OPTIONS IN POWERING IRRIGATION EQUIPMENT FOR TUBEWELLS AND LOW-LIFT PUMPS IN BANGLADESH

Consultant's Report
To
BANGLADESH AGRICULTURAL RESEARCH COUNCIL
Dhaka, Bangladesh

by

RICHARD R. HOWES

December 7, 1983

I. INTRODUCTION

This report summarizes the results relating to power use in irrigation of a seven-week consultancy in Bangladesh.

The main topic of this report concerns the choice between diesel and electric power for tubewell and low-lift pump irrigation equipment. In addressing this question heavy reliance has been placed on past research efforts on this topic and on the Bangladesh government's goals as expressed in the second five year plan.

This report addresses the problem of diesel power versus electricity in a way that tries to help planners who are asked to secify prime movers for a particular tubewell (or low lift pump) or group of tubewells (or a group of low-lift pumps) in some small area of Bangladesh.

Section II of this report considers recent studies of the choice between diesel and electric power supply for tubewell irrigation equipment. Government policies concerning the choice between diesel and electricity are reviewed in Section III. A preliminary framework for addressing the choice between diesel and electricity is introduced in Section IV. This "framework" is intended to be a step toward the development of process by which decisons for particular pump units. In Section V the potential liquid petrolium gas as a possible fuel for irrigation equipment is considered. Section VI contains the conclusions of the study and recommendations for further research.

II. REVIEW OF STUDIES ON THE CHOICE BETWEEN DIESEL AND ELECTRICITY

In the final report on the second Tubewell Project in Bangladesh, Sir M. MacDonald and Partners Limited compared the costs of diesel and eletric power for deep tubewells. It was found that electric powered units provided lower cost water because of lower capital costs, lower maintenance and repair costs, and lower energey costs.*

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* See Sir MacDonald and Partners Report: Second tubewell Project (Bangladesh) Vol. 4, pp 37-47.

The MacDonald study utilized, as a basic assumption, the results of a 1979 electric tariff study of PDB which was conducted by Coopers and Lybrand, which recommended a flat tarrif for agricultural power of Tk.1.5 per KWH. MacDonald accepted this tariff and then excluded the distribution costs which were an integral part of the Cooper/Lybrand tarrif. MacDonald then used this tariff of Tk. 1.1 per KWH along with detailed distribution costs that they developed specifically for distribution of electric power to the tubewells.

The MacDonald study* assumed a diesel fuel price of Tk.26 per imperial gallon.

After a specific examination of factors involved MacDonald came to the conclusion that electrifiction of tubewells would provide water at lower cost than would use of diesel power.

MacDonald suggested the following criteria for selecting suitable areas for tubewell electrification:

a) the area should be adjacent to a zone where rural eletrification is or is about to be completed;

b) the existing DTW density should be high;

c) there should be a significant project increment of DTW;

d) a group of thanas which make up a PBS (REB cooperative) should be selected;

e) there should no current electrification plan for the area.

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* Sir M. MacDonald and Partners, Vol. 4, p 46.

In 1981, a study conducted for the U.S. Agency for International Development* compared the cost of electric and diesel power for deep tubewells, shallow tubewells and low-lift pumps. This study was based upon engineering data that was provided for each type of unit by Bangladesh Agricultural Development Corporation and the Rural Electrification Board. These data were used to synthesize a diesel engine-pump unit and an electric motor pump unit for each type of application. The present value of the cost time streams were then compared.

Some of the critical assumnptions used in the analysis are as follows: deep tubewells were assusmed 300 feet in depth, to have an economic life of 20 years, average 1000 hours of pumping per year and require either a 30 HP diesel engine or a 25 HP electric motor. The larger diesel engine was used in the analysis because its effective power declines with use faster than does the power of electric motor. Low lift pump units were assumed to have an economic life of 10 years, averge 700 hours of pumping per year and require a diesel engine of 18 HP or an electric motor rated at 15 HP.

