Technology Brief

Harnessing *Hydro Energy* for Off-grid Rural Electrification

Hydro power is considered the largest and most mature application of renewable energy. The installed capacity worldwide is estimated at 630,000 MW, producing over 20 percent of the world's electricity. In the European Union, hydro power contributes at least 17 percent to its electricity supply. Translated in terms of environmental costs, the hydro installations in the European Union are instrumental in avoiding 67 million tons of CO_2 emissions annually.

There is yet no international consensus on how to classify hydro systems by size. The European Small Hydro Association however has included in the definition of small hydro those systems with capacity up to 10 MW. The Philippines has adapted the European nomenclature, but further breaks down "small" systems into "mini" and "micro." RA 7156 defines mini-hydro systems as those installations with size ranging from 101 kW to 10MW. By inference, micro-hydro systems refer to installations with capacity of 100 kW or less.

Small hydro power plants are mainly 'run-off-river' systems since they involve minimal water impounding. As such, they are regarded environmentally benign forms of energy generation. It is estimated that a 5-MW small hydro power plant that can supply power to about 5,000 families, replaces 1,400 tons of fossil fuel and avoids emissions of 16,000 tons of CO_2 and more than 100 tons of SO_2 annually.

In the Philippines, the Department of Energy has identified 1,081 potential sites of small hydro installations that can produce power up to 13,426 MW. There are currently 102 micro-hydro and 45 mini-hydro operational installations, with aggregate rated capacity of 85 MW. Still in the pipeline for development until year 2008 are hydro projects with a total capacity of 76.8 MW. The projected demand for hydro power is expected to reach 0.29 MMBFOE by year 2008.

Table 1
PHILIPPINE HYDROPOWER POTENTIAL

Status	Type	No. of Plants/Sites	Capacity MW	Capacity %	Annual Energy GWh	Annual Energy %
Definite Design	Large	3	1,130.0	8.4	3,312.0	7.6
	Small	2	43.0	0.3	211.1	0.45
	Mini	40	56.0	0.4	245.2	0.56
	SUBTOTAL	45	1,229.0	9.2	3,768.3	8.7
Feasibility Study	Large	17	3,229.8	24.1	10,617.5	24.45
	Small	41	873.1	6.5	3,113.1	7.2
	Mini	25	88.7	0.7	388.6	0.9
	SUBTOTAL	83	4,191.6	31.2	14,119.2	32.5
Pre-FS and Desk Study	Large	37	4,646.0	34.6	11,957.0	27.5
	Small	93	1,721.0	12.8	6,676.5	15.4
	Mini	823	1,638.9	12.2	6,906.6	15.9
	SUBTOTAL	953	8,005.9	59.6	25,540.1	58.8
Total		**1,081**	**13,426.5**	**100.0**	**43,427.6**	**100.0**

Source: *Guide on Mini-Hydropower Development in the Philippines*, Mini-hydro Division, Energy Utilization Management Bureau, Department of Energy, February 1999.

