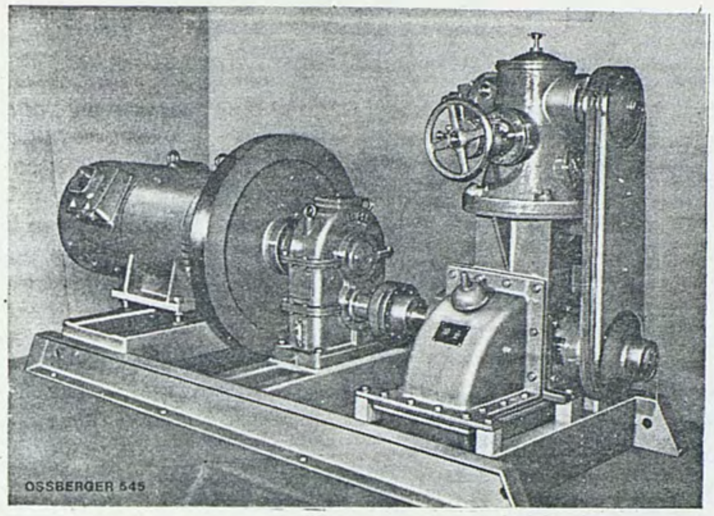
Ossberger Turbinen-Fabrik of Weissenberg, Germany, is the supplier of water power technology for the program of European Economic Aids to Developing Countries, and carries a specialized pre-assembled package crossflow unit especially for implementation in LDC's (See Figures 11 and 13).

The Ossberger design features "simple robust construction of the prime mover with few rotating parts, with roller bearings for practically maintenance free operation, requiring no automatic monitoring system". They also claim:

- insensitivity to flow variations and foul water
- brushless generators
- uncomplicated hydraulics
- ease of installation
- once yearly lubrication, and
- 35 year lifetime

Ossberger has also installed many remote LDC units.

Independent Power Developers of Montana and Idaho provide a complete package unit for either high or low head situations. Their units include rugged brushless D.C. generators, a battery bank for storage, and an AC inverter which supplies 60 Hz, 230 volts. They predict a life-span of 15 years for the battery bank and up to 30 years for the other system components, and the system carries a two year warranty. They estimate equipment costs at approximately $1,100 per KW, depending on site conditions (See Figures 14 and 15).

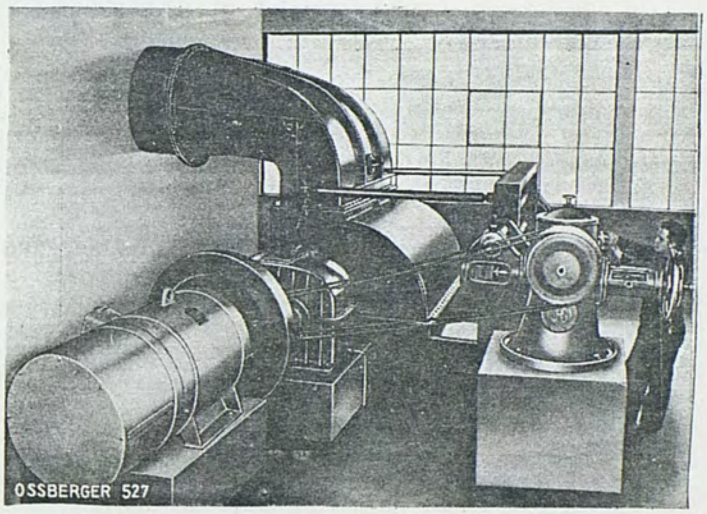


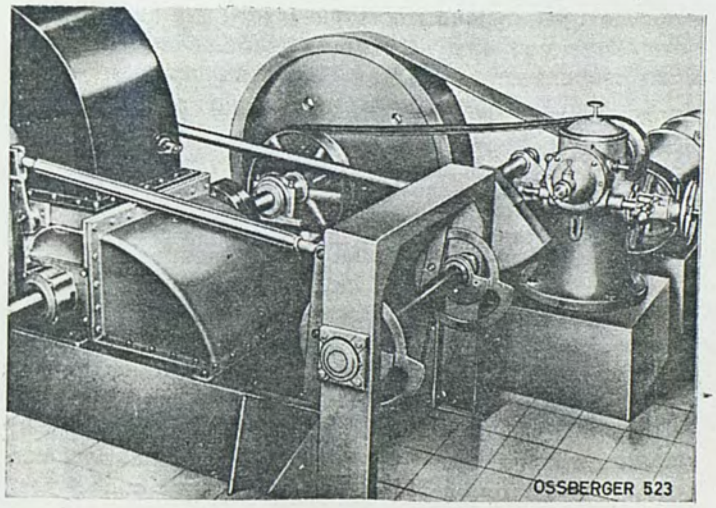
MISSION SEMINARY, TANZANIA

Head: 33 Meters
Flow: 170 L.P.S.
Power: 60 H.P.

OYEM, GABOURN, WEST AFRICA

Head: 6.6 Meters
Flow: 3000 L.P.S.
Power: 212 H.P.





PARANA, PARAGUAY

Head: 16.5 Meters
Flow: 900 L.P.S.
Power: 185 H.P.

Figure 13. Ossberger Asynchronous Generating sets.

