Technology Brief

Harnessing *Solar Energy* for Off-grid Rural Electrification

Photovoltaics is the most popular technology choice for off-grid rural electrification. In the Philippines, some major socio-economic programs of the government utilize photovoltaics to bring electric power and economic development in remote rural areas.

The main advantage of PV over other renewable energy technologies is its virtually inexhaustible source of power, *i.e.,* the sun. PV converts solar radiation directly into electricity.[1] The geographical location of the Philippines enables it to harness solar energy because of high daily insolation, ranging from 3.5 to 5.2 kWh per square meter, and the low seasonal variation of solar radiation. The solar potential is greatest during the summer months of May to July when the sun is positioned over the Northern Hemisphere. Conversely, the months with the weakest sunlight are November to January.

In addition, PV systems are modular and can be employed for both small and large-scale power generation. High reliability, long lifetime, low maintenance cost and zero fuel requirement of PV modules have made the technology a viable and cost-effective option for remote site applications where the costs of grid extension and maintenance of conventional power supply systems are often prohibitive.

While PV technology is already considered commercial, costs remain high as the industry struggles to make its transition from R&D level production to large-scale manufacturing. Nonetheless, the interest on PV has not waned; worldwide, research and development activities on the technology have been sustained. Since 1975, much of the work on PV is focused on increasing the efficiency and stability of different PV cell technologies and on reducing manufacturing costs. In addition, crystalline silicon cells, the dominant PV cell technology, is profiting from the huge R&D activities in the semiconductor industry. The upshot is a steady decline in the price of PV module – from US$4.75 per Wp in 1990 to the current price of US$3.50 per Wp. By 2010, the price of PV module is forecast to fall between US$1.50 to US$2.00 per Wp.[2] These developments have increased the attractiveness of PV as a technology choice for rural electrification.

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.*

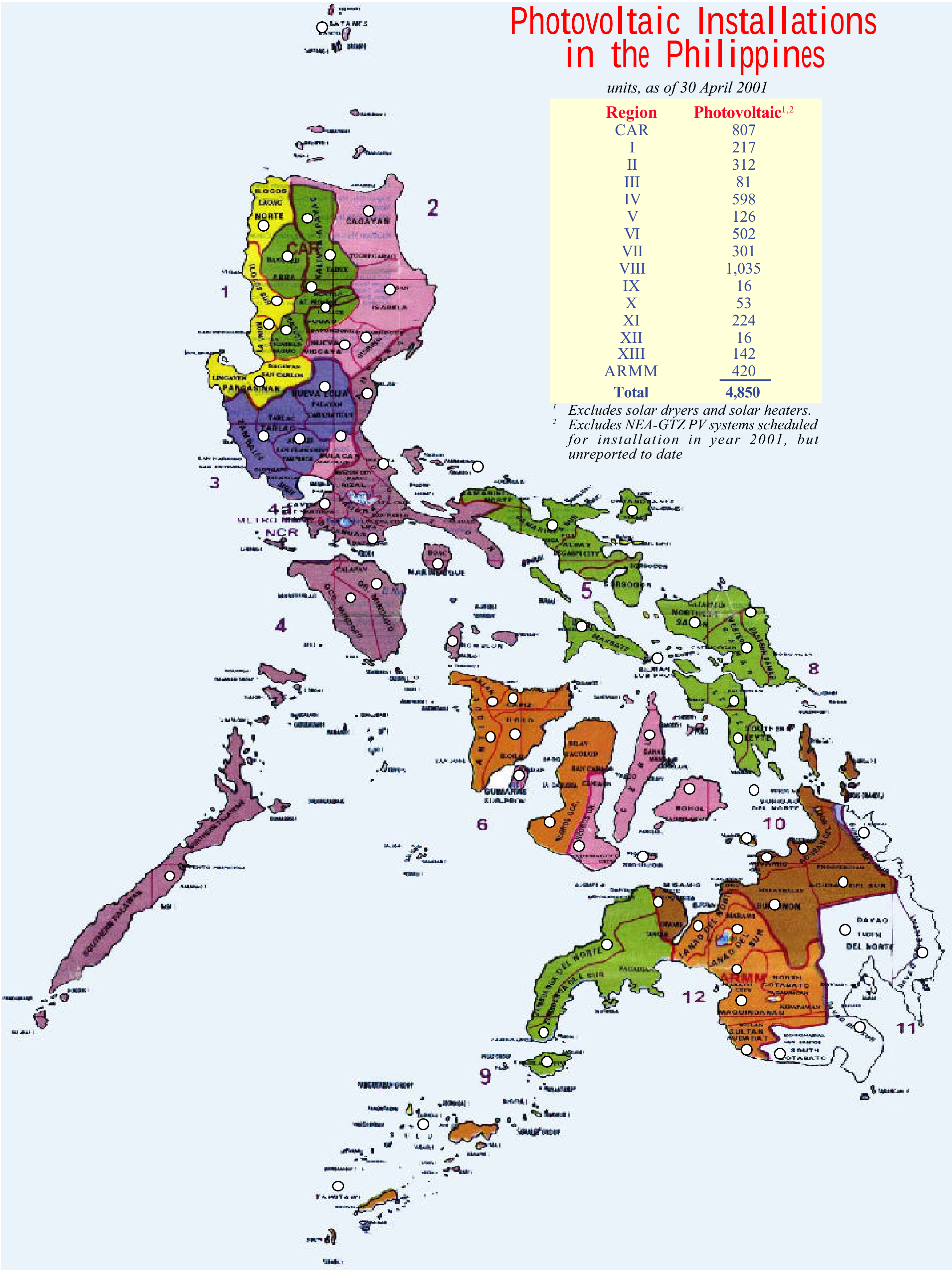
Photovoltaic Installations in the Philippines

