APPENDIX-B

Solar & Wind Power

THE MASTER PLAN STUDY
ON
RURAL ELECTRIFICATION BY RENEWABLE ENERGY
IN THE KINGDOM OF CAMBODIA

FINAL REPORT
VOLUME 5 : APPENDICES

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Appendix-B Solar & Wind Power

1. SOLAR POWER

Table AP-B.1.1 Satellite Data on Annual Average Solar Irradiation

Region	Boundary (In degree)		Elevation (m)	Monthly Averaged Isolation Incident on Horizontal Surface (kWh/m^2/day)											
	Latitude	Longitude		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	10 S - 11 N	103 W - 104 E	29	5.35	5.98	6.21	5.96	5.09	4.28	4.34	3.84	4.26	4.54	5.12	5.35
2	10 S - 11 N	104 W - 105 E	65	5.27	5.69	5.86	5.79	5.01	4.36	4.47	3.89	4.25	4.36	4.86	5.08
3	11 S - 12 N	103 W - 104 E	288	5.26	5.58	5.72	5.56	4.95	3.95	3.99	3.44	3.93	4.30	4.86	5.13
4	11 S - 12 N	104 W - 105 E	106	5.24	5.59	5.74	5.76	5.29	4.57	4.70	4.18	4.54	4.45	4.78	5.01
5	11 S - 12 N	105 W - 106 E	6	5.19	5.70	5.89	5.95	5.54	5.14	5.20	5.09	5.08	4.79	4.92	4.98
6	11 S - 12 N	106 W - 107 E	56	5.30	5.72	5.99	5.96	5.55	5.09	5.17	4.92	4.87	4.70	4.97	5.03
7	12 S - 13 N	102 W - 103 E	212	5.25	5.54	5.73	5.64	4.78	4.30	4.38	4.13	4.32	4.45	4.97	5.19
8	12 S - 13 N	103 W - 104 E	181	5.17	5.64	5.67	5.60	5.24	4.70	4.73	4.37	4.51	4.33	4.49	4.80
9	12 S - 13 N	104 W - 105 E	73	5.35	5.87	6.04	6.09	5.63	5.16	5.21	4.90	4.93	4.66	4.86	4.99
10	12 S - 13 N	105 W - 106 E	47	5.39	5.87	6.03	6.01	5.62	5.18	5.25	4.90	4.76	4.70	4.96	5.11
11	12 S - 13 N	106 W - 107 E	91	5.44	5.91	6.11	5.99	5.57	5.09	5.08	4.63	4.75	4.71	5.01	5.16
12	12 S - 13 N	107 W - 108 E	488	5.37	5.96	6.16	5.92	5.45	4.87	4.84	4.51	4.65	4.55	4.76	4.94
13	13 S - 14 N	102 W - 103 E	92	5.16	5.60	5.71	5.76	5.20	4.80	4.73	4.55	4.66	4.54	4.83	4.95
14	13 S - 14 N	103 W - 104 E	24	5.28	5.79	5.90	5.98	5.59	5.09	5.17	4.87	4.88	4.66	4.87	4.96
15	13 S - 14 N	104 W - 105 E	70	5.34	5.82	5.95	5.99	5.67	5.16	5.24	4.84	4.69	4.62	4.94	5.03
16	13 S - 14 N	105 W - 106 E	71	5.46	5.90	6.05	6.04	5.58	5.07	5.12	4.59	4.66	4.72	5.04	5.19
17	13 S - 14 N	106 W - 107 E	107	5.51	5.99	6.16	6.01	5.51	4.91	4.95	4.50	4.69	4.72	4.98	5.17
18	13 S - 14 N	107 W - 108 E	221	5.44	6.04	6.26	6.04	5.51	4.73	4.73	4.24	4.63	4.69	4.84	5.01
19	14 S - 15 N	103 W - 104 E	131	5.25	5.76	6.02	6.12	5.71	5.18	5.19	4.90	4.91	4.61	4.86	4.99
20	14 S - 15 N	104 W - 105 E	126	5.30	5.76	5.95	6.02	5.69	5.12	5.20	4.79	4.78	4.62	4.90	5.00
21	14 S - 15 N	106 W - 107 E	304	5.41	5.81	5.92	5.84	5.29	4.59	4.59	4.09	4.51	4.71	4.92	5.07
22	14 S - 15 N	107 W - 108 E	660	5.38	5.91	6.05	5.88	5.21	4.33	4.34	3.84	4.42	4.59	4.73	4.99
			Average	**5.32**	**5.79**	**5.96**	**5.90**	**5.39**	**4.80**	**4.84**	**4.45**	**4.62**	**4.59**	**4.88**	**5.05**
			Minimum	**5.16**	**5.54**	**5.67**	**5.56**	**4.78**	**3.95**	**3.99**	**3.44**	**3.93**	**4.30**	**4.49**	**4.80**
			Maximum	**5.51**	**6.04**	**6.26**	**6.12**	**5.71**	**5.18**	**5.25**	**5.09**	**5.08**	**4.79**	**5.12**	**5.35**

Data Source : http//: eosweb.larc.nasa.gov

Table AP-B.1.2 Satellite Data on No Sun or Black Days

Reigon	Boundary (In degree)		Elevation (m)	Equivalent Number of NO-SUN Or BLACK Days (days)												Annual Average (day)
	Latitude	Longitude		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	10 S - 11 N	103 W - 104 E	29	2.25	1.35	1.49	2.51	3.46	5.95	6.77	5.73	9.34	2.38	4.45	1.85	3.96
2	10 S - 11 N	104 W - 105 E	65	1.88	2.11	2.16	1.76	3.27	6.05	6.31	6.93	6.14	2.41	4.07	2.31	3.78
3	11 S - 12 N	103 W - 104 E	288	2.76	2.25	2.87	2.64	4.88	3.64	7.38	7.20	8.32	3.59	3.08	1.93	4.21
4	11 S - 12 N	104 W - 105 E	106	2.42	1.25	3.32	2.60	4.10	6.69	5.40	6.37	3.70	3.55	4.07	2.09	3.79
5	11 S - 12 N	105 W - 106 E	6	1.31	1.12	1.47	1.31	2.18	5.01	4.29	3.89	2.42	2.32	2.56	1.43	2.44
6	11 S - 12 N	106 W - 107 E	56	1.52	1.02	1.91	1.61	1.67	2.23	4.13	3.15	3.44	3.29	2.53	1.35	2.32
7	12 S - 13 N	102 W - 103 E	212	3.48	1.31	3.08	2.81	1.94	2.36	4.30	5.16	7.08	4.11	3.07	1.97	3.38
8	12 S - 13 N	103 W - 104 E	181	2.75	1.43	2.51	2.62	2.83	3.51	5.11	4.61	4.12	2.86	4.74	1.86	3.24
9	12 S - 13 N	104 W - 105 E	73	1.50	1.47	1.33	1.72	1.87	3.60	3.98	3.98	3.16	2.46	2.96	1.18	2.43
10	12 S - 13 N	105 W - 106 E	47	1.61	0.76	2.05	1.19	1.59	3.35	4.13	3.03	2.14	3.10	3.20	1.33	2.29
11	12 S - 13 N	106 W - 107 E	91	1.48	1.46	1.62	1.70	1.78	2.00	5.43	4.40	2.52	4.14	3.64	0.84	2.58
12	12 S - 13 N	107 W - 108 E	488	1.50	1.31	2.01	1.46	1.99	3.57	4.79	4.39	1.54	4.14	3.15	1.56	2.61
13	13 S - 14 N	102 W - 103 E	92	2.16	1.95	1.52	2.55	1.60	3.67	4.58	4.82	3.02	1.98	3.78	1.75	2.78
14	13 S - 14 N	103 W - 104 E	24	1.87	1.40	1.99	2.25	2.71	4.82	4.43	3.24	3.68	1.79	4.18	1.62	2.83
15	13 S - 14 N	104 W - 105 E	70	2.08	1.01	1.97	1.65	1.42	5.23	3.31	2.94	2.68	2.28	3.40	1.60	2.46
16	13 S - 14 N	105 W - 106 E	71	1.76	1.47	2.10	0.94	1.27	2.54	3.39	4.38	3.47	4.13	4.16	1.43	2.58
17	13 S - 14 N	106 W - 107 E	107	1.46	1.21	1.61	0.94	1.29	2.26	2.56	4.27	3.39	4.40	4.15	0.95	2.37
18	13 S - 14 N	107 W - 108 E	221	0.91	1.01	1.68	0.94	2.36	3.17	4.32	5.84	4.65	5.35	4.15	1.29	2.97
19	14 S - 15 N	103 W - 104 E	131	1.59	1.36	2.00	2.40	1.90	3.18	3.04	3.98	3.48	2.42	2.77	1.86	2.49
20	14 S - 15 N	104 W - 105 E	126	1.28	1.40	2.44	2.84	1.68	3.39	3.39	2.97	3.07	2.28	2.87	1.61	2.43
21	14 S - 15 N	106 W - 107 E	304	1.14	1.83	1.72	2.36	2.05	2.87	4.11	4.46	3.32	4.73	3.10	1.58	2.77
22	14 S - 15 N	107 W - 108 E	660	0.74	1.37	2.25	3.06	3.03	2.42	5.71	7.10	3.52	5.45	3.17	1.49	3.27
			Average	**1.79**	**1.40**	**2.05**	**1.99**	**2.31**	**3.70**	**4.58**	**4.67**	**4.00**	**3.32**	**3.51**	**1.58**	**2.90**

Data Source : http//: eosweb.larc.nasa.gov

Table AP-B.1.3 Details of PV System Sizing for Solar BCS

	Size of PV system for BCS	For 100 Ah Battery				For 70 Ah Battery				For 50 Ah Battery			
		Min. Insolation		Avg. Insolation		Min. Insolation		Avg. Insolation		Min. Insolation		Avg. Insolation	
	Parameter	**Value**	**Unit**	**Value**	**Unit**	**Value**	**Unit**	**Value**	**Unit**	**Value**	**Unit**	**Value**	**Unit**
1	Total DC Current is (50% DOD)	50.0	Ah/day	50.0	Ah/day	35.0	Ah/day	35.0	Ah/day	25.0	Ah/day	25.0	Ah/day
2	Solar Irradiation	**4.6**	h/day	**5.1**	h/day	**4.6**	h/day	**5.1**	h/day	**4.6**	h/day	**5.1**	h/day
3	Module derating factor	10	%	10	%	10	%	10	%	10	%	10	%
4	Charge Controller (C/C) consumption	10	mA/h	10	mA/h	10	mA/h	10	mA/h	10	mA/h	10	mA/h
5	Total Charging hour In a day	8	h/day	8	h/day	8	h/day	8	h/day	8	h/day	8	h/day
6	Total Consumption by Charge controller	**0.08**	Ah/day	**0.08**	Ah/day	**0.08**	Ah/day	**0.08**	Ah/day	**0.08**	Ah/day	**0.08**	Ah/day
7	System voltage is	12	V DC	12	V DC	12	V DC	12	V DC	12	V DC	12	V DC
8	Columbic efficiency (Charging eff. of Battery)	90	%	90	%	90	%	90	%	90	%	90	%
9	Required voltage for charging*	16.0	V	16.0	V	16.0	V	16.0	V	16.0	V	14.5	V
10	Required DC current to charge each battery	**61.8**	Ah/day	**61.8**	Ah/day	**43.3**	Ah/day	**43.3**	Ah/day	**30.9**	Ah/day	**30.9**	Ah/day

[yellow box] **= Input Value**

* Even at higher ambient temperature system need to charge battery efficently, for this out put of C/C need to be at around 13.5 to 14Volts. Therefore, here total loss of the system is considered to be 2.0 Volts.