Shallow tubewells were assumed to have an economic life of 15 years, average 700 hours of pumping per year and require a diesel engine rated at 6 HP or an electric motor of 4.5 HP. The analysis ws based on a price for diesel fuel of Tk.18.94 per imperial gallon and an electric power rate of Tk.0.70 per killowatt hour. Given these energy prices in ws estimated that the cost of irrigating the same acreage with electricity was 23 percent cheaper than those with diesel for deep tubewells; for low-lift pumps it was estimated that irrigating with electricity was 28 percent cheaper than with diesel; and for shallow tubewells it was estimated that the cost of irrigating with electricity was 35 percent less than with diesel.

Ahmed** also estimated the comparative cost of irrigation with electricity and with diesel, keeping all assumptions the same but allowing the electricity power rate to changes.

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* Ahmed, Akter Uddin, Diesel and Electric Power Pump Irrigation; A Comparative Cost Analysis, U.S. Agency for International Development, May 1981.

** Diesel and Electric Powered Pump Irrigation, p 7.

It was estimated that at an electric power rate per KWH of Tk.1.0 that deep tubewell irrigation using electricity was less costly by 11 percent, low lift pump irrigation using electricity was less costly by 13 percent and shallow tubewell irrigation using electricity was less costly by 27 percent (Table 1). At an electric power rate per KWH of Tk.1.30 and at higher rates diesel powered pumps come out to be less costly to operate for both deep tubewells and low lift pumps. However, even at electric power rates of Tk.1.50 per KWH electric powered shallow tubewell pumps were cheaper to operate.

Generally in Bangladesh, electrification of tubewells is favored. Bangladesh Agricultural University Professors S.M. Farruk, A.A. Mainul Hossain support electrification of tubewells over use of diesel power. Farmers themselves have the impression that electrically powered tubewells are going to be cheaper to operate, suffer from fewer breakdowns and be easier to have repaired when breakdowns occur. Current staff members of Sir M. MacDonald and Partners, BADC consultants, favor electrification of tubewells where possible and they "offer" the following reasons for this conclusion: cheaper operation with fewer breakdowns and an elimination of the problems with diesel fuel.

Concerning the problems associated with diesel fuel, various ones have been reported by people in the field of irrigation and water management, although research was not found on the subject. One problem that was reported was that fuel is sometimes adulterated with the resulting mixture causing damage to the engine. It was reported that kerosene, used motor oil and water have been employed to adulterate diesel fuel. Another problem that has been reported is that farmers often pay for fuel that they do not receive, with those responsible for delivery or others in positions of power obtaining this fuel without payment. Shortages of diesel fuel can also develop in the agricultural areas just when fuel is needed most: at the height of the irrigation season.

Table 1. An Analysis of Savings from Powered Irrigation at Alternative Power Rates

(Amount in Taka)

Electric Power Rates (TK/KWH)	Savings Over Diesel: Deep Tubewell Amount	%	Low Lift Pump Amount	%	Shallow Tubewell Amount	%
0.50	143,159	30	43,638	38	30,275	40
0.60	124,514	26	37,961	33	28,149	38
0.70	105,868	23	32,284	28	26,073	35
0.80	87,222	19	26,607	23	23,997	32
0.90	68,577	15	20,930	18	21,921	29
1.00	49,931	11	15,253	13	19,845	27
1.10	31,285	7	9,576	8	17,768	24
1.20	12,640	3	3,899	3	15,692	21
1.30	(-6,006)	(-1)	(-1,778)	(-2)	13,616	18
1.40	(-24,652)	(-5)	(-7,455)	(-6)	11,540	15
1.50	(-43,297)	(-9)	(-13,132)	(-11)	9,464	13

Source: Ahmed, Akhter Uddin, Diesel and Electric Powered Pump Irrigation, May 1981.

With all of these various factors and pressures favoring electric power for irrigation, it appears that an infrastructure in support of electric power is in the process of development. One thing that is happening to support electrification of tubewells is that SIDA is working with the Vocational Taining Institutes of Bangladesh on the development of programs to train personnel to maintain and repair electric motors for irrigation pumping. Training for maintenance and repair of electric motors will eventually decrese the time that it takes to obtain repair service and therefore will tend to increase the output and profits of land irrigated with electric power.