USAID

SATMP

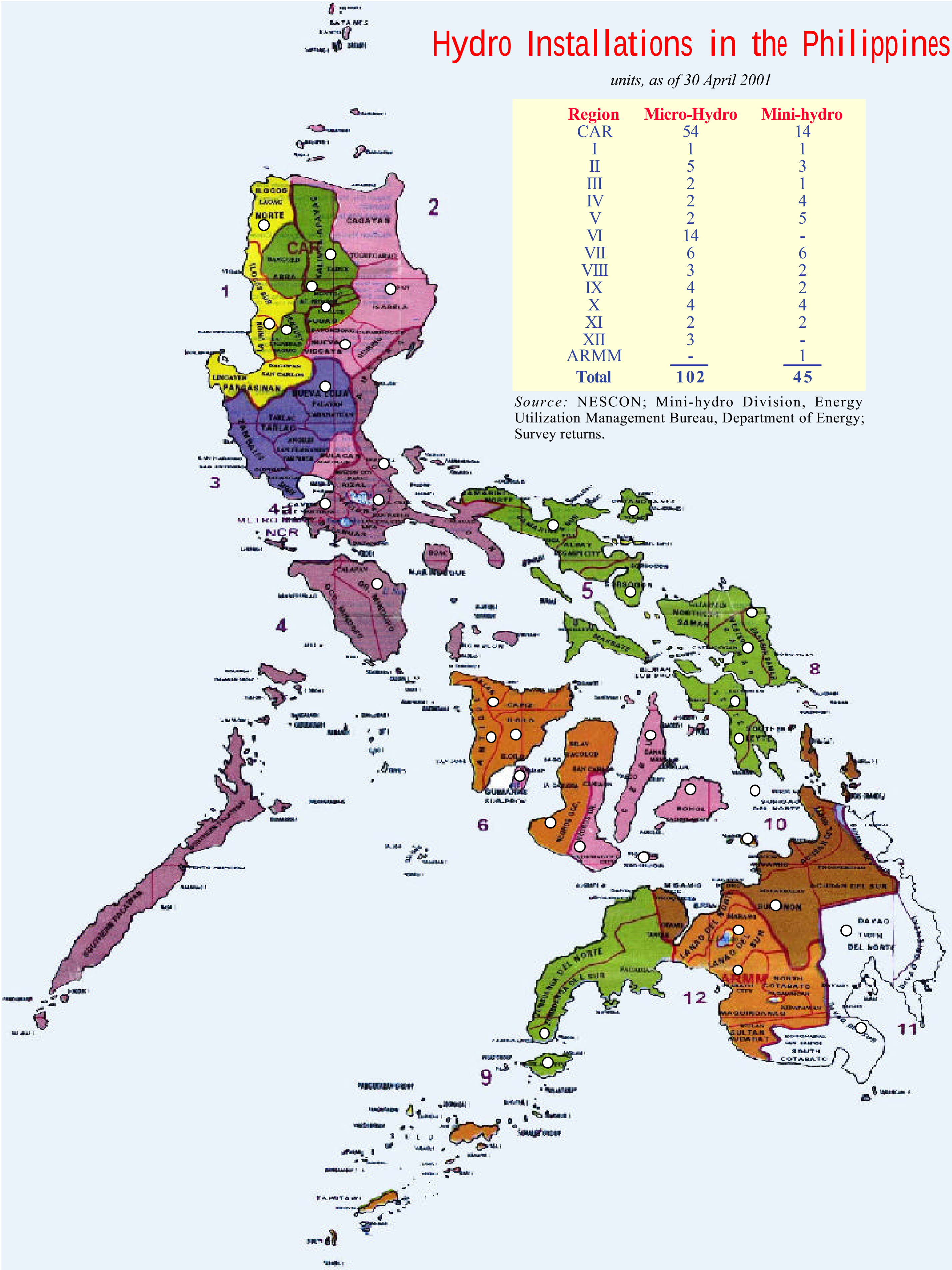
Prepared by the Society for the Advancement of Technology Management in the Philippines with the support of the Department of Energy and U.S. Agency for International Development as part of the *Technical Assistance to the DOE for Enhancing Private Sector Participation in Renewable Energy.*

Hydro Installations in the Philippines

units, as of 30 April 2001

Region	Micro-Hydro	Mini-hydro
CAR	54	14
I	1	1
II	5	3
III	2	1
IV	2	4
V	2	5
VI	14	-
VII	6	6
VIII	3	2
IX	4	2
X	4	4
XI	2	2
XII	3	-
ARMM	-	1
Total	**102**	**45**

Source: NESCON; Mini-hydro Division, Energy Utilization Management Bureau, Department of Energy; Survey returns.



Investing in Small Hydro Power Facilities

In constructing a hydro power system, an artificial water head is created so that water can be diverted through a pipe (penstock) into a turbine where it is discharged usually through a draft tube, or diffused back into the river at a lower level. Various types of turbine have been developed to cope with different sizes of head and flow.