units, as of 30 April 2001

Region	Photovoltaic[1,2]
CAR	807
I	217
II	312
III	81
IV	598
V	126
VI	502
VII	301
VIII	1,035
IX	16
X	53
XI	224
XII	16
XIII	142
ARMM	420
Total	**4,850**

[1] *Excludes solar dryers and solar heaters.*

[2] *Excludes NEA-GTZ PV systems scheduled for installation in year 2001, but unreported to date*



Investing in Photovoltaic

As is the case for most renewable energy systems, the biggest hurdle in nurturing the market for PV in rural areas is the large upfront cost. However, because of the modularity of the system (*i.e.,* it can be sized variably depending on the energy requirement of target users), ease of operation and low maintenance costs, PV systems are appropriate supplying the energy needs of low-income rural households.

In what follows, the levelized economic cost of various PV installations are calculated under the following assumptions: (i) aaily insolation of 5 kWh per sq. m. per day; (ii) autonomy period of 3 days; (iii) 20-year life of the PV module; (iv) 12% capital recovery factor; and (v) 12% cost of loan with repayment amortized over the life of the system.

Solar Home Systems

A solar home system consists of PV modules and balance of system components, *i.e.,* battery, charge controller, support and wiring. More than half of the investment cost is due to PV modules. The systems use automotive (shallow-type) batteries that are replaceable every three years.

Since the system is individualized, no operating cost is imputed. The annual maintenance cost represents the value of time of the person charged to periodically refill the battery with distilled water. Utilizing maintenance-free but more expensive battery will reduce the cost of maintenance to nil. In addition, the battery and charge controller are replaced every 3 and 5 years, respectively.

Table 1
Investment Costs of Solar Home Systems
In pesos

	SHS1	SHS2	SHS3	SHS4
Daily load (Wh)	125 – 150	180 – 225	250 – 300	360 – 450
PV (Wp)	50	75	100	150
Battery (A-hr)	70	100	140	200
Controller (A)	5	6	10	12
Typical load	❑ 2 units of 10W lamp at 4 hrs. each ❑ 5W radio at 3 hrs. B&W TV at 2 hrs.	❑ 3 units of 10W lamp at 4 hrs. each ❑ 15W radio at 4 hrs. or 30W 30W B&W TV ar 3 hrs.	❑ 4 units of 10W lamp at 4 hrs. each ❑ 15W radio at 6 hrs. or ❑ 30W B&W TV ar 4 hrs.	❑ 4 units of 10W lamp at 5 hrs. each ❑ 15W radio at 4 hrs.
Investment cost	**26,000**	**35,000**	**43,200**	**57,500**
PV module	13,500	20,000	25,000	36,000
Battery	2,450	3,500	4,900	7,000
Controller	1,750	2,100	3,500	4,200
Auxilliary	2,300	2,400	2,600	2,800
Installation	6,000	7,000	7,200	7,500
Investment Cost per kWh	**520,000**	**466,667**	**432,000**	**383,333**
Annual costs:				
Operation	0	0	0	0
Maintenance	250	350	500	700
Life-cycle cost	54,563	73,711	93,708	125,520
Levelized Cost per kWh	**145.55**	**133.51**	**124.99**	**113.68**

PV Street Lighting System

PV street lighting systems are designed for 12-hour daily operation. Automotive shallow-type battery is used. The sizes of the battery and controller are compatible to the capacity of the PV module. No operating cost is imputed since each system is individualized and therefore the operation involves simple switching of the system. The maintenance of the system entails periodic water refilling of the battery. Thus, as in solar home systems, operation and maintenance costs are kept to the minimum..