A 1983 research project*, the report of which is still in preliminary form, has investigated and extent to which ten electrified tubewells experienced electrical problems of various types. This study found that ten electrically powered pumps in the Thakurgaon Tubewell Project had power problems of an average of 160 hours each during the dry season of 1982 (This average number of hours was arrived at by counting only a maximum of 8-hours of outage per day even if the outage prevailed for a longer duration on that date). These 10 pumps were actually operated an average of 208 hours during this same period.

For all tubewells taken together there were 1548 hours of electrical outages, with all calculations made on the basis of the above-mentioned assumption. Between 84 and 94 percent of all electrical problems were due to a loss of electrical power. Switchboard malfunction accounted for between 1 and 13 percent of the electrical problems whereas stolen wire was reported by only one pump operator and accounted for only 2 percent of the time that these 10 pumps were out of order due to electrical problems.

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* BRRI, Dhaka, Progress Report: A Preliminary Report on "Applied Research for Irrigation Effectiveness and Crop Production", April 1983.

Gunter Schramm* in a study of the utilization of natural gas in Bangladesh concluded that potentially the highest value use of natural gas produced domestically is as a replacement fuel for petroleum products in non-conventional uses and sectors. This study estimated the economic value of natural gas, which included both the marginal cost of production and user costs, to be less than US$1.00 per mcf for industrial plants using large volumes of gas. The following computations are based upon an economic value of natural gas produced in Bangladesh of US$1.00 per mcf.

The Schramm study also estimated the cost of imported fuel oil to be US$5.26 per mcf-equivalent** and the cost of imported kerosenes to be US$7.74 per mcf-equivalent. The author has estimated the cost of diesel fuel to be approximately US$7.74, the same as kerosene.

Therefore, according to Schramm, in Bangladesh whenever imported fuels can be replaced by domestic natural gas dramatic savings results: For every mcf-equivalent of fuel oil that is replaced by natural gas the savings would be US4.26 and for every mcf-equivalent of kerosene or diesel that is replaced by natural gas the savings would be approximately US$6.74.

An excellent way of accomplishing these savings is to replace fuel oil with natural gas in the generation of electricity. This is a direct substitution of fuels which is considered below.

Electricity* contains 3413 BTU per KWH. However, to produce one KWH of electricity it takes about four times as many BTU of fuel. This is based upon generating plant efficiency of 27 percent and transmission line losses of 2 percent, or an overall efficiency of 25 percent.

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* Schramm, Gunter, "The Economics of Gas Utilization in a Gas-Rich Oil-Poor Country: The Case of Bangladesh", The Energy Journal, Vol. 4, No. 1, 1983.

** 1 cmf-equivalent is equal in volume to 6.30 Imperial gallons of kerosene and diesel fule, to 5.68 Imperial gallons of fuel oil.

The average electric motor at the pump is quite efficient in its use of electricity. In the following calculations the average electric motor is assumed to be 88 percent efficient. Thus, considering all these factors, the power available for irrigation pumping is 22 percent of the BTU available in fuel used to generate the electricity.

Diesel powered engines, on the other hand, are assumed to 25 percent efficient in converting the BTU in fuel into useful work. The cost of fuel for generating electricity is compared to the cost of fuel for powering the average diesel pump unit, using the above assumptions (Table 2).

The economic value of natural gas used in the generation and transmission of electric power is only 15 percent of the cost of diesel fuel. The average deep tubewell in Bangladesh is assumed to operate 1000 hours annually*. Thus, the cost of diesel fuel for the deep tubewell engine is US$1845, asuming the cost of diesel fuel to be US$1.23 per gallon (Imperial Gallons used throughout this analysis). The economic value of natural gas required to produce and transmit the necessary electric power to drive this same pump would be US$270, a savings of 85 percent on fuel cost.

For the average shallow tubewell, assumed to operate 700-hours annually, the cost of diesel fuel is US$430. The economic value of natural gas necessary to produce enough electricity to pump the same amount of water would be only US$63. The average low-lift pump, operating 700 hours annually, uses diesel fuel costing US646. The economic value of natural gas needed to produce and transmit enough electricity to do the same amount of irrigation pump is US$95.