Total nos. of households to be covered	**0 to 25** HH		**26 to 50** HH		**51 to 75** HH		**76 to 100** HH	
100Ah Capacity battery 20% of total household	5.0	nos.	10.0	nos.	15.0	nos.	20.0	nos.
70Ah Capacity battery 50% of total household	12.5	nos.	25.0	nos.	37.5	nos.	50.0	nos.
50Ah Capacity battery 30% of total household	7.5	nos.	15.0	nos.	22.5	nos.	30.0	nos.

Charging interval is in every	5	day
Size of each module is (Example)	50	Wp
Each module produce (Ipm) current	3.00	Amp

Total System Capacity

	Household nos. 0 to 25				**Household nos. from 26 to 50**				**Household nos. from 51 to 75**				**Household nos. from 76 to 100**			
	At 4.6	**h/day**	**At 5.1**	**h/day**	**At 4.6**	**h/day**	**At 5.1**	**h/day**	**At 4.6**	**h/day**	**At 5.1**	**h/day**	**At 4.6**	**h/day**	**At 5.1**	**h/day**
Required total DC current for charging	**217**	Ah/day	**217**	Ah/day	**433**	Ah/day	**433**	Ah/day	**650**	Ah/day	**650**	Ah/day	**866**	Ah/day	**866**	Ah/day
Required power to charge	**3.5**	kW/day	**3.5**	kW/day	**6.9**	kW/day	**6.9**	kW/day	**10.4**	kW/day	**10.4**	kW/day	**13.9**	kW/day	**13.9**	kW/day
Total current generation by each module	12.1	Ah/day	13.4	Ah/day	12.1	Ah/day	13.4	Ah/day	12.1	Ah/day	13.8	Ah/day	12.1	Ah/day	13.4	Ah/day
Number of modules in parallel	19.9	no.	18.0	no.	39.8	no.	35.9	no.	59.7	no.	52.4	no.	79.6	no.	71.8	no.
Total Number of module in parallel (Rounded u	20.0	no.	18.0	no.	40.0	no.	36.0	no.	60.0	no.	53.0	no.	80.0	no.	72.0	no.
Number of module in series (12V nominal)	1.0	no.	1.0	no.	1.0	no.	1.0	no.	1.0	no.	1.0	no.	1.0	no.	1.0	no.
Current produced by system	52.6	Ah	47.3	Ah	105.1	Ah	94.6	Ah	157.7	Ah	143.1	Ah	210.2	Ah	189.2	Ah
Total Current produce by the system	241.8	Ah/day	241.3	Ah/day	483.6	Ah/day	482.5	Ah/day	473.0	Ah/day	429.3	Ah/day	967.1	Ah/day	965.0	Ah/day
Total PV Capacity	**1.00**	kWp	**0.90**	kWp	**2.00**	kWp	**1.80**	kWp	**3.00**	kWp	**2.65**	kWp	**4.00**	kWp	**3.60**	kWp
Total power generation by the system	4.1	kWp/day	4.1	kWp/day	8.3	kWp/day	8.3	kWp/day	12.4	kWp/day	12.2	kWp/day	16.6	kWp/day	16.5	kWp/day

Required Capacity of PV	**at 4.6**	**at 5.1**	$kWh/m^2/day$
for 0 to 25 households	1.0	0.9	kWp
for 26 to 50 households	2.0	1.8	kWp
for 51 to 75 households	3.0	2.7	kWp
for 76 to 100 households	4.0	3.6	kWp

Roundup Capacity of PV System	**at 4.6**	**at 5.1**	$kWh/m^2/day$
for 0 to 25 households	**1.0**	**1.0**	kWp
for 26 to 50 households	**2.0**	**2.0**	kWp
for 51 to 75 households	**3.0**	**3.0**	kWp
for 76 to 100 households	**4.0**	**4.0**	kWp

Value from this table is used to calculate system cost

From the detail calculation it is clear that if total capacity is rounded up to a digit than even thought solar irradiation varies (in this case) the out put is same.

Source: JICA Study Team

Table AP-B.1.4 Cost Estimation of PV System for Solar BCS

Required no. of Charge Controller	**Min**	**Avg**	**Unit**
for 0 to 25 households	**5.0**	**5.0**	nos.
for 26 to 50 households	**10.0**	**10.0**	nos.
for 51 to 75 households	**15.0**	**15.0**	nos.
for 76 to 100 households	**20.0**	**20.0**	nos.

Present International Market price	**Unit**	**Cost**
Photovoltaic (PV) module	**3.7**	US$/Wp
Charge Controller (C/C) with Amp Hour Meter	**265.0**	US$/pcs.

Item		**Cost of System (US$)**							
		for 0 to 25 HH		**for 26 to 50 HH**		**for 51 to 75 HH**		**for 76 to 100 HH**	
		at 4.6 $kWh/m^2/day$	at 5.1 $kWh/m^2/day$	at 4.6 $kWh/m^2/day$	at 5.1 $kWh/m^2/day$	at 4.6 $kWh/m^2/day$	at 5.1 $kWh/m^2/day$	at 4.6 $kWh/m^2/day$	at 5.1 $kWh/m^2/day$
Photovoltaic (PV) module	(a)	3,700	3,700	7,400	7,400	11,100	11,100	14,800	14,800
Charge controller (C/C)	(b)	1,325	1,325	2,650	2,650	3,975	3,975	5,300	5,300
Accessories cost 15% {(a+b) * 15%} (Structure, Breaker, Wires etc.)		754	754	1,508	1,508	2,261	2,261	3,015	3,015
Charging Station (Shade/House) cost		500	500	900	900	1,300	1,300	1,700	1,700
Total Cost		**6,279**	**6,279**	**12,458**	**12,458**	**18,636**	**18,636**	**24,815**	**24,815**

Note: (1) System is calculated on the base of country annual average ($5.1kwh/m^2/day$) and minimum average (4.6kwh/m2/day) solar Irradiation
(2) From the calculation it is clear that even thought system is deigned for different irradiation if out put is rounded up it does not differ
(3) Capacity of PV System is calculated on the base of 3.0 Imp, 50Wp module for reference.
(4) Required Capacity is rounded up to minimize the differences between seasonal average solar Irradiation
(5) PV system need to generate enough voltage to charge battery even at higher Ambient Temp (35 deg Celsius) and C/C must supply 13.5V and above.

Source: JICA Study Team

Table AP-B.1.5 PV System Designing for Typical Public Facilities (1/3) [Health Post]

DC Loads of Health post	Value	Unit	Quantity	Total Load (Watts)	Using (hours)	Total Load (kWh/day)
Lights (FL) 20 Watt	24.0	Watts	4	96.00	3.0	0.29
Lights (FL) 40Watt	48.0	Watts	4	192	3.0	0.58
			Total load	**288**		**0.86**

= **Input Values**

Array Sizing parameter			
Incline Solar Irradiation (Avg)	5.1	kWh/m²/day	
Module derating factor	10	%	Normally **10%**
If size of each module is	50.0	Wp	
If each module produce (Ipm) current	3.00	Amp	
Load			
Total power consumption at DC side	**0.86**	kWh/day	
Peak load	**0.29**	kWh	
Columbic efficiency	90	%	Normally **90%**
Charge controller Consumption	20	mA/h	
Total Consumption by Charge controller	**0.5**	Ah/day	
If System voltage is	12	V DC	
Hour In a day	24	h	
Battery Sizing parameter			
Battery Depth of Discharge (DOD)	80	%	
Days of Autonomy	3	days	
Rate Factor	1.3		

$$\textbf{Rate Factor} = \frac{\text{Ah (Calculated hour rate)}}{\text{Ah (Standard hour rate of manufacturer)}}$$

$$\textbf{Avg. Rate of Discharge} = \frac{\text{3 days x 24 hours/day}}{\text{0.8 max. discharge}}$$

Therefore,	***Value***	***Unit***
Total DC Load is	**1.00**	kWh/day
Total DC Load Current is	**83.3**	Ah/day
Average rate of Discharge	**90**	**hours rate**
Total current generation by each module	**13.8**	Ah/day
Number of modules in parallel	**6.7**	no.
Number of module in parallel (Rounded up)	**7**	no.
Number of module in series (12V nominal)	**1.0**	no.
Total number of module	**7.0**	no.
Total required PV Capacity for the system	**350.0**	Wp
Total power generation by the system	**1.6**	kWp/day
Total Current produce by the system	**96.4**	Ah/day
Size of Charge controller *(Rounded up)*	**19.0**	Amp
Required Battery capacity (Calculated hours rate)	**313**	Ah
Required Battery capacity *(at 10 hours rate)*	**240**	Ah

Note: First chose the size of battery in **Calculated hours rate**.
If not available bring the battery at manufactures standard rate.
For this if you don't know any value then average Rate factor is **1.3** (safety value)

(Source: JICA Study Team)

Table AP-B.1.6 PV System Designing for Typical Public Facilities (2/3) [Night School]

DC Loads of Night school	Value	Unit	Quantity	Total Load (Watts)	Using (hours)	Total Load (kWh/day)
Lights (FL) 20 Watt	24.0	Watts	4	96.00	3.0	0.29
Lights (FL) 40Watt	48.0	Watts	10	480	3.0	1.44
			Total load	**576**		**1.73**