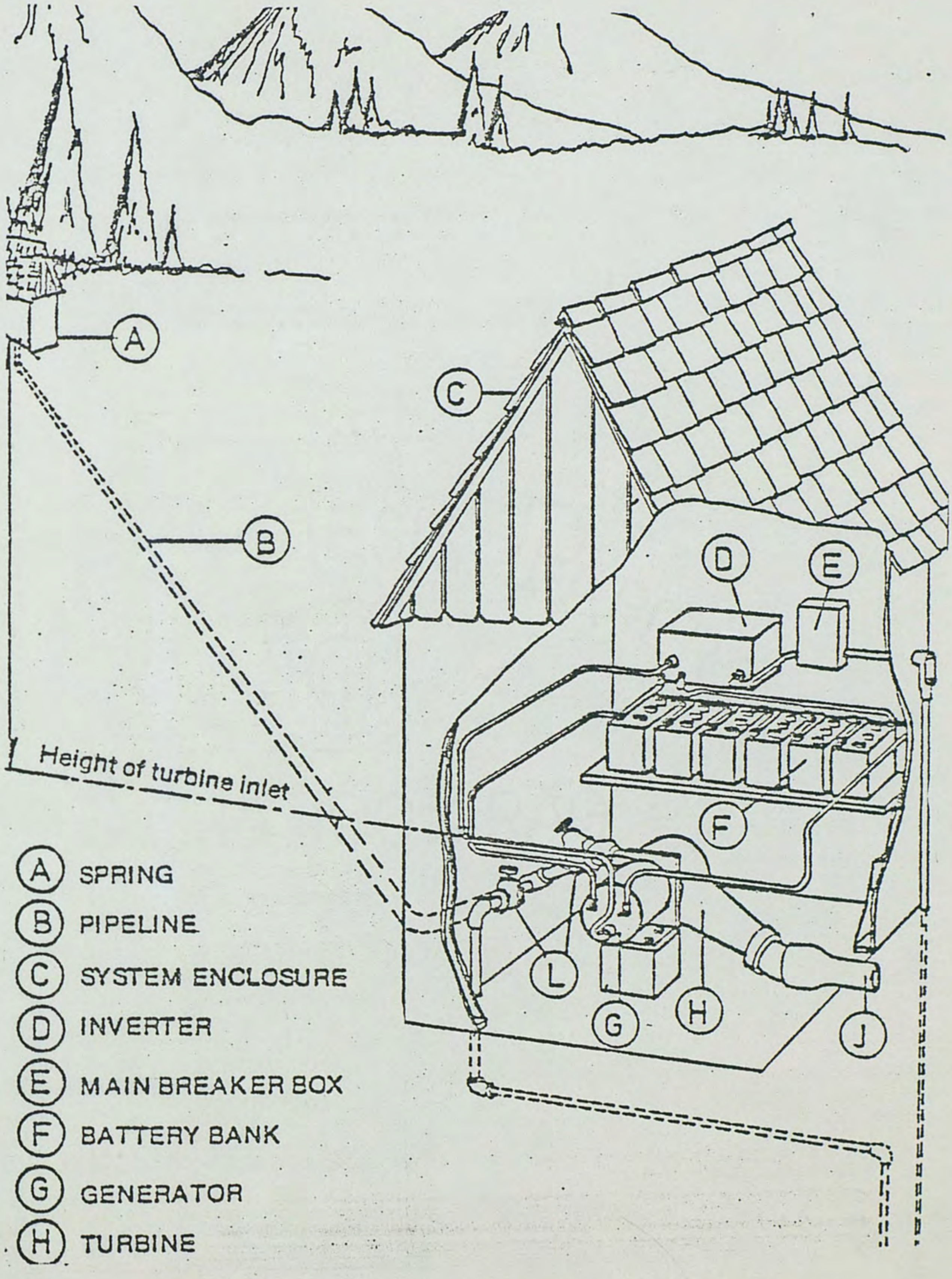


Figure 14. Independent Power's high head package.