Turbines are of two kinds: impulse and reaction. In impulse turbines (*e.g.,* Pelton), a jet of water impinges on the runner that is designed to reverse the direction of the jet and thereby extract momentum from the water. Reaction turbines (*e.g.*, Francis and Kaplan), run full of water and in effect generate hydrodynamic "lift" forces to propel the runner blades. The sizing of turbines is adapted to the flow characteristics of the river or water stream to be used. The amount of energy captured depends on the sizing strategy. On one hand, the larger the turbine at site, the poorer is its load factor (or capacity factor) since it will only run at rated power for a shorter period. On the other hand, a turbine that is designed to utilize the minimum flow can have a load factor approaching 100 percent, but it will extract less energy than a larger turbine. If the system can be made flexible to account for variations in the flow and volume of water, then its capacity can be maximized throughout the seasons. It will also eschew the need to employ different sizes of turbines, and therefore reduce the investments costs.

In what follows, the economics of small hydro facilities for power generation is explored. The levelized energy costs of the installations are calculated under the following assumptions: (i) 20-year life of the system; (ii) 12 percent capital recovery factor; and (iii) 12 percent cost of loan with repayment amortized over the life of the system.

Table 2 compares the financial costs of installing micro-hydro facility under two possible modes: by contract and by administration. The first is turnkey, while the latter has the proponent administering the project. The basis of the estimates is a 75-kW installation. By contract or turnkey installation is 30 to 40 percent more expensive than self-administered construction. However, in turnkey contracts, the proponent is freed of the supervisory hustles inherent in engineering projects.

Table 2
Economics of Micro-Hydro System
By Mode of Construction, in pesos

	By Contract	By Administration
Capacity (kW)	75	75
Investment cost	29,036,250[a]	20,025,000[b]
Iinvestment Cost per kW	387,150	267,000
Annual cost:		
Operation	500,625	500,625
Maintenance	200,250	200,250
Life-cycle cost	56,111,437	40,322,243
Levelized Cost per kWh	**24.96**	**17.94**

[a] *Excludes distribution cost, estimated at P 47,850 per kW.*
[b] *Excludes distribution cost, estimated at P 33,000 per kW.*

Three installations were selected to demonstrate the economics of mini-hydro facilities: a prospective 550-kW installation in Surigao del Norte, 960-kW installation in Camarines Sur and 1,500-kW installation in Lanao Sur.

Table 3
Economics of Mini-Hydro System
In pesos

	Hydro1	Hydro2	Hdyro3
Capacity (kW)	550	960	1,500
Location	Loreto, Dinagat Is., Surigao del Norte	Inarihan, Camarines Sur	Malabang, Lanao Sur
Year installed	2001*	1998	1995
Historical investment cost	-	48,000,000	40,000,000
Present values:			
Investment cost	42,179,534	67,309,170	70,002,747
Investment cost per kW	76,690	70,114	46,668
Annual Costs:			
Operation	1,182,279	1,496,872	1,253,837
Insurance	105,449	168,273	175,007
Maintenance	227,456	1,871,091	2,696,425
Life-cycle cost	85,282,109	144,350,463	153,469,801
Levelized Cost per kWh	3.78	3.65	1.71

**Scheduled for construction in July 2001.*

Economies of scale is evident in large mini-hydro installations. The Matling project in Lanao Sur highlights major cost differential in power generation compared to smaller systems. The levelized cost is estimated at only P1.71/kwh, or more than 50% compared to the proposed Surigao project. For this reason, some large mini-hydro installations are not only competitive against conventional power systems, but can also be sold below grid electricity prices.

Some Major Small Hydro Installations in the Philippines

1.5-MW Matling Mini-hydro Project in Malabang, Lanao Sur

In 1995, the Matling Industrial and Commercial Corporation (MICC) replaced its 30-year old, four units of 250-KW diesel-fed generators with a 1.5 MW mini-hydro power facility. The decision to shift to environmentally-friendly power source was spurred by increasing market competition confronting MICC. The mini-hydro system can generate power at a levelized cost of P1.71 per kWh, much lower than the cost of diesel-generated power. The system utilizes 6 cu.m. per sec. flow of water and 35 meters head from the Matling River. The river flow has a potential to generate electricity up to 10 MW.

When the project was completed in May 1995, it was the first mini-hydro facility in the Autonomous Region of Muslim Mindanao, and indeed a model case for off-grid electrification. It energizes the 3,000 hectare MICC compound, including the town of Malabang that surrounds the complex.