= **Input Values**

Array Sizing parameter			
Incline Solar Irradiation (Avg)	5.1	kWh/m²/day	
Module derating factor	10	%	Normally **10%**
If size of each module is	50.0	Wp	
If each module produce (Ipm) current	3.00	Amp	
Load			
Total power consumption at DC side	**1.73**	kWh/day	
Peak load	**0.58**	kWh	
Columbic efficiency	90	%	Normally **90%**
Charge controller Consumption	20	mA/h	
Total Consumption by Charge controller	**0.5**	Ah/day	
If System voltage is	12	V DC	
Hour In a day	24	h	
Battery Sizing parameter			
Battery Depth of Discharge (DOD)	80	%	
Days of Autonomy	3	days	
Rate Factor	1.3		

$$\textbf{Rate Factor} = \frac{\text{Ah (Calculated hour rate)}}{\text{Ah (Standard hour rate of manufacturer)}}$$

$$\textbf{Avg. Rate of Discharge} = \frac{\text{3 days x 24 hours/day}}{\text{0.8 max. discharge}}$$

Therefore,	***Value***	***Unit***
Total DC Load is	**1.96**	kWh/day
Total DC Load Current is	**163.3**	Ah/day
Average rate of Discharge	**90**	**hours rate**
Total current generation by each module	**13.8**	Ah/day
Number of modules in parallel	**13.2**	no.
Number of module in parallel (Rounded up)	**14**	no.
Number of module in series (12V nominal)	**1.0**	no.
Total number of module	**14.0**	no.
Total required PV Capacity for the system	**700.0**	Wp
Total power generation by the system	**3.2**	kWp/day
Total Current produce by the system	**192.8**	Ah/day
Size of Charge controller *(Rounded up)*	**38.0**	Amp
Required Battery capacity (Calculated hours rate)	**613**	Ah
Required Battery capacity *(at 10 hours rate)*	**471**	Ah

Note: First chose the size of battery in **Calculated hours rate**.
If not available bring the battery at manufactures standard rate.
For this if you don't know any value then average Rate factor is **1.3** (safety value)

(Source: JICA Study Team)

Table AP-B.1.7 PV System Designing for Typical Public Facilities (3/3) [Community Hall]

DC Loads of Community hall	Value	Unit	Quantity	Total Load (Watts)	Using (hours)	Total Load (kWh/day)
Lights (FL) 20 Watt	24.0	Watts	2	48.00	2.0	0.10
Lights (FL) 40Watt	48.0	Watts	4	192	2.0	0.38
			Total load	**240**		**0.48**

(Yellow) = **Input Values**

Array Sizing parameter			
Incline Solar Irradiation (Avg)	5.1	kWh/m^2/day	
Module derating factor	10	%	Normally **10%**
If size of each module is	50.0	Wp	
If each module produce (Ipm) current	3.00	Amp	

Load			
Total power consumption at DC side	**0.48**	kWh/day	
Peak load	**0.24**	kWh	
Columbic efficiency	90	%	Normally **90%**
Charge controller Consumption	20	mA/h	
Total Consumption by Charge controller	**0.5**	Ah/day	
If System voltage is	12	V DC	
Hour In a day	24	h	

$$\textbf{Rate Factor} = \frac{\text{Ah (Calculated hour rate)}}{\text{Ah (Standard hour rate of manufacturer)}}$$

Battery Sizing parameter		
Battery Depth of Discharge (DOD)	80	%
Days of Autonomy	3	days
Rate Factor	1.3	

$$\textbf{Avg. Rate of Discharge} = \frac{\text{3 days x 24 hours/day}}{\text{0.8 max. discharge}}$$

Therefore,	***Value***	***Unit***
Total DC Load is	**0.57**	kWh/day
Total DC Load Current is	**47.8**	Ah/day
Average rate of Discharge	**90**	**hours rate**
Total current generation by each module	**13.8**	Ah/day
Number of modules in parallel	**3.9**	no.
Number of module in parallel (Rounded up)	**4**	no.
Number of module in series (12V nominal)	**1.0**	no.
Total number of module	**4.0**	no.
Total required PV Capacity for the system	**200.0**	Wp
Total power generation by the system	**0.9**	kWp/day
Total Current produce by the system	**55.1**	Ah/day
Size of Charge controller *(Rounded up)*	**11.0**	Amp
Required Battery capacity (Calculated hours rate)	**179**	Ah
Required Battery capacity *(at 10 hours rate)*	**138**	Ah

(Source: JICA Study Team)

Note: First chose the size of battery in **Calculated hours rate**.
If not available bring the battery at manufactures standard rate.
For this if you don't know any value then average Rate factor is **1.3** (safety value)

Table AP-B.1.8 Cost Estimation of PV System for Typical Public Facilities

Cost of component		
Item	Cost	Unit
Photovoltaic (PV) Module	3.7	US$/Wp
Charge Controller (12Ah)	95	US$/pcs
Charge Controller (20Ah)	115	US$/pcs
Charge Controller (40Ah)	220	US$/pcs
Battery (Deep cycle)	1.47	US$/Ah
Light (FL) 20W	15	US$/set
Light (FL) 40W	30	US$/set

Note: (1) Prices are on large volume purchase.
(2) Charge controller (C/C) is adjusted to the available size

Cost of System									
Item	Photovoltaic PV (a)		Charge controller (b)		Battery (d)		Light (e)	Accessories Cost (a+b+d+e)*20 % (f)	Total (before Taxes)
	Wp	US$	Ah	US$/pcs	Ah	US$	US$	US$	US$
Health Post	350	1,295	20	115	240	354	180	389	2,333
Night School	700	2,590	40	220	471	695	360	773	4,638
Community Hall	200	740	12	95	138	203	150	238	1,426

Note: Accessories includes Switch, Wires, Structure etc.
(Source: JICA Study Team)

2. WIND POWER

Table AP-B.2.1 Satellite Data on Annual Average Wind Speed at 50m above Ground Level

Reigon	Boundary (In degree)		Elevation (m)	Monthly Averaged Wind Speed at 50m above Surface of the Earth (m/s)												Annual Average (m/s)
	Latitude	Longitude		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	10 S - 11 N	103 W - 104 E	29	3.55	3.60	3.66	3.11	3.00	4.09	4.00	4.38	3.36	3.14	4.32	4.46	3.72
2	10 S - 11 N	104 W - 105 E	65	2.78	2.82	2.97	2.61	2.43	2.88	2.88	2.99	2.24	2.37	3.28	3.41	2.80
3	11 S - 12 N	103 W - 104 E	288	3.31	3.20	3.19	2.77	2.60	3.50	3.44	3.65	2.72	2.80	3.88	4.13	3.26
4	11 S - 12 N	104 W - 105 E	106	2.67	2.64	2.78	2.48	2.29	2.71	2.73	2.78	2.02	2.29	3.23	3.30	2.66
5	11 S - 12 N	105 W - 106 E	6	3.29	3.08	3.08	2.59	2.31	2.87	2.92	3.01	2.12	2.44	3.57	3.73	2.91
6	11 S - 12 N	106 W - 107 E	56	5.19	4.51	4.09	3.08	2.66	3.98	3.99	4.32	3.03	3.24	4.88	5.40	4.03
7	12 S - 13 N	102 W - 103 E	212	3.88	3.52	3.34	2.91	2.62	3.70	3.57	3.77	2.78	2.98	4.09	4.61	3.48
8	12 S - 13 N	103 W - 104 E	181	3.50	3.24	3.14	2.76	2.48	3.25	3.18	3.31	2.41	2.71	3.77	4.12	3.15
9	12 S - 13 N	104 W - 105 E	73	3.12	2.96	2.95	2.62	2.34	2.81	2.79	2.85	2.04	2.44	3.46	3.62	2.83
10	12 S - 13 N	105 W - 106 E	47	3.60	3.33	3.21	2.71	2.37	2.99	2.98	3.09	2.16	2.16	3.80	3.96	3.03
11	12 S - 13 N	106 W - 107 E	91	4.95	4.36	3.93	3.04	2.58	3.77	3.75	4.03	2.76	3.24	4.80	5.15	3.86
12	12 S - 13 N	107 W - 108 E	488	6.31	5.39	4.63	3.36	2.78	4.55	4.53	4.97	3.36	3.86	5.81	6.33	4.65
13	13 S - 14 N	102 W - 103 E	92	4.07	3.68	3.56	3.16	2.74	3.53	3.38	3.53	2.56	2.95	4.04	4.51	3.47
14	13 S - 14 N	103 W - 104 E	24	4.09	3.73	3.53	3.09	2.65	3.35	3.21	3.36	2.44	2.88	3.99	4.43	3.39
15	13 S - 14 N	104 W - 105 E	70	4.13	3.78	3.50	3.02	2.54	3.18	3.04	3.19	2.31	2.81	3.95	4.34	3.31
16	13 S - 14 N	105 W - 106 E	71	4.51	4.09	3.70	3.07	2.56	3.34	3.21	3.42	2.44	3.03	4.30	4.67	3.52
17	13 S - 14 N	106 W - 107 E	107	5.28	4.69	4.13	3.24	2.67	3.84	3.73	4.05	2.82	3.53	5.09	5.39	4.03
18	13 S - 14 N	107 W - 108 E	221	6.03	5.28	4.58	3.42	2.78	4.33	4.25	4.69	3.19	4.03	5.86	6.11	4.54
19	14 S - 15 N	103 W - 104 E	131	3.69	3.38	3.25	2.89	2.48	3.03	2.92	3.01	2.15	2.59	3.58	3.90	3.07
20	14 S - 15 N	104 W - 105 E	126	3.98	3.65	3.39	2.96	2.50	3.06	2.93	3.05	2.21	2.70	3.79	4.13	3.19
21	14 S - 15 N	106 W - 107 E	304	5.17	4.65	4.15	3.33	2.69	3.78	3.64	3.91	2.81	3.70	5.14	5.33	4.02
22	14 S - 15 N	107 W - 108 E	660	5.86	5.22	4.61	3.56	2.81	4.25	4.11	4.47	3.19	4.33	5.97	6.06	4.53
			Average	**4.22**	**3.85**	**3.60**	**2.99**	**2.58**	**3.49**	**3.41**	**3.62**	**2.59**	**3.01**	**4.30**	**4.59**	**3.52**

Data Source : http//: eosweb.larc.nasa.gov

Table AP-B.2.2 Satellite Data on Annual Average Wind Speed at 20m above Ground Level