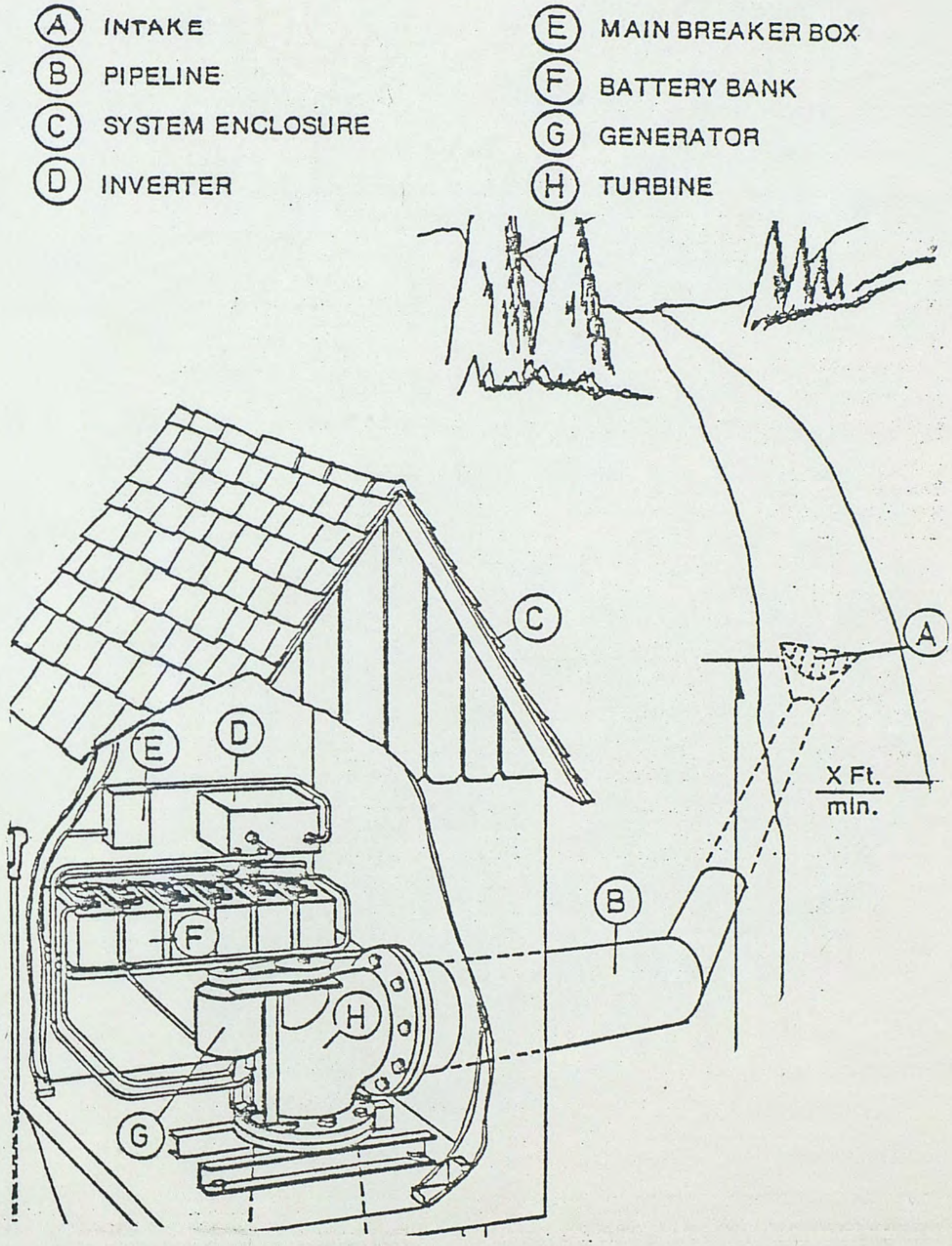


Figure 15. Independent Power's low head package.

The James Leffel and Company of Springfield, Ohio also provides package type units. Their Hoppes hydro electric unit offers direct couple generator design, complete speed control and instrumentation for generation of 10-50 KW (See Figure VI-7). It is housed in a steel case (for micro units) and offers life expectancies greater than thirty years. The Leffel Company also carries a larger package line of turbines. The "Samson" units range from 50-500 KW, applicable to a wide range of heads. Leffel reports unit costs for the Samson units at around $700-$1200/KW.

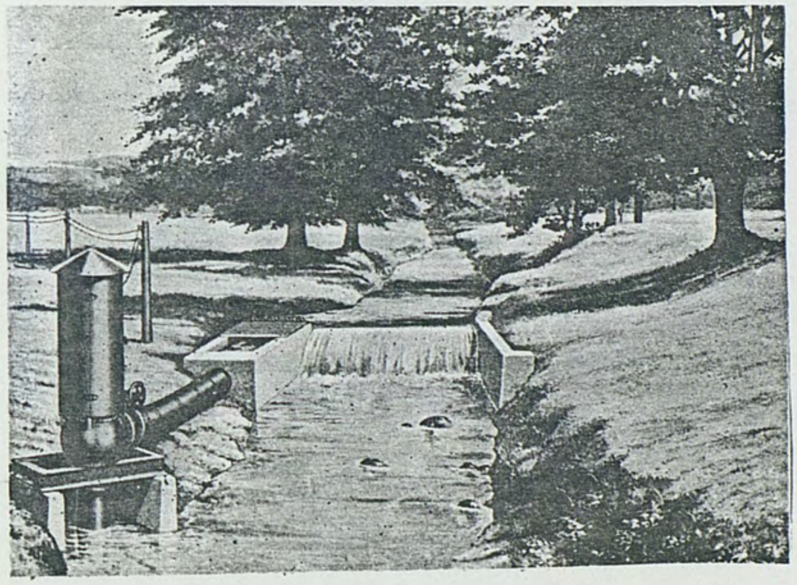


Figure 16. Hoppes hydro-electric unit.

Jyoti, Ltd., of Vadodara, India, also provides a micro packaged unit. Their "Mini-Hydel" unit utilizes a Francis turbine at medium heads. Their unit is complete with synchronous generator, governors and full instrumentation (See Figure 17).

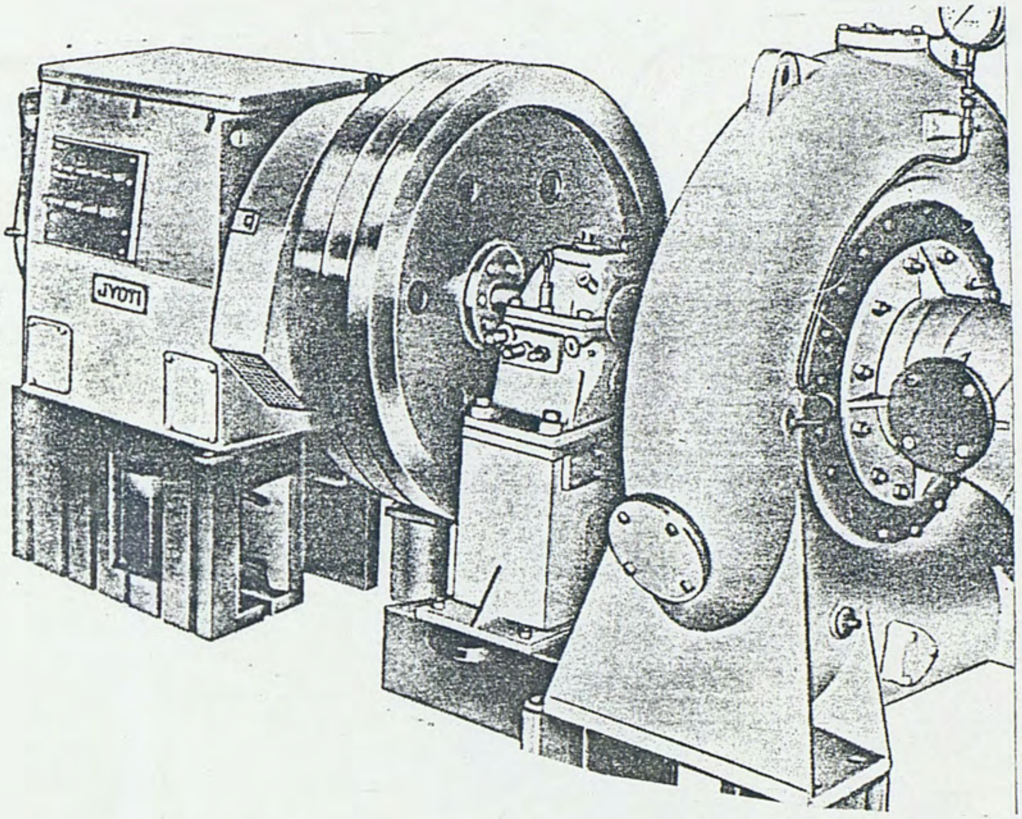


Figure 17. Typical Jyoti Horizontal Hydel set comprising horizontal Francis Turbine or Turgo-Impulse or Pelton Wheel as the prime-mover, besides other major constituents like alternator, governor and panel, etc.