Table 2
Investment Costs of PV Street Lighting Systems
In pesos

	PSLS1	PSLS2	PSLS3	PSLS4	PSLS5	PSLS6
Lighting load W	10	12	16	18	23	25
PV (Wp)	50	50	50	75	100	100
Battery (A-hr)	70	100	100	140	140	200
Controller (A)	5	5	6	6	10	10
Investment cost	**27,000**	**28,500**	**35,000**	**37,000**	**43,500**	**45,000**
PV Module	13,500	13,500	19,000	19,000	25,000	25,000
Battery	2,450	3,500	3,500	4,900	4,900	7,000
Charge Cont.	1,750	1,750	1,750	2,100	3,500	3,500
Auxilliary com.	3,300	3,750	3,750	4,000	2,600	2,000
Installation	6,000	6,000	7,000	7,000	7,500	7,500
Investment Cost per kW	**540,000**	**570,000**	**466,667**	**493,333**	**435,000**	**450,000**
Annual costs:						
Operation	0	0	0	0	0	0
Maintenance	250	350	350	500	500	700
Life cycle cost	56,316	61,947	73,336	81,344	94,234	102,867
Levelized Cost per kWh	**172.13**	**157.79**	**140.10**	**138.13**	**125.23**	**125.77**

Battery Charging Stations

Another popular application of PV system is a community battery charging station. The facility is sized according to the target number of household users. For example, a battery charging station can have 2 channels, designed for the use of 10 households whose batteries have load of 70 ampere-hours. At any day, two households can charge their batteries with power supply sufficient for their 5-day use. Assuming an average daily energy requirement of a rural household of about 150 Wh, the station can supply energy equivalent to 1.5 kWh per day.

Table 3
Investment Costs of Battery Charging Stations
In pesos

	BCS1	BCS2	BCS3	BCS4	BCS5	BCS6
No. of households served	10	20	40	10	20	40
Daily load (Wh) per household	150	150	150	150	150	150
Battery (A-hr)	70	70	70	100	100	100
Channel Specs						
PV (Wp)	300	300	300	450	450	450
Controller (A)	25	25	25	36	36	36
No. of channels	2	4	8	2	3	5
Investment cost	**220,000**	**440,000**	**880,000**	**325,000**	**487,500**	**812,500**
PV module	150,000	300,000	600,000	225,000	337,500	562,500
Controller	15,000	30,000	60,000	20,000	30,000	50,000
Other materials	5,000	10,000	20,000	5,000	7,500	12,500
Installation	50,000	100,000	200,000	75,000	112,500	187,500
Investment Cost per kW	**366,667**	**366,667**	**366,667**	**361,111**	**361,111**	**361,111**
Annual costs:						
Operation	6000	6000	6000	6000	6000	6000
Maintenance	0	0	0	0	0	0
Life-cycle cost	446,374	847,932	1,651,047	635,712	931,160	1,522,055
Levelized Cost per kWh	**109.15**	**103.67**	**100.93**	**155.45**	**113.85**	**93.05**

The annual operation costs in Table 3 pertain to the salary of the administrator of the station. No maintenance cost is imputed since the system does not have a battery to maintain. The costs of maintaining the batteries owned by the households are assumed to be on the individual household account.[3] The only replaceable part is the battery charge controller which has an expected life of 5 years.

PV Pumping Stations

Various sizes of PV water pump packages can be deployed in rural communities depending on water source and demand. As in other PV installations, smaller systems have higher investment and levelized costs per output unit.

In this system, the pump controller is typically replaced every 10 years. It is usually designed with a submersible pump and without a battery since the water tank can serve as storage. Operation is simple, thus the operating cost pertains only to the honorarium of the administrator.