Reigon	Boundary (In degree)		Elevation (m)	Adjusted Monthly Averaged Wind Speed for 20 meters height & Vegetation type (m/s)												Annual Average (m/s)
	Latitude	Longitude		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	10 S - 11 N	103 W - 104 E	29	2.74	2.73	2.96	2.25	2.17	2.97	2.90	3.18	2.43	2.32	3.25	3.41	2.77
2	10 S - 11 N	104 W - 105 E	65	2.15	2.14	2.40	1.89	1.76	2.08	2.08	2.16	1.62	1.75	2.46	2.61	2.09
6	11 S - 12 N	103 W - 104 E	288	2.56	2.43	2.58	2.01	1.88	2.53	2.49	2.64	1.97	2.06	2.92	3.16	2.43
7	11 S - 12 N	104 W - 105 E	106	2.06	2.00	2.25	1.79	1.66	1.96	1.98	2.01	1.46	1.69	2.43	2.52	1.98
8	11 S - 12 N	105 W - 106 E	6	2.54	2.33	2.49	1.87	1.68	2.08	2.11	2.18	1.53	1.80	2.68	2.85	2.17
9	11 S - 12 N	106 W - 107 E	56	4.01	3.43	3.31	2.23	1.93	2.88	2.89	3.13	2.19	2.39	3.68	4.13	3.01
10	12 S - 13 N	102 W - 103 E	212	3.00	2.67	2.70	2.11	1.90	2.68	2.59	2.73	2.01	2.20	3.07	3.53	2.59
11	12 S - 13 N	103 W - 104 E	181	2.70	2.46	2.54	2.00	1.79	2.35	2.30	2.40	1.74	2.00	2.83	3.15	2.35
12	12 S - 13 N	104 W - 105 E	73	2.41	2.24	2.38	1.90	1.69	2.03	2.02	2.06	1.48	1.80	2.60	2.77	2.11
13	12 S - 13 N	105 W - 106 E	47	2.78	2.52	2.60	1.96	1.71	2.16	2.16	2.24	1.56	1.92	2.86	3.03	2.29
14	12 S - 13 N	106 W - 107 E	91	3.82	3.31	3.18	2.20	1.87	2.73	2.72	2.92	2.00	2.39	3.61	3.94	2.89
15	12 S - 13 N	107 W - 108 E	488	4.88	4.09	3.75	2.43	2.01	3.30	3.28	3.60	2.43	2.85	4.37	4.85	3.48
16	13 S - 14 N	102 W - 103 E	92	3.14	2.79	2.88	2.29	1.98	2.56	2.45	2.56	1.85	2.18	3.04	3.45	2.59
17	13 S - 14 N	103 W - 104 E	24	3.17	2.83	2.85	2.24	1.92	2.43	2.32	2.43	1.77	2.12	3.00	3.39	2.53
18	13 S - 14 N	104 W - 105 E	70	3.19	2.87	2.83	2.19	1.85	2.30	2.20	2.31	1.67	2.07	2.97	3.33	2.48
19	13 S - 14 N	105 W - 106 E	71	3.49	3.11	2.99	2.22	1.85	2.42	2.32	2.48	1.77	2.23	3.24	3.58	2.64
20	13 S - 14 N	106 W - 107 E	107	4.08	3.56	3.35	2.35	1.93	2.78	2.70	2.94	2.04	2.60	3.83	4.13	3.02
21	13 S - 14 N	107 W - 108 E	221	4.66	4.01	3.70	2.48	2.01	3.14	3.08	3.40	2.31	2.97	4.41	4.68	3.40
23	14 S - 15 N	103 W - 104 E	131	2.85	2.56	2.63	2.09	1.79	2.19	2.11	2.18	1.56	1.91	2.69	2.98	2.29
24	14 S - 15 N	104 W - 105 E	126	3.07	2.77	2.74	2.14	1.82	2.22	2.12	2.21	1.60	1.99	2.85	3.16	2.39
26	14 S - 15 N	106 W - 107 E	304	4.00	3.53	3.36	2.41	1.95	2.74	2.64	2.83	2.03	2.73	3.86	4.08	3.01
27	14 S - 15 N	107 W - 108 E	660	4.53	3.96	3.73	2.58	2.03	3.08	2.98	3.24	2.31	3.20	4.49	4.64	3.39
			Average	**3.26**	**2.92**	**2.91**	**2.16**	**1.87**	**2.52**	**2.47**	**2.62**	**1.87**	**2.23**	**3.23**	**3.51**	**2.63**

Data Source : http//: eosweb.larc.nasa.gov

Note : Vegetation type crop : 20-m brodleaf - deciduous trees (10%) & Crops (Like rice, wheat)

3. CALIBRATION OF SOLAR IRRADIATION

1. Surface Solar Irradiation Data of Sihanouk Ville and Kampong Cham Province

In Cambodia there are few sites where surface solar irradiation is recorded. From the two sites recorded data are collected in June, 2005.

The data collected sites are;

(i) Sihanouk Ville (SHV)
The data is recorded at the roof of 'Water Treatment and Supply Center (WTSC)'.

(ii) Kampong Cham (Kg. Cham)
The data is recorded at PV + Micro-hydro Research Demonstration project between MIME (Cambodia) and NEDO (Japan).

The recorded data at the above sites are of solar irradiation at 12 degree inclined angle facing south.

Table AP-B.3.1 and AP-B.3.2 summarize the recorded values of the two sites and details are given in Attachment-1 & 2, respectively.

Table AP-B.3.1 Recorded Values at WTSC (Sihanouk Ville Province)

Recorded average solar irradiation at WTSC of Sihanouk Ville (kWh/m^2/day)													
Year / month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2003	***	***	***	***	***	***	***	4.03	3.69	4.09	5.00	5.18	4.40
2004	4.82	5.28	5.68	---	4.14	4.24	3.57	3.63	---	4.92	5.03	5.52	4.68
2005	5.28	5.80	5.43	5.11	4.03	***	***	***	***	***	***	***	5.13
Average	**5.05**	**5.54**	**5.55**	**5.11**	**4.08**	**4.24**	**3.57**	**3.83**	**3.69**	**4.51**	**5.01**	**5.35**	**4.63**

Note: (1) '***' data not available (2) '---' data recording failure (3) All data are collected from SHV

From above table it is understood that the monthly average solar irradiation value from November to April are above 5.0kW/m^2/day and in rainy season months from July to September it is below 3.9kW/m^2/day. The average is above 4.6kW/m^2/day. Even thought monthly average values are lower in rainy season months it is higher than the annual average value of Tokyo, which is 3.5kW/m^2/day.

Table AP-B.3.2 Recorded Values at PV & MH Hybrid Site (Kampong Cham Province)

Recorded average solar irradiation at Kampong Cham province PV & MH project site (kWh/m^2/day)													
Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2004	***	***	***	***	***	***	***	4.58	4.64	5.46	5.44	5.76	5.18
2005	5.40	5.81	***	***	***	***	***	***	***	***	***	***	5.60
Average	**5.40**	**5.81**	***	***	***	***	***	**4.58**	**4.64**	**5.46**	**5.44**	**5.76**	**5.30**

Note: (1) '***' data not available. (2) From August 2004 to December 2004, data collected at project site. (3) 2005 January and February, data is form NEDO (JAPAN).

In the case of Kampong Cham except in the months August and September the solar irradiation values are above 5.0kW/m^2/day. Even thought there is no data from the month March to July, the monthly vales are higher than the annual average of SHV.

2. Satellite data of Sihanouk Ville (SHV) and Kampong Cham (Kg. Cham) area.

To understand the distribution of solar irradiation of SHV and Kg. Cham areas the satellite data is downloaded from NASA home page. The downloaded data is given as data indicating irradiation of horizontal surface. Every year data varies in some extend due to weather variation. Therefore, the longer the data recording period is, the more the data accuracy increases. The downloaded data is monthly average data of 1983 to 1993.

Table AP-B.3.3 shows the differences of monthly average irradiation between the satellite data recorded at SHV and Kg. Cham with its minimum and maximum value within 10 years recorded period.

Table AP-B.3.3 Average Satellite Irradiation Data and Differences with its values Recorded at SHV and Kg. Cham.

Months	Satellite data of SHV area			Satellite data of Kg. Cham area		
	Solar irradiation ($kWh/m^2/day$)	Differences in respective months daily average irradiation data for 10 Years		Solar irradiation ($Wh/m^2/day$)	Differences in respective months, daily average irradiation data for 10 Years	
		Minimum (%)	Maximum (%)		Minimum (%)	Maximum (%)
January	5.35	-7	6	5.39	-5	4
February	5.98	-5	7	5.87	-3	3
March	6.21	-5	5	6.03	-7	5
April	5.96	-8	7	6.01	-4	3
May	5.09	-11	9	5.62	-5	5
June	4.28	-20	18	5.18	-11	10
July	4.34	-22	15	5.25	-13	7
August	3.84	-18	22	4.90	-10	10
September	4.26	-31	13	4.76	-7	9
October	4.54	-8	10	4.70	-10	7
November	5.12	-15	10	4.96	-11	9
December	5.35	-6	6	5.11	-4	5
Annual Average	5.03	-13.0	10.7	5.32	-7.5	6.4

Note : Satellite data are downloaded from NASA home page.

In above table the differences mean that the minimum and maximum value for a given month in percentage indicating the least (minimum) or most (maximum) monthly averaged direct normal radiation within the 10-year period.

From Table AP-B.3.3 in SHV area the highest difference at minimum side is 31% in September and 22% at maximum side in August. In the case of an annual average the difference is around 13% at minimum side and around 10.7 % at maximum side.

In Kg. Cham area the difference at minimum side is 13 % in July and 10% at maximum side in June and August. In the case of an annual average the difference is 7.5% at minimum side and 6.4 % at maximum side.

From above table it is understood that the percentage of difference is high in rainy reasons months and difference is higher in minimum side compared to maximum side.

3. Comparison of data

It is not rational to compare inclined surface data directly with satellite data of that region. For more accurate comparison, the satellite horizontal irradiation data is converted to the estimated value at 12 degree inclined angle utilizing tilt factor (F_T). The tilt factor (F_T) is calculated from the Azimuth angle of the Sun to estimate the value. The comparison between measured data at site and satellite data, is made only to get some view of solar irradiation of that particular area at an inclined angle within the measured period.