The Allis Chalmers Corporation, of York, Pennsylvania, produces a line of standardized tube-propeller and Francis units. Allis Chalmers suggests unit costs for their standardized units at $500-$1000 per kilowatt.

CHAPTER VII

SSH ECONOMICS

In LDC's, capital is scarce, and interest rates are generally high. Therefore, it has been suggested that the yearly income (benefit) obtained from implementing an "appropriate" technology should be at least half of the capital investment (Revelle, 1978). Small unit costs are desirable, and it should also be possible to amortize the capital over a long lifetime.

Small scale hydro, with its aforementioned benefits and 30 year service life, adapts well to these requirements. The capital expenditures involved in installing a hydroelectric facility are always site specific. Cost factors are directly related to the scale of the project, and the availability of skills, materials and manpower.

Capital cost factors include:

1) Design cost - can be high for small, single units
2) Real estate cost - can be nil in LDC's
3) Construction cost
4) Materials cost - including mechanical and civil works

Operational cost factors include:

1) Generator load factor
2) Level of maintenance skills required
3) Repairs and technical assistance
4) Amortization and depreciation

The custom design of small units can yield a very high cost factor. If a standard size unit is produced, however, this cost factor can be reduced.

Small scale hydropower system unit costs are greatly affected by scale. A one kilowatt package unit can cost as much as $25,000 per KW. The cost for a 10 KW unit is approximately the same as for a one kilowatt unit, as reported by the James Leffel Company of Springfield, Ohio, for their small Hoppes units. X

ND In the developing countries, due to the required simplicity of installations, economies of scale associated with large projects are normally not applicable. Technological equipment of the micro scale exhibits its own economy of scale.

This scaling effect is mostly attributed to commercial availability. Mass production of any of the specific unit sites would greatly decrease its unit cost. Inevitably, the cost associated with any project will always be site specific. Installation costs will be highly dependent on the training ability of the local people, and indigenous construction materials availability.

General cost data for micro hydro systems are available from a number of sources. Cost data for small scale hydropower units from the 1963 General Electric survey are presented in Table 9. These estimated costs have been adjusted to reflect current economic conditions (e.g., GNP Implicit Price Inflator).

TABLE 9

ESTIMATED COSTS OF SSH UNITS

Item	Output (KW)				
	25	50	75	100	125
Turbine-Generator	423	330	278	258	245
Hydraulic Works (1)	62	64	64	64	65
Electro Mechanical Works (2)	427	356	297	259	217
Gate House (3)	215	108	71	54	43
Total Cost $/KW	1127	858	710	635	570

(1) Typical penstock (100 ft), two elbows, sluice gate.

(2) Governor, drive, electric control and associated equipment

(3) Nominal 20' x 20' x 10'

(These costs do not include construction labor, taxes, duties, transportation, or technical assistance charges. It is assumed that all buildings including the dam will be made from indigenous materials such as stone, wood, etc.).

Note that the electromechanical equipment of a hydropower station can represent up to 40 percent of the total costs. Simplicity can offer great savings here, not only in design and equipment, but also in construction costs. If the speed control unit can be eliminated and replaced by an electronic switching-load control device, some savings can be effected.

Possibilities exist for installing such a system, which can sense a load reduction and resultant turbine speed increase. This load can then be replaced by switching on some type of useful equipment, such as a water pump, air compressor or other machinery. Possibilities also exist for switching for some type of electrical storage.

This type of system would, of course, result in some small speed variations, however, these variations could be acceptable in rural LDC areas, or could be dampened with a battery storage system. The design of such a switching system would likely face some problems, and is beyond the scope of this report. The special attention of an electro-mechanical and possibly a micro processor engineer would undoubtedly be required. However, with the present day level of electrical technology and electrical equipment costs, the production of such a system is indeed possible. The application of such a system would probably not replace all of the mechanical control works, but would serve to greatly reduce them.

Other measurements are also available for reducing the cost of implementing SSH systems in LDC's. A Japanese study to minimize the accessories, maintenance, and operational costs suggest:

1) Utilization of most economic material
2) Fixed blade propeller runners

3) Dry bearings

4) Induction generators where possible (not in many rural LDC's)

5) Automatic speed regulating devices

6) Open, self-ventilating generator cooling system

7) Selection of the most economic terminal voltage

Data for capital and production expenses from DOE Plant-cost studies for hydro and other pertinent technologies are presented in Table 10. Notice that the four sensible alternatives for small scale development (Table 3) include fossil engines, photo voltaics, wind and small scale hydropower. Production expenses tend to eliminate "fossil engine" and capital costs eliminate photovoltaics. Wind machines of mini/micro scale may be feasible in some localities depending upon storage battery economics. SSH has the clear advantage.

TABLE 10

TYPICAL UNIT COSTS OF VARIOUS ENERGY SCHEMES

Technology	Installed Capacity $/KW (1)	Production Expenses Mills/KWH (1)
	Ignores Civil Works	
Nuclear	800-900	4-8
Coal, Oil, Gas	300-400	15-20
Fossil Engine (2)	300-400	300-450
Photovoltaic (2)	18,000-23,000 (3)	Nil
Wind (2)	1,500-2,200 (4)	Nil
Hydro (2)	200-3,000 (5)	1-2

(1) Data from various sources including DOE Plant Construction Cost and Annual Production Expenses reports.

(2) Sensible alternatives considering scale (Table 3).

(3) Estimates are in $5,000-$6,000 range for 1985.

(4) Optimistic-does not include storage batteries.

(5) $3,000/KW average cost of President Carter's "Rural Energy Initiative".

CHAPTER VIII

CASE STUDIES

The People's Republic of China

Since liberation in 1949, the Chinese Government has attached a great importance to the utilization of the hydropower resources. The long term development of China's hydropower resources is seen as one of the most effective developmental strategies.