Table 4
Investment Costs of PV Pumping Stations
In pesos

	PVP1	PVP2	PVP3	PVP4
Daily water supply (li)	600 – 750	900 – 1,125	1,800 – 2,250	3,000 – 3,750
Head	30	30	30	30
PV (kWp)	0.10	0.15	0.30	0.50
Pump Controller (A)	10 @ 12 V	12 @ 12 V	30 @ 12 V	50 @ 12 V
Investment cost	**78,000**	**104,000**	**195,000**	**312,000**
PV module	25,000	36,000	75,000	110,000
Pump controller	20,000	25,000	40,000	100,000
Other materials	15,000	19,000	35,000	30,000
Installation	18,000	24,000	45,000	72,000
Investment Cost per cu m	**115,556**	**102,716**	**96,296**	**92,444**
Annual costs:				
Operation	6,000	6,000	6,000	6,000
Maintenance	1,800	2,400	4,500	7,200
Life-cycle cost	201,370	253,018	432,980	677,469
Levelized Cost per cu m	**109.42**	**91.66**	**78.43**	**73.63**

	PVP5	PVP6	PVP7	PVP8
Daily water supply (kl)	4.8 – 6.0	9.6 – 12.0	18.0 – 22.5	48.0 – 60.0
Head	30	30	30	30
PV (kWp)	0.8	1.6	3.0	8.0
Pump controller	20 @ 48 V	40 @ 48 V	75 @ 48 V	80 @ 120 V
Investment cost	**520,000**	**715,000**	**1,105,000**	**2,080,000**
PV module	180,000	320,000	600,000	1,350,000
Pump controller	188,000	195,000	215,000	215,000
Other materials	32,000	35,000	35,000	35,000
Installation	120,000	165,000	255,000	480,000
Investment Cost per cu m	**96,296**	**66,204**	**54,568**	**38,519**
Annual costs:				
Operation	6,000	6,000	6,000	6,000
Maintenance	12,000	16,500	25,500	48,000
Life-cycle cost	1,106,107	1,483,645	2,240,654	4,117,077
Levelized Cost per cu m	**75.13**	**50.39**	**40.59**	**27.96**

PV Power Plants

PV power plants are designed to generate electricity of 220 volts. Deep-cycle batteries are used; these are imported and have an expected life of 5 years. The inverter is replaced every 10 years. Its operating cost is significantly higher than other PV installations since the system administrator has to be an engineer. Maintenance expenses increase with the size of the plant.

Table 5

Investment Costs of PV Power Plants

In pesos

	PVPP1	PVPP2	PVPP3	PVPP4
Daily load (kWh)	2.4 – 2.7	7.2 – 8.0	12.0 – 13.5	24.0 – 27.0
No. of households served*	12	36	60	120
PV (kWp)	1	3	5	10
Battery (kWh)	10	30	50	100
Inverter @ 0.6 DF (kW)	1.4	4.5	7.5	12.5
Investment cost	**455,000**	**1,170,000**	**1,755,000**	**3,250,000**
PV module	200,000	600,000	900,000	1,800,000
Battery	45,000	90,000	187,500	375,000
Inverter	60,000	135,000	187,500	250,000
Other materials	45,000	75,000	75,000	75,000
Installation	105,000	270,000	405,000	750,000
Investment Cost per kW	**455,000**	**390,000**	**351,000**	**325,000**
Annual costs:				
Operation	180,000	180,000	180,000	180,000
Maintenance	4,500	9,000	18,750	37,500
Life-cycle cost	2,242,910	3,601,713	4,820,989	7,801,669
Levelized Cost per kWh	**322.62**	**173.83**	**138.69**	**112.21**

* Assumes an average daily load per household of 200 Wh.

One may compare the economic viability of installing solar home systems and constructing a PV power plant. If solar home systems are installed, the investment cost for 120 household amounts to P4.2 million (for SHS2 in Table 1). This is higher than the P3.25 million required by a comparable PV power plant (*i.e.,* PVPP4 in Table 5). The levelized energy costs are P123.98 per kWh for solar home and P104.10 per kWh for PV power plant. In this case, the PV plant is optimal.

On the other hand, a smaller community of 60 households will require investments of P2.1 million and P1.8 million for solar home and PV plant (PVPP3), respectively. But the life-cycle cost of solar home systems is smaller, *i.e.,* P4.1 million, compared to P4.5 million for a PV plant. Corollarily, the levelized cost is lower for solar home, P123.98 per kWh, versus P132.52 for PV plant. Here, solar home system has an advantage over PV plant. Thus, for small communities, solar home systems are more economical than PV power plant. Apart from costs, another consideration is the relative ease of operating and maintaining solar home systems compared to PV plant.