This concludes the review of studies and of views of various individuals in the field of irrigation and water management. Government policies relating to the choice between diesel and electric power are now considered.

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* The deep tubewell is assumed to consume 1.5 gallons of fuel per hour, the shallow tubewell 0.5 gallons per hour and the low-lift pump 0.75 gallons per hour.

Table-2. Cost of Diesel Fuel Used Directly in Irrigation Pumping Compared to the Economic Value of Natural Gas used in Electrical Generation and in Electrical Transmission to the Pump Site.

	Cost of Diesel Fuel	Economic Value of Natural Gas Fuel	Economic Value of Natural Gas Fuel as a percent of the Cost of Diesel Fuel
	(US$)	(US$)	(Percent)
Deep Tubewells	1845	270	15
Shallow Tubewells	430	63	15
--Lift Pumps	646	95	15

Source: Based upon estimate of the economic value of natural gas in Schramm, Gunter, "The Economics of Gas Utilization in a Gas-Rich Oil-Poor Country: The Case of Bangladesh", The Energy Journal, Vol. 4, No. 1, 1983.

III. REVIEW OF GOVERNMENT POLICIES RELATING TO THE CHOICE BETWEEN DIESEL AND ELECTRICITY

Perhaps the most fundamental Government Policy that relates the energy use in irrigation is the policy that attemps to substitute domestic natural gas for imported fuel to the extent feasible. To the degree possible additional fossil-fuel electric generating stations are going to use natural gas. Thus, one could view the generation of electricity as a transformation of domestic natural gas energy to electrical energy. Thus, substitution of electric power for diesel power in irrigation equipment is in effect the substitution of a domestically produced fossil fuel for diesel fuel, that has to be imported.

Individually, some areas are currently served by electricity which is generated at electric generating stations that are fueled by imported fuel. However, with the completion of the East West Interconnector the additional electrical power in all regions of Bangladesh will be generated with domestic natural gas. Thus, use of electricity to power new irrigation equipment is to be preferred over diesel, other variables constnt, in all areas of the country.

At first it seems that with rural Electrification, with new and planned electric generating stations to be fueled with natural gas and with the Interconnector connecting the energy-rich East with the West that everything would favor electrically powered irrigation equipment However, there are two problems with electrical irrigation equipment that must be resolved before electricity can function effectively as a power source in irrigation. Both these problems involve the reliability of electricity from the standpoint of the irrigating farmer.

The first concerns the reliability with which electrical power is supplied to region. The second concerns the security of local electrical lines that are supplying a particular pump.

The following section suggests a framework which will help irrigation project planners decide if there is or is not a reliable electric supply. The security of local electric lines could vary greatly from place to place and it is going to be necessary to do some research to determine how serious a problem it is.

IV. A PRELIMINARY FRAMEWORK FOR MAKING THE CHOICE BETWEEN DIESEL AND ELECTRICITY

Government policy favors the use of electricity over diesel power for irrigation. Studies that were reviewed showed that electricity would lower irrigation costs. Also, several persons familiar with irrigation projects thought that electrified pumps might increase the area under irrigation at the average project a by offering a cheaper and more reliable water supply.

Therefore, tubewells and low-lift pumps that are to remain in a fixed position should be powered by electricity whenever a reliable source of electrical power is available.

Irrigation pumps in areas not having a reliable power supply should be powered with diesel engines. The question of whether to provide these diesel units with the capability for future electrification was not specifically addresseed in this study. However, if it would not be costly, diesel units should be fitted out so that later conversion can be economically carried out.

In order that irrigation pumps be powered by electricity in those area where a reliable supply is available, authorities which are planning tubewell projects are going to have to find out if reliable supplies exist or are likly to exist. That means that water planners are going to have to coordinate their planning with those who are planning the power line network and power supply. To be most effective, there should be coordination throughout the planning process: from long-term planning right up to construction.