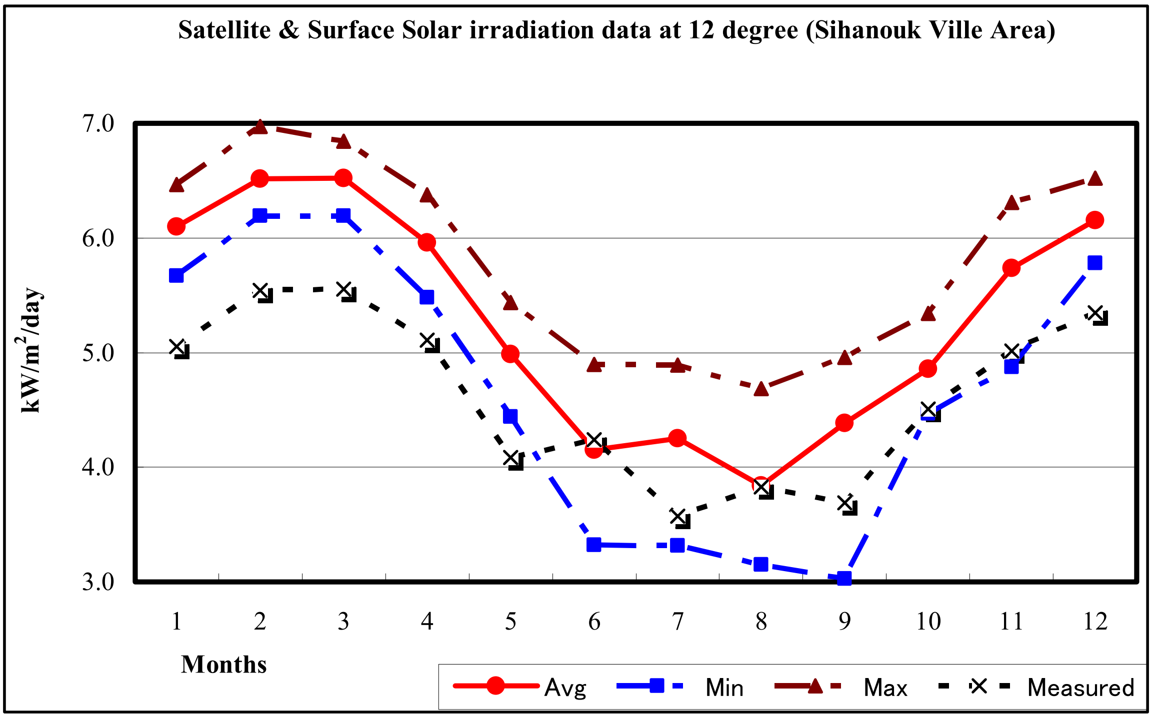
Table AP-B.3.4 and Figure AP-B.3.1, and Table AP-B.3.5 and Figure AP-B.3.2 shows the measured surface data as well as estimated values of SHV and Kg. Cham area at 12 degree inclined surface respectively. In Tables AP-B.3.4 and AP-B.3.5, satellite minimum and maximum value is calculated using percentage of differences from above Table AP-B.3.3. The estimated values at 12 degree inclined angle are calculated using tilt factor for comparison with measured surface data at site.

Table AP-B.3.4 Measured Surface Data and Estimated Values of SHV Area

Months	10 years average Satellite solar irradiation (Min. & Max. Values are calculated using % of differences from Table-3)			Tilt factor (T_F) to calculate the value at 12 deg inclined angle	Satellite data converted to 12 degree inclined angle using tilt factor (Estimated Values)			Measured surface data at 12 degree inclined angle ($kWh/m^2/day$)
	Average ($kWh/m^2/day$)	Minimum side ($kWh/m^2/day$)	Maximum side ($kWh/m^2/day$)		Average ($kWh/m^2/day$)	Minimum side ($kWh/m^2/day$)	Maximum side ($kWh/m^2/day$)	
January	5.35	4.98	5.67	1.14	6.10	5.67	6.46	5.05
February	5.98	5.68	6.40	1.09	6.52	6.19	6.97	5.54
March	6.21	5.90	6.52	1.05	6.52	6.19	6.85	5.55
April	5.96	5.48	6.38	1.00	5.96	5.48	6.38	5.11
May	5.09	4.53	5.55	0.98	4.99	4.44	5.44	4.08
June	4.28	3.42	5.05	0.97	4.15	3.32	4.90	4.24
July	4.34	3.39	4.99	0.98	4.25	3.32	4.89	3.57
August	3.84	3.15	4.68	1.00	3.84	3.15	4.68	3.83
September	4.26	2.94	4.81	1.03	4.39	3.03	4.96	3.69
October	4.54	4.18	4.99	1.07	4.86	4.47	5.34	4.51
November	5.12	4.35	5.63	1.12	5.73	4.87	6.31	5.01
December	5.35	5.03	5.67	1.15	6.15	5.78	6.52	5.35
Average	**5.03**	**4.42**	**5.53**	**1.05**	**5.29**	**4.66**	**5.81**	**4.63**

Note : Measured monthly data is from 2003 Aug to 2005 May.

Figure AP-B.3.1 Graph of Estimated Value and Surface Measured Data of SHV Area



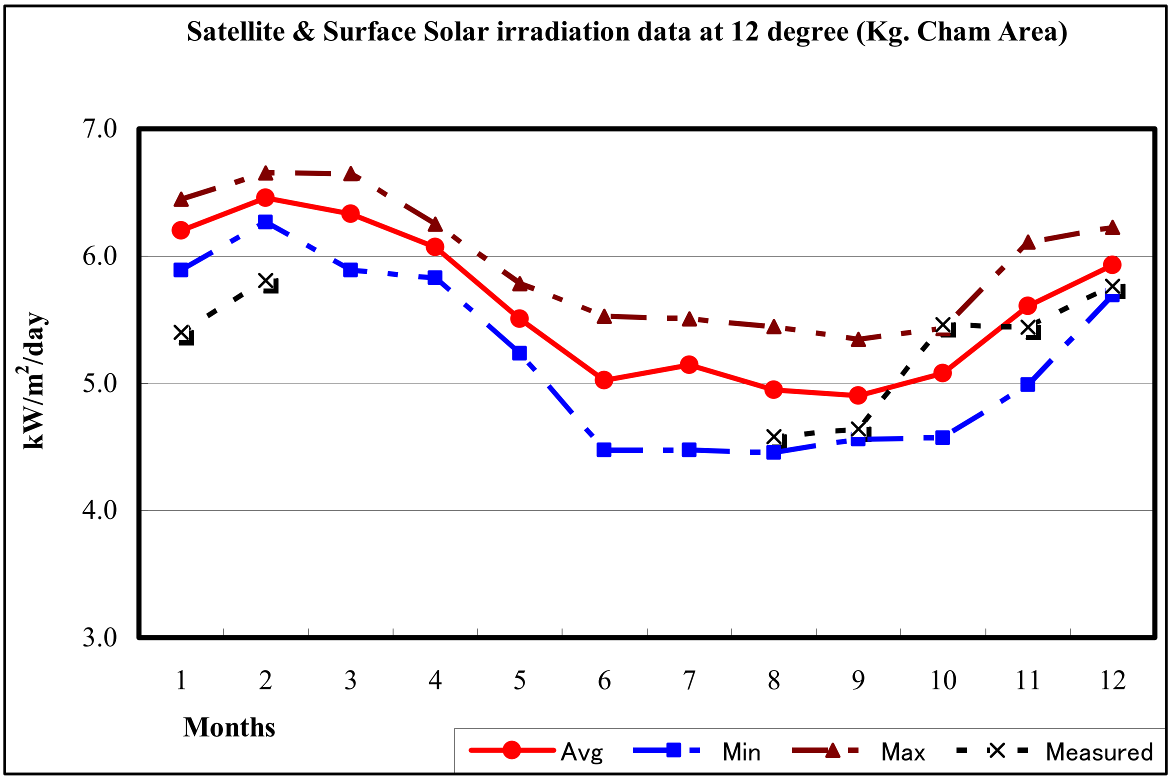
From above the surface measured value is lower than the estimated minimum value from December to May. At June it is slightly higher than the estimated average value and in rainy season when solar irradiation becomes minimum, from July to November the measured values are within the range of estimated minimum and maximum values.

Table AP-B.3.5 Measured Surface Data and Estimated Values of Kg. Cham Area

Months	10 years average Satellite solar irradiation (Min. & Max. Values are calculated using % of differences from Table-3)			Tilt factor (T_F) to calculate the value at 12 deg inclined angle	Satellite data converted to 12 degree inclined angle using tilt factor (Estimated Values)			Measured surface data at 12 degree inclined angle (kWh/m2/day)
	Average (kWh/m^2/day)	Minimum side (kWh/m2/day)	Minimum side (kWh/m2/day)		Average (kWh/m^2/day)	Minimum side (kWh/m^2/day)	Maximum side (kWh/m^2/day)	
January	5.39	5.12	5.61	1.15	6.20	5.89	6.45	5.40
February	5.87	5.69	6.05	1.10	6.46	6.26	6.65	5.81
March	6.03	5.61	6.33	1.05	6.33	5.89	6.65	
April	6.01	5.77	6.19	1.01	6.07	5.83	6.25	
May	5.62	5.34	5.90	0.98	5.51	5.23	5.78	
June	5.18	4.61	5.70	0.97	5.02	4.47	5.53	
July	5.25	4.57	5.62	0.98	5.15	4.48	5.51	
August	4.90	4.41	5.39	1.01	4.95	4.45	5.44	4.58
September	4.76	4.43	5.19	1.03	4.90	4.56	5.34	4.64
October	4.70	4.23	5.03	1.08	5.08	4.57	5.43	5.46
November	4.96	4.41	5.41	1.13	5.60	4.99	6.11	5.44
December	5.11	4.91	5.37	1.16	5.93	5.69	6.22	5.76
Average	**5.32**	**4.92**	**5.65**	**1.05**	**5.60**	**5.19**	**5.95**	**5.30**

Notes: (1) Measured monthly data are from 2004 Aug. to 2005 Feb.
(3) Blank means no data available or not appropriate to take as an average.

Figure AP-B.3.2 Graph of Estimated Value and Surface Measured Data of Kg. Cham Area



From above the surface measured value is lower than the estimated minimum value in January and February and from August to December it is within the range of estimated minimum and maximum values. In October it is even slightly higher than estimated maximum value. But in the case of Kampong Cham, it is not possible to compare the estimated data and actual measured data in March through July because the measured data in the period is not available.

4. Conclusion

From the above data's and figures, it is understood that at both sites except in rainy seasons the measured monthly surface values are lower than the estimated minimum values. When solar irradiation decreases in rainy season, the measured values are above the estimated minimum values.

In the case of Sihanouk Ville, the annual average of measured value is around 13% and the estimated annual average minimum value is 12% lower than the estimated annual average value. In the case of Kampong Cham, the annual average of measured value is around 5% and the estimated annual average minimum value is 8% lower than the estimated annual average value. This means, in both cases, the measured average value is within the range of estimated minimum and average value. From this it can be said that even thought the measured data is available for short period it is within the estimated minimum and average values of that area on an average.

The satellite data recorded for long-term compensates yearly differences than the short-term measured surface data. Therefore, it is reasonable to say that the short-term recorded surface data is less accurate than the satellite data. Hence, the satellite data is the more appropriate value for system deigning in this Master Plan.