Hybrid systems

Since solar is an intermittent source of energy, photovoltaics are often coupled with other systems that rely on other energy resource, such as diesel, wind, biomass and hydro. PV-generated power is often costlier than those of other systems, thus the size of the PV system is usually determined after the use of other generators has been optimized. Consequently, the contribution of PV to the total system is determined after considering the cost of fuel (diesel, gas or biomass) and availability of other resources (wind speed or water flow).

Table 6 considers the economics of five equally sized hybrid systems. The first system, PV-wind, is imported, hence the huge investment cost of P8.8 million. The large life-cycle cost of this system, P18 million, is due to the kind of battery included in the system. It is estimated that such battery costs P1.5 million with a useful life of 10 years.

The inclusion of battery storage in Hybrid2 and Hybrid4 jacks up the upfront investments but lowers the electricity generation costs. As explained earlier, a hybrid system without a battery requires an automated load regulator that permits greater utilization of renewable resource.

Of the five systems, it is clear that the PV-wind-diesel-battery combination yields the lowest power cost but requires the largest investments compared to other local designs. It is interesting to note that this system is similar to the Atulayan facility recently constructed by Synergy Power, Inc.

Table 6
INVESTMENT COSTS OF HYBRID PV SYSTEMS
In pesos

	Hybrid1 (PV-Wind)	Hybrid2 (PV-Diesel-battery)	Hybrid3 (PV-Diesel)	Hybrid4 (PV-Wind-diesel-battery)	Hybrid5 (PV-Wind-Diesel)
Daily load (kWh)	55	55	55	55	55
PV (kWp)	16	1	1	1	1
Wind (kW)	9			1	1
Diesel (kW)		8	8	8	8
Battery (kWh)	250	25		25	
Inverter (kW)	8	4	1.5	4	1.5
Investment cost	**8,800,000**	**975,000**	**730,000**	**1,300,000**	**1,040,000**
PV module	3,000,000	200,000	200,000	200,000	200,000
Wind turbine	1,800,000			250,000	250,000
Diesel generator		200,000	200,000	200,000	200,000
Battery	1,500,000	150,000		150,000	
Inverter	250,000	100,000	60,000	100,000	60,000
Others	650,000	100,000	90,000	100,000	90,000
Installation	1,600,000	225,000	180,000	300,000	240,000
Investment Cost per kW	**550,000**	**121,875**	**91,250**	**162,500**	**130,000**
Annual costs:					
O & M	280,000	320,000	410,000	320,000	415,000
Life-cycle cost	18,278,399	4,284,656	4,652,710	5,181,284	5,261,625
Levelized Cost per kWh	**121.90**	**28.57**	**31.03**	**34.55**	**35.09**

END NOTES

1 Solar energy can also be converted into electricity by concentrating the radiation in thermal power plants. This would require high incidence of sunshine. Where solar radiation is however diffused as in the Philippines, solar thermal plant is not a relevant option.

2 Renewable Energy World, July-August 2000, p. 59.

3 The situation is different when the battery charging station leases the batteries to the households. In which case, the costs of maintaining the batteries are included in the station's account.

Laws and Regulations Relevant to Renewable Energy Projects

Omnibus Investment Code of 1987 (amended by RA 7918)

The Code provides investment incentives to enterprises registered with the Board of Investments (BOI). NRE projects can be registered with the BOI for its "pioneer" status to avail of the following privileges:

(i) Income tax holiday for 6 years
(ii) Exemption from value-added tax
(iii) Simplified customs procedure
(iv) Unrestricted use of consigned equipment
(v) Employment of foreign nationals
(vi) Deduction on taxable income of expenditures on necessary infrastructure related to project development
(vii) Additional deduction on taxable income of 50% of wages corresponding to the increment in direct labor hired within the first five years of registration
(viii) Deduction on taxable income of expansion expenses if additional deduction for labor expense were not claimed.