China's energy development is characterized by the "many small steps" theory. Since 1958, China has constructed more than 80,000 small and micro hydropower stations with a total capacity of 5,400 MW (See Figure 18, Tseng, 1979; Revelle, 1978). Hydropower generating units with capacities below 500 KW account for more than 60% of these small and micro units.

Most of these are built by the people's communes at the county level for the use of commune members. The units supply electricity for local industries and small workshops. Applications include grain drying, wood cutting, oil extraction, lighting, and film showing.

The development of small and micro power stations has not only solved the power problem for domestic commune applications, it also has the advantage of multi-purposed industrial applications.

Figure 18. Small hydro-electric stations (averaging 40 KW) in South China.

Beginning in 1972, work on standardization of the hydropower generating equipment was carried out. Since then, unified design work has been practiced on a national scale.

For the construction of small and micro hydropower stations by counties and people's communes, the Chinese government maintains the following policies:

1) Wherever the water resources show promise for development, the government impels installation of small or micro hydropower stations

2) Huge amounts of state loans with low interest are dedicated annually to people's communes that engage in constructing the aforesaid stations

3) To production plants for hydroelectric power installations and equipment, the government would give timely and appropriate investments to increase production

4) With the small and micro stations that can be integrated into the national grid, the state would supply electricity with a privileged charge to promote rural electrification

In China, an average unit cost of $1,000 (U.S.) per kilowatt is found to be a good estimate. It is generalized that equipment and installation costs are roughly equal. The authors report a cost of $575,000 for a 600 KW ($960/KW) project, as of August, 1980. Transmission costs range from $75-$150 per installed KW (Tseng, Wengin, and Zhaoxiang, 1979).

Panama

The country of Panama, especially the rural areas, was hard hit by the OPEC price squeeze. In Panama most rural large villages were electrified by 60 or more small diesel units. About 40% of the people had no power, and the rest were served by traditional fossil schemes.

Several large hydroelectric stations were planned and built 300 miles west of Panama City. The distribution plan included all areas between the dam and Panama City, and the first phase came on line at the same time as the second OPEC price jump. To serve the most equitable benfit, all the power generated at the hydro station was transmitted directly to the one million people of Panama City. All the intermediate areas were bypassed, except for a few large rural cities.

Transmission levels were lowered to 150 KV to lessen transmission costs and resulted in a need for transformers and sub-stations wherever the power was tapped. This made it even harder for the rural villages to obtain power, and thirty-three percent of the population remained without power.

To help compensate for this problem, the U.S. Agency for International Development developed a small scale hydro technology base and demonstration project. Small decentralized hydro projects were planned for villages in the Cordillera mountain range. The diesel sets being presently used in this region would be transferred to rural areas with no hydro potential.

In the Cordillera mountain range, village runoff is fairly uniform year-round, and in the 33 miles from the peaks to the sea, the water drops about 600 ft. AID, aided by GSA International, Inc., arrived at the following design criteria for SSH implementation in the Cordillera:

1) Design for run of stream greater than 40' head
2) Design for 120% of minimum flow
3) Impulse Turbines
4) Steel penstocks and headpipes
5) D.C. Generator with A.C. inverter up to 10 KW
6) Electronic governor and load diversion system
7) V-belt drive up to 200 KW (gearing above)
8) Diversion ditch 90^o to stream flow
9) Settling basins at each end of diversion ditch
10) 1/2" trash rack spacing
11) Guillotine headgate with worm drive

Three sites greater than 200 KW were completed this year at Santa Fe, San Francisco and Coclesito. Others are being planned and constructed at this time (Grover and Fritz, 1979).

New Guinea

Several small scale hydropower systems can be found in Papau and New Guinea. The Laloki river was developed for Port Moresby in 1957 with the installation of three one-thousand kilowatt machines, at a cost of around $1,200/KW. The second stage of the Laloki's development added another 2,500 KW at a cost of around $1,100/KW.

Other small schemes in New Guinea include an installation at Goroka with a capacity of 600 KW at a cost of $600/KW. This low cost did not include a flume lining, and consequent erosion and landslides required much maintenance. Eventually, the affected areas were encased in Armco piping.

Small installations also exist at Mount Hagen and Tapini. Both had high initial costs, and some of the same erosion problems as the Goroka scheme. The costs of these systems ran up to $1,800/KW but have still proven to be economically superior to diesel installations (See Figure 19, Ryan, 1972).

Morocco

The Agency for International Development was commissioned to study the small decentralized hydro potential of the Atlas and Rif mountains of Morocco. Their efforts included the formation of an information package, development of site selection criteria, location of demonstration units, cost developments, and socio-economic impact assessments.

The information package consisted of precipitation and hydrology records, irrigation patterns, contour maps, power grid maps, and population patterns.

Site selection criteria were listed as follows:

1) Year-round water
2) Need (market) for power
3) Unavailability of network power