To be more accurate and to cover differences of percentage in some extent at the time of system deigning, if annual average satellite data of project area is lower than the country annual average satellite data, than for system deigning country minimum annual average satellite data and if it is higher or equivalent to country annual average satellite data than for deigning country annual average satellite data is recommended.

Attachment-1

Solar irradiation data of SHV (WTSC) (Unit : kWh/m^2/day)

Date	Year 2003					Year 2004												Year 2005				
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	5.85	5.51	4.35	3.11	5.80	5.86	4.85	5.38	---	---	6.07	3.83	0.89	---	---	5.25	6.11	5.20	5.48	5.54	6.31	6.70
2	2.69	5.06	5.51	5.70	5.83	5.13	4.47	6.02	---	---	4.10	2.15	1.29	---	---	3.55	5.30	5.97	5.66	5.06	4.10	6.22
3	2.24	2.37	4.65	5.22	6.00	5.77	6.17	6.44	---	---	4.55	4.78	3.94	---	---	5.52	4.79	5.84	5.81	5.11	6.22	6.34
4	3.94	1.46	3.26	4.57	6.14	4.99	5.30	5.31	---	---	5.24	2.49	4.51	---	1.79	6.46	5.42	5.73	5.78	5.09	5.41	5.43
5	0.99	6.09	3.75	5.55	4.40	4.12	5.17	4.08	---	4.56	5.98	5.59	4.83	---	2.25	5.54	6.18	5.04	4.80	4.44	4.50	6.19
6	0.43	5.33	5.09	6.09	5.58	5.62	6.21	4.59	---	4.99	5.57	4.93	4.76	---	2.82	3.04	5.68	4.64	6.07	5.79	5.24	6.15
7	4.36	3.52	5.92	5.71	6.12	3.77	6.15	4.62	---	4.87	4.17	4.39	0.91	---	4.58	4.40	5.66	5.61	4.92	5.42	4.57	5.70
8	6.20	2.76	3.39	5.91	6.04	5.75	5.54	5.15	---	3.88	2.61	5.05	1.48	---	5.24	2.49	5.77	5.31	6.17	5.66	6.57	2.48
9	3.87	1.44	3.17	3.98	2.90	3.15	4.02	6.59	---	5.21	1.60	4.20	1.52	---	4.56	5.28	5.64	2.75	5.89	5.44	5.67	1.83
10	4.54	0.99	5.56	4.21	3.46	5.97	5.85	5.92	---	3.28	2.68	4.49	4.08	---	5.73	3.55	5.42	5.55	4.53	6.54	4.82	1.39
11	5.36	2.52	5.60	5.00	5.14	4.73	5.46	4.68	---	2.33	2.83	5.06	1.76	---	6.21	4.01	6.05	5.15	5.80	6.32	4.53	1.19
12	4.75	2.48	4.58	4.16	5.71	4.34	5.57	6.46	---	3.30	2.16	3.46	2.68	---	0.89	5.67	5.94	5.61	5.51	6.58	6.40	1.63
13	4.25	2.05	3.50	2.95	6.03	3.37	5.99	5.88	---	0.63	0.62	3.81	6.29	---	4.66	5.28	6.09	5.05	6.06	5.89	5.04	3.56
14	5.94	4.89	3.24	5.01	4.57	4.42	5.74	5.68	---	5.37	1.44	6.54	6.36	---	6.14	4.26	5.71	1.27	5.98	4.78	5.49	1.59
15	4.52	6.01	3.41	5.40	6.11	4.25	3.76	6.65	---	5.05	2.14	5.37	6.37	---	6.23	4.28	6.01	5.60	5.56	5.28	3.78	4.88
16	4.65	5.05	2.21	4.64	4.89	4.53	5.11	6.14	---	4.05	4.05	4.47	6.46	---	4.77	5.11	5.78	5.71	5.11	6.08	2.99	5.72
17	2.10	3.57	4.26	4.33	4.81	4.44	4.27	7.01	---	3.40	5.43	5.39	3.59	---	5.61	4.72	6.01	5.01	6.70	5.01	6.04	4.05
18	3.08	2.84	1.38	5.11	4.30	5.15	4.77	5.24	---	5.54	6.11	3.46	1.91	---	4.49	5.11	5.22	5.82	6.16	6.04	4.04	2.79
19	1.35	4.43	4.02	6.30	2.33	4.35	4.72	4.53	---	6.19	5.34	1.87	1.98	---	4.90	6.19	5.09	5.87	6.27	5.32	5.21	4.20
20	1.67	4.36	3.05	5.85	4.07	3.47	5.23	4.41	---	6.49	2.27	0.89	1.93	---	5.77	6.35	5.63	5.92	5.18	4.48	4.39	4.91
21	3.66	4.67	1.88	5.40	5.72	5.43	5.40	5.32	---	4.47	4.09	2.36	1.80	---	4.97	6.19	3.76	6.18	5.50	6.22	3.89	3.68
22	4.80	1.63	1.20	2.81	4.85	3.67	5.31	5.37	---	3.47	5.57	4.54	2.99	---	4.58	6.04	4.93	5.60	4.87	5.55	3.54	2.45
23	6.07	4.61	3.97	5.47	5.98	5.52	5.72	6.09	---	1.26	4.00	4.06	3.18	---	5.64	6.40	5.68	5.73	5.77	4.34	4.33	4.63
24	5.34	4.24	2.24	4.41	6.08	6.01	5.78	6.34	---	1.35	5.97	3.92	5.76	---	4.71	5.83	5.58	6.25	6.34	4.29	6.06	3.26
25	5.18	4.43	2.52	4.11	5.60	5.26	6.15	5.33	---	0.63	6.17	1.81	5.65	---	6.51	2.94	5.65	4.74	6.71	3.75	5.49	5.04
26	5.93	3.51	6.07	4.80	4.58	5.39	6.07	6.69	---	3.73	5.58	2.15	5.19	---	5.65	4.80	5.32	3.84	6.96	5.07	5.55	5.45
27	6.82	5.40	5.82	6.18	5.86	6.13	5.46	6.74	---	6.07	4.37	1.86	3.76	---	6.39	4.25	5.54	5.72	6.81	5.47	6.11	3.96
28	6.21	3.65	6.23	6.21	5.63	3.01	6.00	5.88	---	6.46	5.23	1.32	5.30	---	4.99	5.97	5.69	5.87	5.88	6.12	5.72	1.30
29	4.20	2.44	5.76	5.71	4.41	5.35	3.01	6.10	---	5.00	6.07	2.92	2.46	---	6.20	6.37	4.93	5.88		5.43	6.26	3.28
30	1.35	3.36	5.52	5.95	5.76	4.60		5.69	---	5.86	5.26	1.12	2.60	---	5.81	6.04	5.31	5.40		6.36	4.93	4.36
31	2.56		5.68		5.80	5.95		5.73		4.27		2.51	6.24		5.73		5.24	5.77		5.79		4.63
Avg.	**4.03**	**3.69**	**4.09**	**5.00**	**5.18**	**4.82**	**5.28**	**5.68**	---	**4.14**	**4.24**	**3.57**	**3.63**	---	**4.92**	**5.03**	**5.52**	**5.28**	**5.80**	**5.43**	**5.11**	**4.03**

Note: (1) '***' no data

(2) '---' data recording failure

(3) The inclined angle of Pyranometer is 12 degree facing south.

Attachment-2

Solar irradiation data of Kampong Cham project site
(kWh/m^2/day)

Date	Year 2004								2005
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	***	4.76	---	3.59	5.81	5.25	5.12	6.38	5.81
2	***	5.08	---	3.29	5.61	4.85	5.71	6.23	6.53
3	***	5.94	---	3.53	3.16	3.92	5.52	4.90	6.51
4	***	5.49	---	3.48	5.37	4.63	6.57	6.00	6.34
5	***	5.52	---	5.84	6.08	3.75	5.64	5.52	6.10
6	***	3.98	---	4.78	5.97	3.25	4.38	6.38	6.22
7	***	4.83	---	5.61	6.32	4.81	6.35	5.26	3.56
8	***	5.76	---	5.10	4.88	5.50	6.18	5.92	5.55
9	***	3.61	2.17	4.91	***	6.06	6.66	4.67	6.10
10	***	5.62	1.77	4.38	***	6.28	5.58	5.66	6.47
11	***	4.11	2.28	4.94	4.89	5.65	3.57	5.15	6.42
12	***	3.93	3.07	2.83	4.36	3.83	***	6.09	5.43
13	***	3.70	2.64	2.21	1.18	6.09	5.48	5.16	4.03
14	***	1.51	0.00	4.90	3.12	6.23	5.48	6.44	4.84
15	***	---	2.84	4.50	4.32	5.78	4.84	6.36	3.81
16	***	---	5.55	6.21	4.81	6.64	4.35	6.21	3.96
17	***	---	5.82	6.46	2.50	6.26	6.18	5.89	4.65
18	***	---	4.89	4.44	4.50	3.68	5.56	5.47	4.80
19	***	---	4.45	2.52	4.11	6.20	6.00	5.50	***
20	***	---	4.90	1.99	4.04	5.75	6.15	6.24	***
21	***	---	3.96	3.27	4.63	5.57	6.19	4.99	***
22	***	---	4.86	4.62	3.87	5.60	6.35	5.01	***
23	***	---	4.61	5.50	5.84	5.82	5.63	5.76	***
24	***	---	5.27	6.20	6.81	5.65	4.60	5.29	***
25	***	---	5.49	6.47	4.66	4.84	5.13	5.86	***
26	***	---	5.06	6.05	4.77	6.80	2.73	6.14	***
27	***	---	4.11	5.59	5.29	6.27	5.07	6.45	***
28	***	---	3.86	4.66	6.41	6.23	5.56	6.19	***
29	6.93	---	5.50	4.94	4.68	6.18	5.46	6.35	***
30	1.08	---	5.51	4.64	2.10	6.27	5.79	5.66	***
31	1.11		4.96	4.63	4.54	5.48	5.40	5.43	***
Avg.	**3.04**	**4.56**	**4.07**	**4.58**	**4.64**	**5.46**	**5.44**	**5.76**	**5.39**

Note:

(1) '***' no data
(2) '---' data not recorded.
(3) Data available from 8th May. Therefore data is not counted as an average value of the month.
(4) Whole system was stopped for maintenance from 15th June.
Therefore value is not counted as an average value of the month.
(5) After maintenance, system started from evening of 8th July.
Therefore value is not counted as an average value of the month.
(6) In September
(a) Data collected on 9th after 14:40:18 and recording restarted at 18:29:06 hours.
(b) Data recording stopped on 10th after 03:59:59 hours.
(c) Data recording started on 10th from 15:33:48 and collected on 17th after 19:09:04 hours.
(d) Data recording started on 17th from 20:12:22 hours.
(7) Data collected on 12th November 2004, 18:23:59 and recording restarted from 20: 58:15 hours.
(8) In January data is only up to 19th (18:59:59 hours).
Therefore data is not counted as an average value of the month.
(9) The inclined angle of Pyranometer is 12 degree facing south.