The dam intake is placed at an elevation of 320 m. and the catchment area at this point is 330 sq. km. The headrace passes on the right bank looking upstream. The water that generates power drops to an elevation of 280 m. for a gross head of 40 m. Two 750-kW generators were set up based on a plan to use half of the power supply internally, and sell the other half to the National Power Corporation.

In present values, the total development cost of the system is P70 million, consisting of P26 million for electro-mechanical equipment sets and the balance of P44 million for civil works. Annual operating cost is estimated at P1.25 million and maintenance cost at P2.69 million. The projected payback period is only 4 years.

960-kW Inarihan Mini-hydro Project in Camarines Sur

The Inarihan Mini-hydro power plant was the first project that availed of the incentives provided to micro-hydro proponents under RA 7156. The project was launched in February 1996 and was completed within two years. It is located in the outskirts of Naga City and operated by the Bicol Hydro power Corporation,

The project is a run-off-the-river scheme utilizing a 1.80-meter high concrete boulder filled weir across a 30-meter wide river. Water flows at a rate of 1.52 cu.m. per sec., passes through an intake structure, and proceeds to a 0.90 m. diameter, 1.6 km-long polyethylene plastic pipe. From the pipeline, the water is temporarily stored in a 55-meter long by 36-meter wide by 4-meter deep concrete lined forebay before it goes through a 0.70-meter by 289-meter long steel high pressure penstock. The water then proceeds to three-Francis type turbines, located at 86 meters below the power intake structure. The system has a capacity for 960 kilowatts of power; annual electricity generation is estimated at 5.30 megawatt-hours.

The actual cost of the project is P48 million (at 1997 prices) or about P50,000 per installed kW. The original project cost estimate was P42 million; an additional P6 million was needed for expenditures on right-of-way acquisition, slope and watershed protection. Annual operating and maintenance expenses are projected at P1.2 million and P1.5 million, respectively. The power will be sold to the Camarines Sur Electric Cooperative II (Casureco II) at a rate of P1.80/kwh, or 5% lower than the rate of the National Power Corporation.

The project enjoys several incentives: (i) tax and duty-free importation of capital equipment sourced from China; (ii) tax credit on Domestic Capital equipment equivalent to 100% of the value of the VAT and custom duties for the local purchase of machinery, equipment, materials and parts; (iii) special Realty Tax rates on equipment and machinery not exceeding 2.5% of original cost; (iv) VAT exemption; and (v) income tax holiday for seven years of operation.

Two problems have surfaced during the first two years of operations. The peak kW capacity utilization is 880 kW or about 92% of the designed capacity. A study has been proposed to determine the reasons for the apparent underperformance of the system and to serve as reference for future designs. The second problem pertains to insufficiency of water. The actual annual generation is about 3-4 million kWh (out of projected 5.3 million kWh) which translates to P6 million in revenues. The full utilization of the three turbines was achieved only for three months of the year due to the depletion of water resource.

Villa Escudero (VESCO) Micro-hydro Project

VESCO maintains an old 75-kW hydroelectric plant that was built in 1937. This unit provided for the electricity requirements of the plantation including a 5-ton ice plant, a coffee mill and other small applications. The expansion of Vesco's corporate activities provided the impetus to develop two micro-hydro systems in 1997: a new 38-KW plant downstream of the original one; and a new 75-kW plant in the original location. These brought total installed capacity to 188-kW, possibly expanding to 230-kW if the feasibility of the third power station is confirmed.

The systems are of the run-off-river type, sourced from two rivers, Bulakin and the Labasin Rivers. The headwaters of the Bulakin river is the Kasunguanan Spring which reaches peak-flows during the dry season while its lowest stream flows occur during the usual monsoon months of July to September. The aggregate watershed area of the two rivers is estimated at 2,000 hectares of lush vegetation and 18 natural springs. The area is also near Mt. Banahaw, the least exploited forest in the country.