As fas as decisions are concerned about the source of power for a pump unit, the goal should be to power as many units as is feasible with electricity. Often, it will probably turn out, planned electric power supply development will lag behind schedule. In these cases the power supply unit is going to have to be changed and therefore, some flexibility should be built into project plans. There will be cases where the reverse is true: where last-minute substitutions of electric power for diesel power will be necessary, although it is probable that there will be fewer of these substitutions.

The location of power transmission lines is based in part on the location of the electric load structure. Tubewells on the other hand made up a substantial fraction of the electric load structure in rural areas. Therefore, the location of tubewells is an important ingredient for the location of tubewells is an important ingredient for the planning of the electrical transmission lines and supply. It is important for good water project planning to know where there is going to be a reliable electric supply.

Information flows in both directions are going to be required for good water planning and for good planning of the electric supply grid. Both planning groups are going to have to alter their plans because of information they receive from the other. Then, after the alterations have been made in their respective plans each planning group has got to inform the other of the revised plan.

Agencies that are funding water development projects and those that are funding electrical distribution projects should see that the necessary coordination occurs. This is a necessary condition for cost-effective completion of a project.

V. LIQUID PETROLEUM GAS AS A POSSIBLE FUEL

Liquid Petroleum Gas (LPG) is a potential fuel for irrigation pumping. With very low cost of conversion LPG can be used as a fuel in 4 cycle gasoline engines. In fact a pump engine can be ordered from the factory in many cases already set up to use LPG fuel and the cost of the unit would be about the same as one set up to run on gasoline. LPG can also be used to provide up to 7/8 of the fuel for any standard diesel engine. In this section a brief synopsis of the LPG industry in Bangladesh is first presented after which LPG use in irrigation is examined.

LPG contains several hyrocarbons including ethane, pantane and hexane but primarily it is a mixture of butane and propane. Under moderate pressure these gases become liquid but when released into the air at atmospheric pressure it becomes an invisible gas. Butane and propane are interchangable in many uses but in industrialized countries most butane goes into the manufacture of gasoline or petrochemical compounds, from which plastics are produced.

LPG Can Originate from two Sources, petroleum refineries and natural gas processing plants. At refineries, it is a product that is normally produced in the refining process along with gasoline, diesel oil, fuel oil, asphalts, etc. When natural gas is brought up from the well, it contains varying quantities of L.P. gases and other hydrocarbon compounds known as "gas liquids". At many natural gas processing plants world-wide, the butane and propane are separated out of "wet" natural gas and prepared for marketing. The natural gas, now "dry", is transported by pipeline to the industrial, commercial and residential user.

In Bangladesh LPG is produced only at Eastern Refinery Limited, the refinery at Chittagong. There it is produced by straight run distillation of crude oil. Although Bangladesh has large natural gas deposits and is producing substantial quantities of natural gas, it does not yet have the processing plants that will separate out the LP gases.

Currently, LPG produced in the refining process at Eastern Petroleum Limited, is moved by pipeline to a Bangladesh Petroleum Corporation (BPC) plant adjacent to the refinery. Here, it is bottled in the LPG plant, which can fill three cylinders at any one time. The actual marketing of LPG is done by three oil companies, MPL, JOCL and BEL. Each company can sell LPG in Chittagong city. The rest of Bangladesh has been divided by BPC into the following marketing areas: MPL's marketing area is west of the Ganges river and includes Khulna and Rajshahi; JOCL's marketing area includes Dhaka and the area north of the Ganges river and west of the Meghna river; while BEL's marketing area includes the area east to the Meghna river and all of southeastern Bangladesh. LPG is currently sold in each marketing area.

Virtually all LPG is put into small cylinders at the LPG plant. These cylinders weigh about 15 to 16 kg when empty and when full contain 12.5 Kg of LPG (26.5 litters). The cylinders are then transported to terminals either by truck, barge, or ship. Sales to retailers are then made from the terminals and the terminals, also make some sales directly to final customers.

In the Chittagong are LPG is used widely as a fuel in 4 cycle engines that have been converted from gasoline. Many trucks and cars in the Chittagong area now are fueled with LPG. The price of LPG is now Tk.110 per cylinder but a price decrease to Tk.95 is under consideration.