APPENDIX-C

Biomass Power

THE MASTER PLAN STUDY
ON
RURAL ELECTRIFICATION BY RENEWABLE ENERGY
IN THE KINGDOM OF CAMBODIA

FINAL REPORT
VOLUME 5 : APPENDICES

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Appendix-C Biomass Power

1. Why Biomass gasification is appropriate for rural electrification in Cambodia

1.1. Type of Biomass Electricity Generation ～Why Gasification?～

Current annual energy consumption in the world is estimated as 400 EJ (Goldemberg 2000) and biomass energy consumption is about 55 EJ. Utilization of biomass energy is the major countermeasure against the global warming and the oil depletion. Many influential organizations predict the increase of use of biomass energy in the future. IPCC (1995) predicts the use of biomass energy increases to 280 EJ in 2050 and 320 EJ in 2100. The utilization of biomass energy in 2050 is estimated as 200-220 EJ by Shell International (1996) and 181 EJ by Greenpeace (1993). Hoogwijk et al. (2005) estimates the potential of biomass energy in 2050 as several times more to current oil consumption. Under the world recognition of the importance of biomass energy, technology development and utilization is progressing rapidly in the world. We examine the potential biomass energy technology appropriate for Cambodia's rural electrification.

(1) Direct combustion and gasification.

There are two major methods (direct combustion and gasification) to generate electricity from solid biomass. Direct combustion is the most common way of converting biomass to energy. For generating electricity, a biomass-fired boiler transfers the heat of combustion into steam. Steam drives turbine-generator to produce electricity. This system is a proven technology and introduced to many agricultural products processing factory around the world. The system is suitable for rather large scale (e.g. > 1 MW) and therefore not appropriate for rural electrification in Cambodia.

Gasification is a thermochemical process that converts biomass into a combustible gas called producer gas which contains about 80% of the energy originally present in the biomass. The producer gas is sent through a cooling and purifying unit before feeding into the engine to generate electricity. The system is commercially available as small as 4 kWe. They are commonly used for rural electrification and thermal application in some countries and small scale biomass gasification is thought as proven technology. The details of biomass gasification are described in section 4 'biomass gasification electricity generation system'.

(2) Bio-digestion gas electricity generation

Produce methane gas by fermentation of animal excrete and generate electricity by using the gas as fuel of engine. Installations of such systems are expanding mainly in developed countries but it is difficult to make the system economically feasible without subsidies. In Cambodia, there is a hybrid of biogas and PV electricity generation plant implemented by NEDO. But it is a technological research facility and not economically feasible yet for broad implementation. In rural area of Cambodia, large cattle shed is rare and graze is mostly used. It is difficult to apply bio-gas electrification widely for rural electrification. The low cost (< $50 for a family size unit) plastic digester system which provides gas for cooking has been introduced to many villages by NGOs. Under the current situation, bio-digestion gas seems more appropriate to be used for cooking than generating electricity in rural villages.

(3) Biofuel

Many kinds of biomass fuel products are developed and used as fuel in the world. Use bio-diesel for existing diesel generator is an interesting option for rural electrification in Cambodia. Use of bio-diesel made by corn, soybeans and rapeseeds are expanding in EU and US. In tropical Asia, Philippines and Thailand use coconuts oil and palm oil and India uses *Jatropha* seeds to produce bio-diesel and its commercial trading is expanding. The majority cases are mixed use of conventional diesel and economic viability is low without subsidies. It is a very interesting idea to encourage cultivation of bio-diesel crops and establish refineries and distribute bio-diesel for replacing conventional diesel. But this is the matter for national energy policy and less relevant to rural electrification at the moment.

There is a small project trying to cultivate *Jatropha* to produce bio-diesel for village use in Cambodia. The project is organized by a NGO called Development of Appropriate Technology (DATE) and funded by Canadian government. They succeeded to run an engine by bio-diesel extracted from locally grown *Jatropha* seeds by simple equipments. The economics and the impact of long-term use of bio-diesel to engines are not known yet. It is an interesting project but more research is required before introducing broadly in Cambodia.

1.2 Required Conditions as Energy Sources of Decentralized Mini-grids

Table AP-C.1.1 Required Conditions as Energy Sources of Decentralized Mini-grids

No.	Item	Diesel	MHP	Solar	Biomass
1.	Operation and maintenance works can be undertaken by trained villagers who have maintenance experience of diesel engines.	P	P	P	P
2.	Fuel is not required or sustainable purchase and procurement is possible.	PWC[1]	P	P	P (Fuel wood farming)
3.	Investment cost can be recovered within the range of ability-to-pay ($3 to 5 per month) (Conditions for investment)	P (Loan)	PWC (High ratio subsidy and soft loan)	PWC (100% subsidy for equipment)	PWC (Soft loan)
4.	Power generation at required scale (10-200 kWe) as a decentralized independent power system is possible.	P	P	D[2]	P
5.	Unit generation cost [3] ($/kWh) Plant factor: 15% Plant factor: 30%	0.59 0.40	0.85[4] 0.40	- -	0.56 0.28

Note: P: Possible , PWC: Possible with condition, D: Difficult

Source: JICA study team

(1) Overview of Renewable Energy Potentials in Cambodia

Potential and features of renewable energy as sources of decentralized mini-grids in the off-grid areas in Cambodia are summarized in Table AP-C.1.2.

1 There are risks of escalation in the fuel price, supply shortage of fuel due to road blockage during the rainy season.
2 Technically possible, but economically unrealistic.
3 Including tax, at consumer end.
4 There are projects also of high economic efficiency with unit electricity costs in an order of $0.30/kWh that utilizes waterfalls.

Table AP-C.1.2 Renewable Energy Potential as Power Sources for Rural Electrification

No.	Energy Source (Type)	Characteristics of Potential
1.	**Micro-hydro power** (mini-grid)	Micro-hydro power (MHP) potential is limited to mountainous or hilly areas mainly in the eastern and south-western part of the country. In the plain areas, which cover more than half of the country, there is hardly any potential for MHP.
2.	**Biomass** (mini-grid)	Blessed with abundant solar irradiation, precipitation, and land resources, biomass resources are abundant all over the country, and there is biomass farming potential as well (even grassland and shrub land alone are more than sufficient to grow the required fuel trees).
3.	**Solar** (BCS, SHS)	Abundant all over the country (annual average monthly minimum is 4.7 $kWh/m^2/day$)
4.	**Wind** (BCS, SHS)	Scarce. Average wind speed at 20 m above ground level is as low as 2.6 m/s. Wind power may be used for BCS in local wind corridors.

Source: JICA study team

As shown in Table AP-C.1.1, BGP satisfies required conditions as energy source of mini-grids[5] except for arrangement of initial capital costs. In addition, if a plant factor[6] (usage ratio) of power generation equipment is higher than 12%, unit cost of electricity will be lower than that of diesel generator. The study team considers it is appropriate to apply three types of renewable energy (micro hydro, biomass gasification power and diesel power) as sources of decentralized mini-grids in Cambodia.

(2) Why by Biomass Power? -- Comparison with Micro Hydro and Diesel Power --

As a result of the comparative study of potentials in the foregoing paragraph, micro hydro, biomass, and diesel power are candidate energy sources of mini-grids in the off-grid areas. Diesel power will be employed if there is no potential of the other renewable energy or if its plant factor is lower than 10% when it is applied as back up purpose of micro hdyro in a short period of the dry season. Table AP-C.1.3 compares pros and cons of the three energy sources adding other aspects to the potential:

Table AP-C.1.3 Comparison of Energy Source Candiates of Mini-grids

No.	Items	Micro Hydro	Diesel Power	Biomass Gasification Power
1.	Potential	Limited to the mountain and hilly area	Anywhere applicable (Road for fuel transportation necessary)	Possible to cultivate all over the country except the city and the area submerged for long time in rainy season.
2.	Technical aspects: Technology maturity	Proven technology	Proven technology	As a whole of the biomass gasification technology, recognized at an entrance to commercialization after passing the demonstration stage. Some small scale downdraft gasifiers often referred to as WWII is a proven technology with over 1 million applications to automobile. Small downdraft gasifiers are at commercial stage in India (mainly woody biomass for

5 As for three candidate power sources of mini-grids (micro hydro, biomass, and diesel), a comparison table for appropriateness is shown in Attachment-11.

6 The plant factor is 100% at full output operation for 24 hours everyday, and 12% at 3.1 hour daily operation.

No.	Items	Micro Hydro	Diesel Power	Biomass Gasification Power
				power generation), China (mainly rice husks for thermal applications), and Myanmar (mainly rice husks for engine and generators).
	2ϕ A.C.	Possible	Possible	Possible
	24-hr operation	Possible	Possible	Difficult (possible by alternate operation of 2 units)
	Output stability	High	High	Some changes observed in frequency[7]
	Automatic operation	Technically possible (However, operator should be stationed to clear drifting wood and tree leaves from trashracks at intake, operation logging, and for station guard.	Possible (start and stop by manual operation in small units)	Not applicable to small unit for rural electrification. Operator must standby at the station for tree chopping, loading to gasifier, monitoring of frequency, and so forth.
	Safety	High	Rick of accident (CO poisoning, fire)	Rick of accident (CO poisoning, fire, igniting and explosion of producer gas)
	Commercial supply	Many manufacturers exist worldwide.	Many manufacturers exist worldwide.	WWII type gasifiers are difficult to scale up. As of 2005, there are a few manufacturers commercially producing gasifiers. Also commercially sold in China and Myanmar but for rice husks. Gasifiers of developed countries are automated and clean. However, from the viewpoints of price and maintenance technology available, it would be difficult to introduce for rural electrification in developing countries. Although Asian products are not fully automated, these contribute to creating job opportunities and to make maintenance works simpler.
	Environmental impacts	It is required to release a certain river flow for maintenance of the river ecology in the river section from the intake down to	Emission of CO_2	It is required not to buy fuel from the local fuel wood markets, in order to avoid pressure to illegal cutting of forest resources.

[7] According to an observation at the existing Anlong Ta Mey Village in September 2005, the frequency was mostly stable with about ±1Hz but sometimes it dropped by about 5Hz. However, the frequency is strictly controlled for management of large power stations under a large power grid, its fluctuation would hardly affect performance and safety of electric appliances used at home. In the case of rural electrification, voltage drops are of major concern. In the Aonlong Ta Mey village scheme, the voltage was stable at 400 V at the generator end. Since the distribution lines were designed and erected with support from an experienced NGO (SMEC), there has been no unacceptable voltage drops except black outs due to overloading.