The 38-kW plant known as the "Kipot" plant has a calculated net head of four feet or half of the original plant and would have the same optimal flow duration discharge of 1200 liters/second. The second "Resort" plant capacity of 75-kW was based on the confirmed flow of 2,000 liters/second occurring in the original plant site. The annual generation of the two plants is estimated at 573,760 kWh per year. At a project cost estimate of P10 million, the payback period would be about 5 years.

Dakkitan Micro-hydro Project

This project, located in Dakkitan, Hungduan, Ifugao, is a 6-kW micro-hydro which began operation in March 1995. The project is a collaboration among the village association, Samahan ng mga Magsasaka para sa Kabuhayan (SAMAKA), the Ifugao Resource Development Center and the Montanosa Research and Development Center. The micro-hydro project provides power using a Pelton turbine powered by a 32.8-meter head from the Dakkitan River. It runs a rice mill at 3kg/min milled rice capacity including several equipment such as welding, vulcaninzing, blacksmithing, wood polishing and battery charging.

The power cum livelihood project costs about P280,000 including the cost of equipment, amounting to P61,000, that comprises the power load. P93,955 represents capital expenditures for the turbine, powerhouse, intake tank, canal rehabilitation and penstock. SAMAKA's counterpart was valued at P54,000 representing labor contribution.

The project generates revenues close to P7,000 for the community. The accessibility of the ricemill has also saved time for the households. Rice milling expenditures fell by about P 21 per milling due to reduced milling charges and zero transport costs.

Dulao and Gacab Microhydro Power Projects

The projects include a 3-kW cross-flow turbine for a rice mill and a 10-kW two-cell cross-flow turbine with an electronic load controller and instrumentation for Malibcong village electrification. The smaller system was completed in 1995. The project was a close collaboration among the Department of Science and Technology, PCIERD and the De La Salle University (DLSU), in partnership with the host community. A parallel objective in installing a second turbine rather than enhancing the existing 3-kW unit was to allow the DLSU team to perform pilot research.

The system runs a rice mill, provides electricity to 44 households, charges automotive batteries and power carpentry and metalworking tools. It operates twice a day (4:00 to 6:00 a.m. and 6:00 to 9:00 p.m.). Each household has two bulb receptacles; a 20-watt bulb is charged P10 per month.

The two projects involved a cash outlay of P 418,475. This is not the true cost of the system since it excludes volunteer work of local residents and technical consultants. Materials and equipment amounted to P130,000 and P180,000 for the first and second phase, respectively. The project reduced rice milling expenses by 20% to P16 per 12-kg can. Moreover, fuel reduction amounted to a maximum of P160 per month in lieu of P 25 tariff for milling.

A much-improved 20-kW version was also designed, fabricated and installed in Gacab, Malibcong. It provides lighting to 72 households. The Electronic Load Controller (ELC) replaces the expensive and imported governor that regulates the speed of the generator. The ELC imposes a constant load on the generator in spite of changing user's load. The controlling element is the inlet guide vane that controls the flow of water coming from the reservoir through the penstock in a cross-flow turbine. The concept is to close the valve if the generator speed becomes faster and open the valve if the generator slows down. The fuzzy logic controller decides which valve to open, and how much opening will be made, *i.e.,* 1/3, 2/3, or full opening, to regulate the frequency. In this manner, the two-cell cross-flow turbine is a 3-in-1 turbine using two generators of different sizes (10 and 20KVA). The fuzzy logic controller will choose the size of the generator needed for optimum efficiency based on the demand load and select which of the two inlet guide vanes will be utilized.

The cash outlay for the latter project was P580,000; again, volunteer labor and technical help were not valued. Imported capital components amounted to P131,000.

Ngibat Microhydro Project

The 5-KW Ngibat project, located in Tinglayan, Kalinga, provides lighting to 32 households and 15 lamp posts in the village. It also supplies electricity to a rice mill that operates 6 hours daily for an average of 8 days operation in a month, and to blacksmiths working on an average of 8 hours daily for 10 days in a month and for 3 to 4 months in a year. The system load also includes the 500-kWh/month consumption of an electric grinder, drill press, hand drill and grinder.