LPG seems to have substantial potential in irrigation pumping especially in areas where small portable low lift pumps might be effectively used. The pump chosen for this application should be small so that it could be carried by hand and used to pump into all fields adjacent to existing feeder canals. This portability aspect, in areas where there is adequate surface water, would enable irrigation without long channels. Field to field irrigation could also be employed so that the second field from the feeder canal could be irrigated.

It is suggested that case studies be undertaken with LPG powered pumps to evaluate how effectively they are used and to evaluate how farmers and others react to this technology. One thing that might be tried is to set up irrigation pumping proprietorships where an individual proprietor owned the pump and offered pumping services, in the market, to farmers in the area. Also, the potential of LPG in shallow tubewells should be studied. Agricultural areas adjacent to Chittagong should be considered for these case studies because it is in this area that LPG is now most widely available.

Bangladesh now produces about 6,000 tons annually, up from 4,300 tons in 1982-83. Plans are to increase the output of LPG from the refinery to about 20,000 tons per year. However, the most important thing that could happen in the LPG industry is for the construction of natural gas processing plants that could separate LP gases from the "wet" natural gas. If processing plants were available to provide for this separation, production of LPG from domestic natural gas alone could equal 135,000 tons annually. This LPG gas will be another domestically produced natural resource that could help to fuel agricultural development and economic development generally. It will be helpful to begin soon to determine how LPG might be used in irrigation, so that when LPG is produced in large quantities from domestic resources, planners will know its potential market in irrigation.

Estimates of the cost of extracting LPG from natural gas were also provided in the Schramm* article. Unit extraction costs, exclusive of natural gas costs, were estimated to be US$1.25 per mcf-equivalent in Egypt and US$2.20 per mcf-equivalent in Thailand. The Egyptian cost data were thought to be more representative of Bangladesh because of similarities in their natural gas resources. The natural gas in Thailand, on the other hand, contains a substantial proportion of carbon dioxide and significant cost are involved in separating out this contaminate.

For Bangladesh, the value of LPG at the separation plant would be equal to the economic value of natural gas, US$1.00 per mcf, plus the cost of extraction, which is taken to be equal to that of Egypt, US$1.25 per mcf-equivalent. Total cost of LPG in Bangladesh on the basis of these estimates would be U.S.$2.25 per mcf-equivalent.

Thus, if LPG extraction plants were constructed in Bangladesh and the above described cost prevailed, each mcf-equivalent of imported fuel oil that is replaced by LPG would result in a savings of US$3.00. Each mcf-equivalent of imported kerosene or of diesel fuel that is replaced by LPG would result in savings of US$5.50

Thus, potentially dramatic savings could result from the substitution of LPG for diesel in irrigation pumping, once separation of the LP-gases from natural gas occurs. In order to keep the following analysis simple, transportation costs, both for LPG and for diesel fuel are not considered.

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* Schramm, Gunter, "The Economics of Gas Utilization in a Gas-Rich Oil-Poor Country: The Case of Bangladesh:, The Energy Journal, Vol. 4, No. 1, 1983.

If LPG were to be priced at its economic value its price would be US$0.24 per gallon. Each gallon of LPG contains approximately 109,000 BTU. Each gallon of diesel fuel contains approximately 162,000 BTU and is priced according to the analysis of Schramm at US$1.23; the following analysis also uses Schramm's estimate of the price of diesel fuel. Thus, approximately, one and one-half gallons of LPG have the pumping power of one gallon of diesel fuel. LPG would cost US$0.24 per gallon to produce once the separation plant is in operation, and therefore an amount of LPG necessary to replace one gallon of diesel fuel would cost approximately US0.36.

Thus, for irrigation pumping purposes LPG fuel would cost only about 29 percent of the cost of diesel fuel. Therefore, if the pricing structure were to reflect these values, farmers would reduce their costs dramatically using LPG for irrigation pumping instead of diesel fuel. Table 3 compares the cost of LPG with the cost of diesel fuel in irrigation pumping. The values in the table would apply in the future, when LPG is separated from domestic natural gas. At that time, savings of about 71 percent are projected.