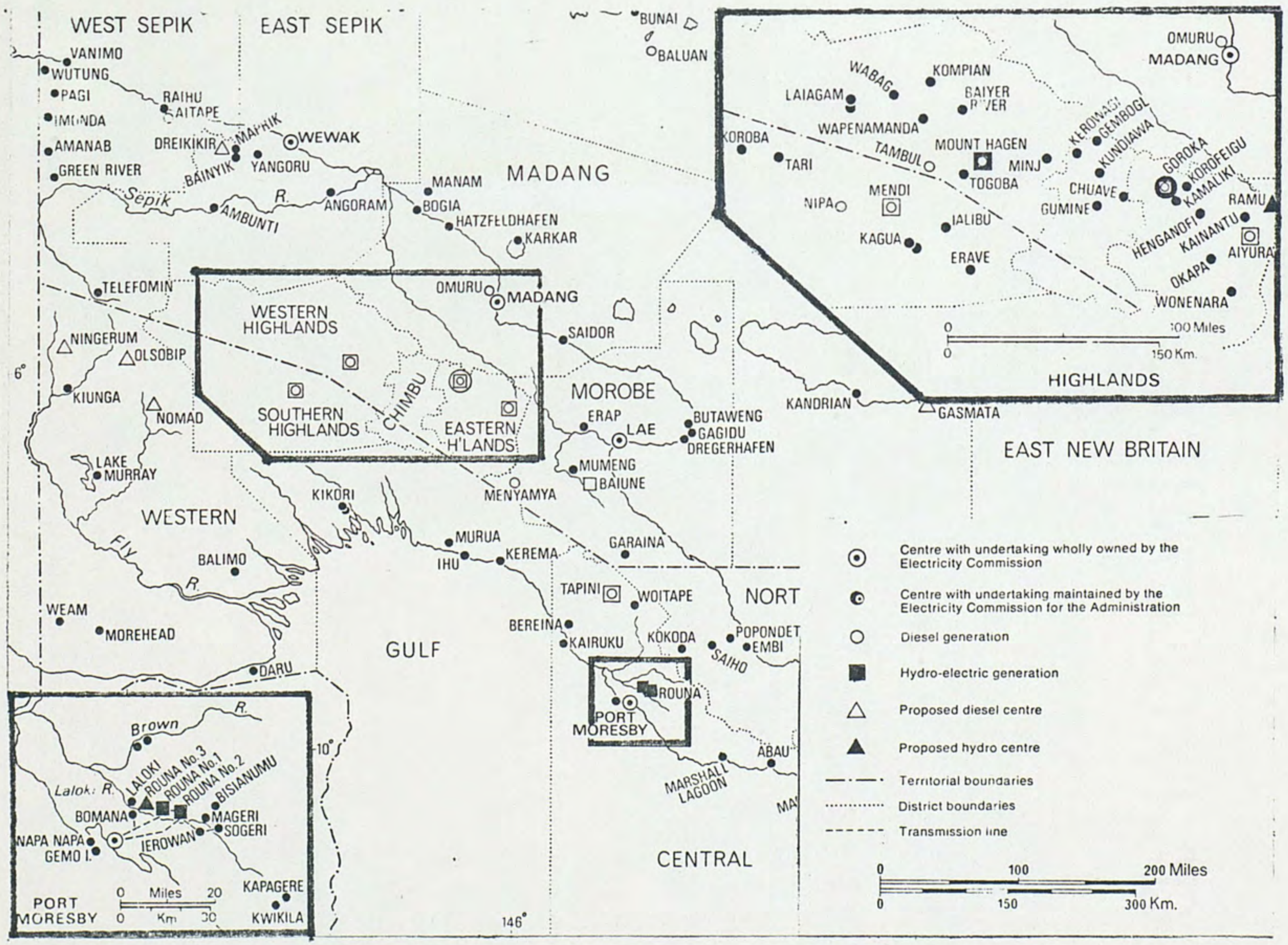


Figure 19. Papua and New Guinea electricity.

4) Run of river schemes
5) Possible secondary water uses
6) Power costs less than diesel
7) Social soundness
8) Technical and administrative feasibility
9) Environmental impact
10) Equitable, distributed benefit ("the greatest good for the greatest number")

Three specific areas are currently under detailed planning. The first, with a potential of 200 KW, is being undertaken on the south side of the Haut Atlas at Msemrir on the Dades River. A diesel generator presently supplies electricity twice daily, but it is expensive and requires frequent maintenance.

The second site, at Tillougguit, is northeast of Alfoure on the north side of the Haut Atlas. A small hydro unit is being planned to give electrical service to 2000 villagers by 1995.

The third site, also in the Dades Valley, is at Ait Arbi, where a large spring emerges from the mountain side about 35 meters above the Dades River. Two-hundred KW is obtainable for two small villages at least half the year, with lesser capacities during the remainder of the year.(See Figure 20, Grover and Fritz, 1979).

Details of the planned hydro unit are as follows:

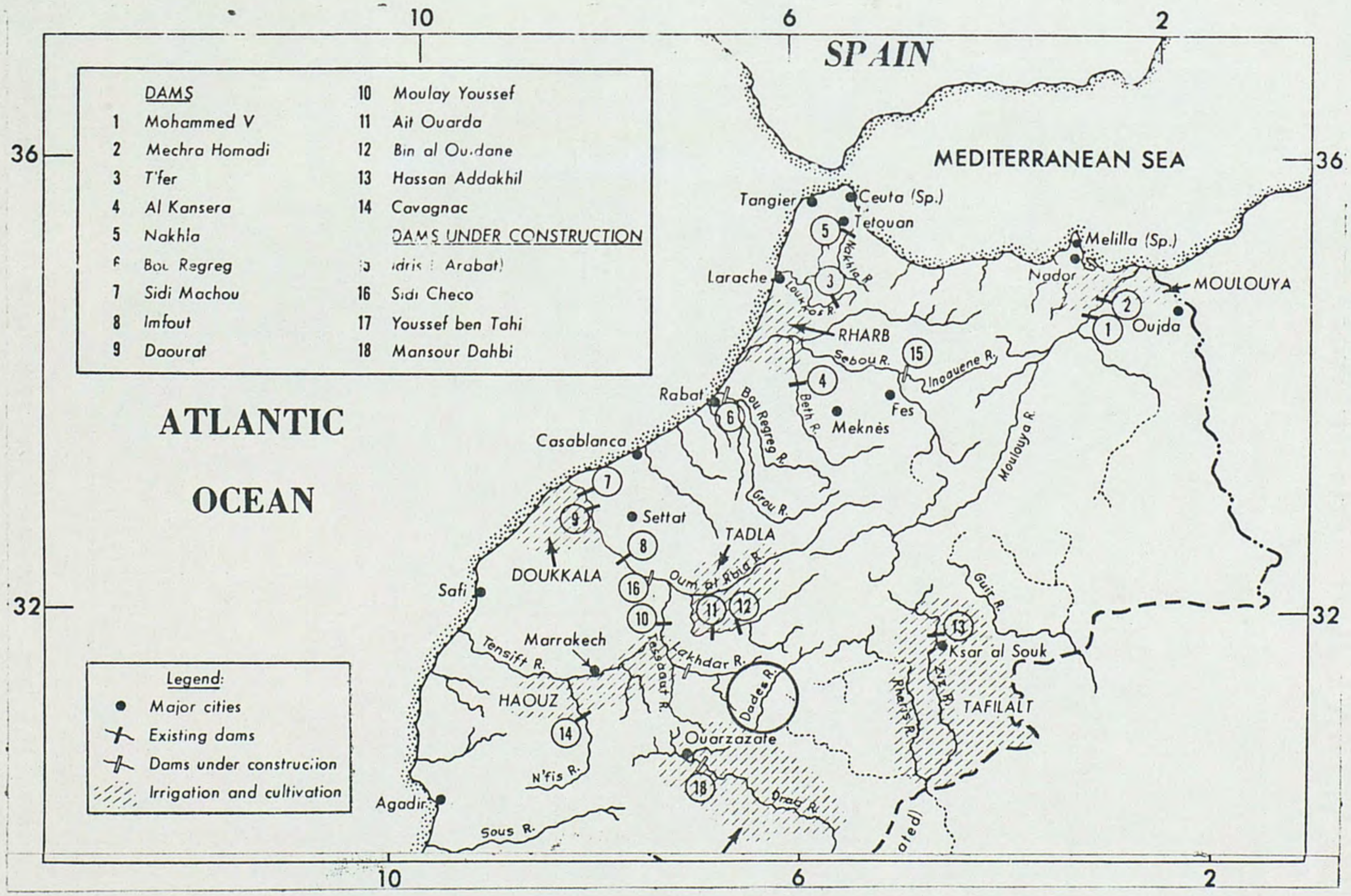


Figure 20. Morocco electricity.

1)	Flow at 1 m^3/sec	= 34 cfs	
2)	Head at 35 meters	= 105 ft. net head	
3)	Penstock 6" PVC	= 300 ft. x $15/ft.	$ 4,500
4)	Pelton turbine	= high speed unit	32,600
5)	Linkage and governor	= Woodward or equal	2,400
6)	A.C. generator	= enclosed, S.E.	20,400
7)	Governor deflector	= nozzle control	3,600
8)	Fabricated baseplate	= w/c foundation bits	2,800
9)	Control panel	= cabinet type	3,400
10)	Electrical equipment	= breakers, gauges, etc.	8,400
11)	Engineering (GSA)	= combining package	11,375
12)	Engineered package	= U.S. funds	$ 89,475
13)	Installation materials	= 600 man-days at $20	12,000
14)	Installation materials	= 22 yards concrete and. re-bar	2.970
15)	Supporting steel	= 2 tons at $.75/#	3,000
16)	Power house	= 150 ft^2 at $\$40/\text{ft}^2$	6,000
	TOTAL COST	=	$102,645
	COST PER KW	=	$513/KW

CHAPTER IX

SUMMARY AND CONCLUSIONS

The last decade brought many changes to the development process. The term "Appropriate Technology" was coined, with the rejection of the large scale industrial model of development. "Appropriate Technology" represents the tools and hardware that are more adaptable to third world societies.

The term "appropriate" suggests that such hardware be low in cost, and emphasize the use of indigenous materials and resources, especially labor.

Appropriate technologies should, if possible, involve decentralized and renewable resources, and offer possibilities for self-production and self-maintenance. Many small, distributed, affordable systems will generally be more appropriate than one centralized, capital intensive project.

Although small scale hydropower systems can be high in capital cost and technically complex, their implementation into rural LDC's energy development is often the most "appropriate" method of serving third world needs. Small hydro systems are presently cost competitive with other electrical generation schemes. Simplification of equipment, and indigenous production can help reduce unit costs as compared to modern commercial units. A major cost savings could be effected by eliminating mechanical speed controls. Local small or medium scale industries can offer great savings in overhead, labor, materials and transportation costs.

If properly implemented, small scale hydro systems can have many positive ramifications on the developmental process. The provision of electricity can lead to direct improvements in agriculture, small scale industries, and the basic residential processes. Indirectly, it can lead to improvements in education, health, and promote the development of local infrastructures and the idea of self reliance. The resultant demand for goods and services would stimulate more interaction between industrialized and rural societies, with social and economic benefits for both.

Proper implementation requires a sensitive analysis of many factors. These include project scale, family incomes, electrical demand projections, and the availability of materials and manpower skills, and social acceptability.

Technical factors requiring careful examination are the topography and hydrology, seasonal storages, the transmission distance, and the type of machine to use. Francis, Pelton and Crossflow seem to be the turbines of choice for small scale applications. All offer low discharge velocities, thus minimizing civil works.

There are a number of corporations that manufacture small scale, package hydropower units. The equipment available through these companies can be quite complex, and cost from $500 to $2,000 per kilowatt, depending on size. The average equipment cost is about $1,000/KW for equipment, and construction costs can equal or exceed this. Transmission costs are around $100/kilowatt, depending on distance and other factors. Small hydro systems offer low to nil operational costs. They are generally very reliable machines, easily maintained, and offer service lives of 30 years or more.

Systems costs, whether imported or produced at home, can be optimized with a line of standardized units. Although hydropower is often referred to as "the site specific energy source", possibilities for standardization through regional/national studies exist. Production of a line of 25, 50 and 100 KW units would be desirable for a national rural electrification plan. These units can be combined in series or parallel to fit the range of demands that the development effort would require.

Small scale hydro systems have been extensively used for rural electrification in China. They have also been successful in many other LDC's and seem to offer the best choice for energy development, where physical conditions permit.

Recommendations for Future Research

Standardization of micro hydropower package units would be very desirable. The need for regional studies of energy demands, hydro potentials, and physical characteristics is evident. These studies would greatly aid in starting small scale industries related to SSH production and installation. They would also help to direct development efforts to where they are most needed or most feasible.

The need for more LDC small scale hydro case studies is also evident. Small hydro installations in the LDC's can be quite different than a U.S. or European project. The literature available on LDC SSH systems is rare, and usually sketchy. Case studies can accent the success of rural SSH programs, as well as aid in standardization.