Mini-Hydro Power Incentives Act (RA 7156)

Mini-hydro proponents can avail of the following incentives:
(i) Special privilege tax rates of 2% of gross receipts from sale of electric power and from transactions incident to the generation, transmission and sale of electric power
(ii) Tax and duty-free importation of capital equipment, materials and parts
(iii) Tax credit on domestic capital equipment
(iv) Realty tax cap not exceeding 2.5% based on original costs of equipment and machinery
(v) VAT exemption on gross receipts from electricity sales
(vi) Income tax holiday for 7 years

Law on OSW (EO 462, amended by EO 232)

For generation projects exceeding 1 MW, the private sector is allowed to participate in the exploitation, development, utilization and commercialization of ocean, solar and wind (OSW) energy resources, through a production sharing contract with the national or local government. The Department of Energy can extend assistance to OSW developers in obtaining all applicable fiscal and non-fiscal incentives, including registration as pioneer industry with the Board of Investments. In addition, OSW developers can charge the cost of assessment, field verification and feasibilty studies on other sites to their current commercial projects. They can also secure access to lands and/or offshore areas where OSW energy resources can be harnessed.

Agriculture and Fisheries Modernization Act of 1997 (RA 8435)

Apart from providing trade and fiscal incentives on the agricultural and fisheries sectors, the Act provides for duty-free importation of machinery and equipment, including renewable energy systems such as solar panels, provided that such equipment shall be for the exclusive use of the importing enterprise.

Clean Air Act (RA 8749)

The Act sets emission standards on stationary and mobile sources for greenhouse gases, including power plants. NRE projects are favored to the extent that some of its technologies, such as photovoltaics, have zero emissions. But the Act imposes outright ban on incineration facilities which may have adverse impact on biomass combustion facilities. Combustion should be set at very high temperature levels for it to be complete and free of emissions.

National Integrated Protected Areas System (NIPAS) Act of 1992 (RA 7586)

Some areas in the Philippines have been declared protected, thus construction of NRE projects in these sites would require special permit. The Department of Environment and Natural Resources (DENR) issues the Environment Compliance Certificate to projects complying with the environmental standards . For NRE projects that are located in areas considered ancestral domain, the proponent must secure permits from the concerned indigenous communities and the National Commission on Indigenous Peoples.

RA 6957 BOT Law as Amended by RA 7718

Power plants may be constructed under a build-operate-transfer (BOT) scheme whereby the private sector project proponent can recoup its investments through the charging of toll fees and rentals during the contract period. Section 10 of RA 7718 provides that BOT projects in excess of P1 billion shall be entitled to incentives as provided by the Omnibus Investment Code.

DOE Circular No. 2000-03-004

This Circular amends the law that seeks to elicit private sector participation in power generation. Relevant to NRE development are the following proviso:

(1) Companies do not have to show a five-year track record to receive accreditation for NRE generation facilities, provided that the technology being proposed has already achieved commercial status and can be demonstrated to be adaptable to local conditions; or if the project is for self-generation purpose, or the proponent is technically and financially capable.
(2) The provision for spinning reserve imposed on Private Sector Generation Facility shall not apply to RRPPF/NREF projects if (a) the project is not connected to either the national backbone grid, or regional or island mini-grids; or (b) the project is connected to a regional or island mini-grid powered by conventional generation reasonably capable of load following, e.g., peaking or intermediate diesel generation plants. If the RRPF/NREF project is proposed for connection to the national backbone grid, the provision on spinning reserve shall be subject to negotiation with the transmission system operator or from any future regulatory body overseeing the operations of the transmission grid system.
(i) Thermal efficiency requirement for cogeneration facilities using NRE, including hybrid systems has been removed.
(ii) Renewable resource power production facilities are exempt from submitting 10-year power supply agreement and are only required to demonstrate potential net foreign exchange savings by virtue of utilizing renewable energy sources.
(iii) For projects that supply electricity to a designated utility or user, or for internal use, the power development plan review and approval requirements of the Department of Energy shall not be required.

DOE Circular No. 2000-10-011

This Circular mandates the acceleration of Rural Electrification Program by instituting summary procedures in the approval and subsequent release of the electrification fund to the franchised distribution utility or project implementor. Section 2f of the Circular provides that the electrification of target areas should be accomplished in the least-cost possible manner which means either adopting the conventional line design or utilizing indigenous and renewable energy sources.

DOE Circular No. 2000-03-003

This Circular amends the 1994 DOE regulation that prescribes the provision of direct benefits to local government units (LGU) hosting energy resource development projects and/or energy-generating facilities. The amendments streamlined provisions concerning allocation of fund and generation of livelihood projects. Section 7 provides that in cases where the grid type is deemed unavailable for energizing a particular LGU, the electrification fund may be redirected by the DOE in favor of utilizing NRE system to speed up the electrification of the concerned area.