The average cost of fuel for deep tubewells for a season at that time would be reduced from US$1845 to US$531. The cost of fuel for shallow tubewells for a season could be reduced from US$430 to US$124 and the cost of fuel for the average low-lift pump would be reduced from US$646 to US$186. For each type of pump unit, reduction in fuel cost is approximately 71 percent.

Table 3. Average Seasonal Cost of Diesel Fuel Used in Irrigation Pumping Compared to the Estimated Cost of LPG

	Cost of Diesel Fuel	Economic Value of Natural Gas Fuel	Economic Value of Natural Gas Fuel as a percent of the Cost of Diesel Fuel
	(US$)	(US$)	(Percent)
Deep Tubewells	1845	531	29
Shallow Tubewells	430	124	29
Low-Lift Pumps	646	186	29

Source: Estimates of LPG production cost and economic value of natural gas from Schramm, Gunter, "The Economics of Gas Utilization in a Gas-Rich Oil-Poor Country: The Case of Bangladesh", The Energy Journal, Vol. 4, No. 1, 1983.

VI. CONCLUSION AND RECOMMENDATIONS

This study has reviewed recent studies that bear on the choice between electricity and diesel power for tubewells and low-lift pumps. For tubewells and low-lift pumps that are going to remain in a fixed location, electricity is preferred over diesel power where a reliable supply of electricity is to be found. The available research on this question favored electric power over diesel, but there were not overwhelming differences between costs of these power sources. It is rather that the cost differences which do exist coincided with opinions of those in the field of irrigation and water management to create a pervasive climatic of opinion in favor of electricity. Adding additional weight in favor of electricity is that its use in irrigation is consistent with the Bangladesh government's strategy with respect to energy: to substitute domestic natural gas and energy produced from it for imported fuel, to the extent that it is feasible.

Therefore, the first conclusion of this study is that tubewells and low-lift pumps be electrified which are fixed in position and to which a reliable supply of electricity is available. Low-lift pumps that were moved from place to place are likely to have to use diesel power.

The second conclusion of this study is that in order to determine if the electric supply is reliable in a particular area, tubewell and low-lift pump project planners should coordinate their planning with agencies which are planning electric supplies and the routing of transmission lines, REB and PDB.

This study also focused on LPG as a potential fuel and it was found that it could offer substantial future potential for powering irrigation pumps. At the present time LPG is produced from imported crude oil at the refinery in Chittagong. In the future LPG may be produced from domestic natural gas in large quantities and at that time it could be very advantageous for some irrigation pumps to be powered with LPG.

In order to be ready when LPG is produced from domestic natural gas and is available in large quantities, the third recommendation is that a case study be undertaken that involves irrigation with LPG at a number of locations.

It is suggested that the highest priority be given to research to assess how well irrigation projects are functioning. One thing that could be addressed in this work would be the effectiveness of electrically powered and diesel powered irrigation systems. This research should be directed at the estimation of parameters for Bangladesh as a whole and perhaps for regions of the country. In this research it might be possible to use a panel-type design, where a probability sample of irrigation projets is drawn and data collected from the panel each year. The objectives of this study should be to develop unbiased estimators of the area irrigated by minor irrigation projects in the country. In the process of developing these estimates projects that involve cooperatives could be compared to other types of organizations and those using electrical power could be compared to those using diesel.

It is further suggested that BARC determine how rural electrification has affected power use in irrigation and develop research aimed at estimating how future rural electrification is likely to affect energy-use patterns in irrigation This research will help to indicate the likely breakdown between electricity and internal combustion power for irrigation. These indications will in turn be valuable in planning for possible future use of LPG in irrigation.

Finally, it is suggested that BARC organize a workshop that focuses on issues and options concerning power and its relationship to irrigation. Subjects that could be addressed concerning diesel power are maintenance and repair problems, availability of spare parts, problems relating to diesel fuel, and the impact of the various problems on yields and farm income. Subjects that could be addressed concerning electricity are problems of powering deep tubewells with single phase electric power, strategies to counteract power outages, problems of maintenance, and repair of electric equipment. This workshop will be helpful in determining priorities for further research in the area of power use in irrigation.

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