The project was partly financed by an interest-free loan of P189,000, a grant from Montanosa Research and Development Center of P130,000 and local counterpart labor valued at P64,000. As this is a community-initiated project, households are charged P22 per month, which is equivalent to the avoided fuel costs. Some households are unable to pay the tariff while others are exempted from payment for humanitarian reasons.

Yamog Renewable Energy Development Group, Inc.

In September 1999, the Yamog Renewable Energy Development Group, Inc. constructed a 20-KW Pelton turbine project in Sitio Polokon, Lamanan, Calinan District, Davao City to provide power to 105 households for 24 hours daily during rainy seasons, and for 7 hours daily during normal dry seasons. It derives energy from the strong water flow (50 liters/sec) and head (68 m.) of five contributing natural springs. This project replicates a 3-KW micro project in Sto. Niño, Megkawayan, Calinan that serves 30 households.

The locally-manufactured Pelton turbine has two nozzle jets discharging water that strikes a series of 20 buckets. The bucket splits into two parts so that a central area would not act as a dead spot incapable of deflecting water away from incoming jet. A cut-away notch on the lower lip allows the following bucket to move farther into place before interfering with the jet which is still propelling the earlier bucket. This innovation maximizes the energy provided by the water; the overall hydraulic efficiency of the system is designed at no less than 60%. To economize on cost, the system uses an induction motor to serve as generator. Apart from being more economical compared to the synchronous type of generator, the use of an induction motor-generator is deemed to provide reliability and robustness of the generating equipment.

The project, which costs P890,000, is a collective effort of the community in Polokon. An offshoot of the hydropower project is the rehabilitation of the watershed area. Biodiversity protection and reforestation activities are on-going with the establishment of tree nurseries for hardwood species such as narra, mahogany, lauan and fruit-bearing trees. To provide operating and maintenance expenses for the long-term sustainability of the project, the community has set up a capital replacement fund, a welfare development fund and a maintenance fund. Additional revenues are expected with the establishment of agro-industrial facilities such as corn mill, battery chargers and coffee huller.

Future Developments in Small Hydro in the Philippines

There is a marked shift towards community-based initiatives in developing hydro resources for power generation in tandem with promoting livelihood projects. This is but a natural offshoot, especially in areas where work has been traditionally carried out manually and without the benefit of electricity. With the rising cost of fuel and the constraints imposed by a ballooning budget deficit that causes delay in grid electrification, communities are pressured to seek alternative and cheaper source of energy. Below are illustrative cases of innovation to harness the potential of hydro power.

550-kW Hinubasan Minihydro Project in Loreto, Dinagat Island, Surigao del Norte

This project is a typical case of remote island electrification. It is located in Loreto muunicipality, in Dinagat Island, about four hours by pump boat from Surigao City. The Hinubasan project is envisioned to provide 24-hour power supply to 1,686 households of the municipality. The Development Bank of the Philippines has earmarked P48.5 million funding for the project. Construction is scheduled to commence in July 2001.

The project involves the installation of two 275-kW Turgo impulse turbines at 162 m. net head and flow of 0.228 cu.m per sec per unit. The turbines, generators, governors, control panels and transformers will be sourced from China. It is expected that the costs of generating power from the facility is P2.96 per kWh. This rate compares favorably against the basic power charge in the area of P3.97 per kWh. The proponents expect to recoup their investments within 5 years.

Romblon Mini-hydro Project

This 900-kW mini-hydro project is the second project of the Development Bank of the Philippines (DBP) under its FINESSE program. A pre-feasibility study had been completed. Technical experts attest to exceptionally good resource potential. The Romblon Electric Cooperative, the principal project proponent, is exploring DBP financing for the construction of the plant. The main project is expected to cost about P55 million.

Bubunawan Hydro Project

This 7-MW mini-hydro project, located in Baungon, Bukidnon, has the potential to generate 37.6 MWh of electricity annually. The project proponent is the Bubunawan Power Company. The system was commissioned in the later part of 2000.

Steady Flow Hydro Power Plant

A promising innovation in the hydro energy system has been recently developed by Mr. Cornelio Seno of Laguna. Although still at R&D stage, Seno's invention, dubbed as "Steady Flow Hydro System," received a special citation for innovation in the Nationwide Contest for New and Renewable Energy Systems sponsored by the Philippine National Oil Company last year. The innovation ensures constant flow rate, rotative speed, frequency and voltage for all operating conditions of head and electrical load, while eliminating problems involving water hammer, surging and silting-up.