A reduction in civil and mechanical works is needed for the LDC. Replacement of the governor, and its associated flow control devices could effect a major cost savings. Research aimed at an electric load-switching speed controller is needed. Perhaps even a microprocessor could be used to divert excess productions for irrigation or pumped storage.

Studies are also needed on energy demands that would be exerted through SSH, or any other small scale energy development scheme. The sensitivity of the preliminary energy forecast will reflect the success of the project. Comparisons with past attempts can greatly aid classifying levels of development, and predicting their respective energy growth rates.

REFERENCES

Allis Chalmers Corporation. *Hydropower Fundamentals*. York, Pennsylvania: Allis Chalmers Corporation, 1979.

Barber Hydroelectric Corporation. *Hydraulic Turbines*. Ontario, Canada: Barber Hydroelectric Corporation, 1980.

Brown, Norman L., Ed. *Renewable Energy Resources and Rural Applications in the Third World*. Denver: Westview Press, 1978. pp. 1-3.

Cecelski, Elizabeth; Dunkerly, Joy; and Ramsay, William. *Household Energy and the Poor in the Third World*. Washington, D.C.: Resources for the Future, 1979.

Cortes-Comerer, Nhord. "Changing Concepts for a Developing World." *Civil Engineering*, January 1977, pp. 66-69.

Ermenc, Joseph J. "Small Hydroelectric Prime Movers for Rural Areas of Developing Countries - A Look at the Past." In *Renewable Energy Resources and Rural Applications in the Third World*, pp. 89-91. Edited by Norman L. Brown. Denver: Westview Press, 1978.

Forbes, R.J. "Power." In *History of Technology*, p. 589. Edited by Charles Singer, E.J. Holmyard, A.R. Hall, and T.I. Williams. Oxford: Clarendon Press, 1956.

General Electric Corporation. *Preliminary Report of Field Study Teams on the Generation and Utilization of Power in Rural Areas of Developing Countries*. Washington, D.C.: US AID, REPAS, 1963.

Grover, Kenneth, and Fritz, Jack. "Small Decentralized Hydropower for Developing Countries." New York, 1980. (Mimeographed).

Grubbs, Eugene. "Can We Really Help?" *The Commission* 42 (July 1979): 7.

Hubbert, King M. "Energy Resources." In *Resources and Man*, pp. 207-209. Edited by The National Academy of Sciences. San Francisco: W.H. Freeman, 1969.

Hyde, Charles K. "The Development of Hydroelectric in the Midwest." *Proceedings of the Midwest Regional Small-Low Head Hydroelectric Power Conference, May 1978*. East Lansing, Michigan: p. 7.

Independent Power Developers. *Hydroelectric Power*. Sandpoint, Idaho: Independent Developers, 1979.

James Leffel and Company. *Hydroelectric Power from a Hoppes Hydroelectric Unit*. Springfield, Ohio: James Leffel and Company, 1979.

Jyoti, Limited. *Small Sets with Big Benefits*. Vadodara, India: Jyoti, Ltd., 1979.

Kersten, Robert D., and Harper, Stephen R. "Small Scale Hydropower: An Appropriate Energy Technology for Less Developed Countries." *Proceedings Third International Symposium for Engineering - Appropriate Technology for Less Developed Countries*. San Salvador, El Salvador: 1980, pp. 365-375.

Lord Wilson of High Wray. "Natural Sources of Power - Part I: Water Power." In *A History of Technology*, pp. 195-210. Edited by Charles Singer, et al. Oxford: Clarendon Press, 1978.

Muiga, Michael I. "Small Hydro Systems for LDC's." Research Proposal to the Division of Sponsored Research, Orlando: University of Central Florida, 1979.

National Academy of Sciences. *Energy for Rural Development - Renewable Resources and Alternative Technologies for Developing Countries*. Washington, D.C.: Commission on International Relations, 1976. p. 154.

National Center for Appropriate Technology. *Micro Hydro Power - Reviewing an Old Concept*. Boise Idaho: USA DOE, 1979.

Ossberger Turbinfabrik. *Water Power from Weissenburg*. Weissenburg, Germany: Ossberger, 1980.

Palmedo, Philip F. *The Role of Renewable Energy Technologies in Developing Countries*. New York: Brookhaven National Laboratory, 1977. p. 2.

Powell, J.W. "Wood Waste as an Energy Source in Ghana." In *Renewable Energy Resources and Rural Applications in the Third World*, p. 127. Edited by W.L. Brown. Denver: Western Press, 1978.

Revelle, Roger. "Requirements for Energy in the Rural Areas of Developing Countries." In Renewable Energy Resources and Rural Applications in the Third World, p. 12. Edited by W.L. Brown. Denver: Western Press, 1978.

Rouse, Hunter. Hydraulics in the U.S. - 1776-1976. Iowa City, Iowa: Institute of Hydraulic Research, 1976.

Ryan, Peter. "Hydroelectric Power." In Encyclopedia of Papau and New Guinea, p. 362. Australia: Melbourne University Press, 1972.

√Smith, Norman. A History of Dams. London: Peter Davies, 1971.

Stowers, A. "Watermills c. 1500 - c. 1850." In A History of Technology, pp. 199-212. Edited by Charles Singer, et. al. Oxford: Clarendon Press, 1958.

Thomas, Carl O., and Baquont, Jawaharlall. "Resource Utilization in Emerging Nations: Technical, Economic and Policy Relationships." Proceedings Appropriate Technology for Underdeveloped Countries, Second International Symposium of Engineering. San Salvador, El Salvador: February, 1979, pp. 1-35.

Tseng, A.A.; Wengin, M; and Zhaoxiang, T. "The Role of Small Hydroelectric Power Generation in the Energy Mix Development for The People's Republic of China." San Francisco: 1979. (Mimeographed).

United States Census Bureau. Compendium of the Sixth Census of the United States. Washington, D.C.: 1840.

Wark, Kenneth, and Warner, Cecil F. Air Pollution - Its Origin and Control. New York: Harper and Row, 1976.