The need for a speed governor is eliminated since a synchronous speed is assured by a metering pump at the forebay. The pump delivers fixed water flow rate at negligible head from the forebay through the penstock and to the hydro engine. This set up allows the latter to run at synchronous speed with the generator. Since the head of the metering pump is negligible, the pipeworks connecting the forebay and tailrace exert siphoning effect. Consequently, the electric motor is used only to surmount mechanical friction; its power consumption is a small fraction of the total hydropower output. The metering pump and its driver can be conveniently controlled and monitored for performance at the control panel of the generator.

There are other notable innovations in local small hydro facilities that were developed out of necessity to adapt the system to the specificities of local conditions. With proper support, innovations, such as the one developed by Seno, may find commercial applications that will enhance the economic profile of small hydro facilities.

Boosting Hydro Power

Hydropower project proponents have to secure four kinds of permits or licenses to set up a project. Water rights are issued by the National Water Resources Board for the use of water. Once operational, a fee is charged for water use. The Department of Energy provides the clearance for the project. The Environment Management Bureau of the Department of Environment and Natural Resources issues the Environment Clearance Certificate, especially in areas identified as protected areas under the National Integrated Protected Areas System (NIPAS). If the project is located in ancestral domain, a permit must be secured from the affected community and from the National Commission on Indigenous Peoples. It should be noted that part of the revenues arising from NRE installations are mandated by law to redound to tbe benefit of host communities.

RA 7156, also known as the Mini-hydroelectric Power Incentive Act, promulgated on 12 September 1991, provides the necessary incentives and privileges to mini-hydroelectric power developers. The objectives of the Act are as follows:

(i) To encourage entrepreneurs to develop potential sites for hydroelectric power existing in their respective localities;
(ii) To encourage entrepreneurs to develop potential sites for hydroelectric power existing in the country by granting the necessary incentives which will provide a reasonable rate of return;
(iii) To facilitate hydroelectric power development by eliminating overlapping jurisdiction of the many government agencies whose permits, licenses, clearances and other similar authorizations issued by various government agencies as presently required for such development, and by vesting in one agency the exclusive authority and responsibility for the development of mini-hydroelectric power;
(iv) To apportion a part of the realty and special privilege taxes and other economic benefits of the hydroelectric power potential to the respective localities where they are established; and
(v) To provide a contractual framework wherein some stability of conditions can be relied upon for long-term financing purposes.

The Office of Energy Affairs/DOE shall be the sole and exclusive authority responsible for the regulation, promotion and administration of mini-hydroelectric power development and the implementation of the provisions of the Act. Any person authorized to engage in mini-hydroelectric power development shall be granted the following tax incentives or privileges:

(i) Special Privilege Tax Rates limited to two per cent (2%) of gross receipts from the sale of electric power and transactions incident to the generation, transmission and sale of electric power;
(ii) Tax and Duty-free Importation of Machinery, Equipment and Materials applicable within seven (7) years of the award, subject to certain conditions that said machinery, equipment and parts: (i) are not manufactured domestically in reasonable quantity and quality at reasonable prices; (ii) are directly and actually needed in the project; (iii) are covered by shipping documents in the name of the duly registered developer; and (iv) prior approval of the OEA/DOE was obtained before such importation.
(iii) Tax Credit on Domestic Capital Equipment equivalent to 100% of the value of the VAT and customs duties that would have been paid on the machinery, equipment, materials and parts had these items been imported.
(iv) Special Realty Tax Rates on Equipment and Machinery shall be limited to 2.5% of their original cost.
(v) Value-added Tax Exemption on gross receipts derived from the sale of electric power whether through the NPC grid or through existing electric utility lines; and
(vi) Income Tax Holiday for seven (7) years from the start of commercial operation.

Apart from the above incentives, privately-owned mini-hydroelectric power plants shall be eligible for foreign loans and grants without further evaluation by the National Economic and Development Authority.