No.	Items	Micro Hydro	Diesel Power	Biomass Gasification Power
		the outflow point of the power station.		
	Issues	In general the smaller scale, the higher kW construction cost. It is difficult for CEC to assess potential and make a development plan.	There is a risk of price hike following the demand-supply balance in the world oil market and of shortage of supply.	The condensates from gas cleaner contain tar and phenol that has disinfecting effect (having acute toxicity of medium extent). Accordingly, method of their final disposal is an issue. The exhaust gas from engine contains unburnt CO. (Siting of gasifier apart from residential houses, well ventilation of station house, and gas detector are required.)
3.	Construction costs of generating facilities	Generating facilities $4,000/kW	Generating facilities $500/kW	Generating facilities $1,300-5,000/kW In EU, Euro3,000/kW for 10 MW class、and Euro6,000/kW for MW class
	Initial capital investment[8]	$1,229 per household	$424 per household	$592 per household (in the case of products from a manufacturer in India)
	Unit electricity cost[9] ($/kWh) at P.F. 15% at P.F. 30%	 0.85 0.40	 0.59 0.40	 0.56 0.28
	Fuel cost	nil	$0.23/kWh	$0.03/kWh (nil as community since fuel costs will remain within the community)
4.	Implementation period	2-3 years	1 year (distribution lines)	1 -2 years (gasifier, distribution lines, and fuel tree farming)
5.	Lifetime of generating equipment	20 years (Depending on the water quality and specs, 10-30 years, generators for 30 years)	5-10 years for engine depending on design specifications	About 10 years for gasifiers[10], 5-10 years for engine depending on design specifications
6.	Possibility of planning and design by CEC	Difficult for CEC to undertake planning and design	Possible (difficult for distribution lines)	Basic planning may be possible with Visual Guide prepared as part of the Master Plan. However, basic design is difficult.
	Implementation	CEC can provide labour forces for construction works.	CEC can provide labour forces for construction works.	CEC can provide labour forces for construction works.
	Management	Operation and management of electricity business are possible. However, periodical	Operation and management of electricity business are possible. However, periodical inspection and	Operation and management of electricity business are possible. However, periodical inspection and maintenance works are difficult. (In the case of product of A

8 Including costs for design, construction guidance, supports to CEC, administration costs, and contingency.
9 At consumer end including taxes.
10 In the case of a company, it will be required to replace some parts that are exposed to high temperature every 3,000 hour operation.

No.	Items	Micro Hydro	Diesel Power	Biomass Gasification Power
		inspection and maintenance works are difficult.	maintenance works are difficult.	company, technology required for operation and maintenance of gasifier is at the similar level to that of diesel engine.)
7.	Possibility of installing additional unit along with demand increase	Difficult (not possible when all the potential has been fully developed.)	Easy	Easy (It will be required to have land for farming additional fuel trees. Since there are many farmers who wish to grow fuel trees, no specific difficulty is foreseen in fuel supply.)

Based on the comparison above, the study team recommends that 1) first the suitability of application to Cambodia and technical issues of the biomass gasification power should be confirmed through implementation of pilot projects; and then 2) the biomass gasifier power be adopted as the main sources of mini-grids in the plain areas of Cambodia

Issues to be examined through biomass pilot projects are shown in Table AP-C.1.4.

Table AP-C.1.4 Issues to be Examined Through Biomass Pilot Projects

No.	Issues	Remarks
1.	Operation and maintenance by CEC	■ Monitoring if fuel tree farming is ongoing as planned; ■ Monitoring if power generation is achieved as designed; ■ Monitoring if the safety procedure for operation is observed; ■ Measurement of gas concentration in the station house, monitoring safety aspects such as pre-ventilation of gas piping system before igniting gasifier, etc.
2.	Management of electricity business by CEC	■ Training and monitoring meter reading, billing, tariff collection, accounting, deposit of surplus money, management of reserved fund of CEC
3.	Treatment of wastewater from gasifier	■ Testing if natural decomposition of tar (organic matter) by soil bacteria is dependable, or if we need another option such as drying condensates and reburn in the gasifier
4.	Operation and maintenance of gasifier	■ If operator can undertake operation and maintenance works as required; ■ If the ratio of forced outage is within tolerable extent; ■ Monthly hours required for maintenance works.

2. BIOMASS RESOURCES IN CAMBODIA

A great quantity of agricultural residues such as rice husk and old rubber trees is produced in Cambodia (see Part 1, Section 5.2.1. for details). They are potential fuel for biomass gasification electricity and it is encouraged to consider using agricultural residues as fuel at where massive excess amount is available. But fuel tree planting is recommended as major energy resource in the Master Plan because of following reasons.

- Agricultural residues are generally well utilized.
- The sizes of agricultural products processing factories such as rice mills, sugar mills and cashew nuts mills are generally small and therefore stable and sufficient supply of residues through a year is questionable.
- Planned and stable fuel wood supply is possible in the case of tree planting.

- Even in the case of cultivation of energy trees, the fuel cost holds only small fraction of total electricity generation cost (11% in the case of 13 kWh monthly electricity consumption per household). Using agricultural residues does not reduce the cost dramatically.
- The purchasing cost of cultivated trees is not high (about \$20/t). Using agricultural residue could be more expensive when transportation cost occurs.
- Woody biomass is generally the best fuel for gasification.
- There is sufficient (0.02ha/HH) wasteland (grassland and shrubland) in 8008 villages which is 77 of un-electrified villages.

3. Fuel wood cultivation plan

3.1 Required land for fuel tree planting

Fuel wood required for generating 1 kWh electricity is about 1.5 kg (air-dried basis). Annual biomass production of conservative estimate is around 10 t/ha (see Part 2, 1-4-4 for explanation). In the case of average monthly electricity consumption per household is 10 kWh, the required land for fuel tree planting for sustainable supply is 0.018 ha.

3.2 Purchasing fuel wood by CEC

Purchasing cultivated fuel wood by CEC from community members is recommended for fuel supply. The recommended purchasing price is about \$20 per tonne. In this case, fuel cost for unit electricity generation is \$0.03/kWh. CEC members are possibly to produce at least 10 t/ha/year wood and make \$200/ha/year for cultivating fuel trees. Once people plant trees in the land not in use like fallow gardens, they can obtain this much income by just cutting branches every four to six months. It is assumed that many people would like to plant trees. Anlong Ta Mei Energy Cooperative is purchasing cultivated *Leucaena* wood from its members at \$20/t and currently the supply exceeds the requirement.

3.3 Appropriate tree species

Woody biomass is the most appropriate material for gasification and most of tree species are suitable for gasification. But there are a few species might not be suitable to use in some type of gasifier. For example, *Piper aduncum* (Piperaceae) is a very common weed vigorously growing in heavily degraded forest. This species has high ash content and especially high potassium content and this might cause formation of sludge. Some test is required for using this tree. Species already used for gasification such as *Eucalyptus* spp., *Acacia* spp., *Gliricidia sepium* and *Leucaena leucocephala* is not problem. But gasification trial should be conducted in the case of planning to use local weed trees.

3.4 Cultivation methods

There are various ways of cultivating fuel trees. We divided them to following three major methods. 1) Very short harvesting cycle (<1 year) in and around garden. 2) Longer harvesting cycle (> several years). 3) Cultivation in seasonally waterlogged land wide spread in Cambodia. Because of the easiness and fast income return for farmers 1) would be the major cultivation method. On the other hand, in the case of large mini-grid where limited number of farmers supply fuel wood to meet the demand of much larger number of people, method 2) would be used as well because of higher labour efficiency. Mixture of different methods is preferable for stable fuel supply. Details of each method are described below.

(1) Cultivation in and around gardens (hedge row planting)

In the case of cultivation in fallow garden, as hedge and mixed planting with agricultural crops, trees have aerial nitrogen fixing and vigorous coppicing characteristics are appropriate. Legume tree species such as *Gliricidia sepium* and *Leucaena leucocephala* are most commonly used tree species for tropical agroforestry. These species grow a few centimetres in diameter and started to be harvested after about a year after planting. Coppiced branched can be harvested 2-3 times a year afterwards. 20-30t/ha/year woody biomass production is generally expected. In Battambang province, Ministry of Agriculture, Forestry and Fishery conducted small trial of *Leucaena leucocephala* cultivation and recorded 80t/ha/year woody biomass production. We conducted biomass production analysis at one-year-old *Leucaena leucocephala* gardens in Anlong Ta Mei CEC. The annual woody biomass production was 8.2t/ha/year. Biomass production of the first year usually much smaller than that of following years because roots settlement takes time. The annual biomass production after second year is expected to be much larger than 10t/ha. These species fix aerial nitrogen and return them to soil as litter fall. Consequently planting these trees contribute to improve chemical and physical property of soils. The foliage of *Gliricidia sepium* and *Leucaena leucocephala* are good stock feed for domestic animals. If people harvest everything including foliage, the soil degradation is expected because of very limited return of nutrient and organic matter to the soil. In the case of harvesting foliage as well as branches, applying fertilizer would be needed for sustainable production.

(2) Cultivation by longer harvesting cycle

Community based tree planting programs are widely conducted by Forestry Administration and NGO. Planted *Acacia* and *Eucalyptus* trees along roads and in villages are often seen. Some people own small scale *Acacia* and *Eucalyptus* plantation for selling as wood chip materials. *Eucalyptus* and *Acacia* are suitable for gasification as well. The purchasing price of $20/t for biomass electricity plant makes equal profitability to producing wood chip materials. Following difference to 1) method should be noted.

- Biomass production would be slightly smaller in many cases.
- It will take several years for the first harvest.
- There are many tree species with coppicing characteristics but may not grow as vigorous as 1) species.

Tree form and size do not matter in the case of fuel wood production. Method 1) would be easier and convenient for farmers. Method 2) is appropriate for long-term management as reserve fuel plantation by CEC. Plant high value species and sell as timber materials if the fuel wood shortage never happened. Teak often planted in Cambodia. Kumar et al. (1998) reported that mixed planting with *Leucaena leucocephala* resulted higher production of Teak. Plant Teak with *Leucaena* and harvest *Leucaena* in early years for fuel supply and early income generation as well as workload reduction of weeding would be a possible method. In the case of fuel tree plantation is far from the power plant, transportation efficiency would be higher for harvesting relatively larger size trees.

(3) Seasonally waterlogged land

Seasonally (<3 months per year) waterlogged land is widely spread in Cambodia. Such land is often used as rice field but majority area is not in use. There are certain tree species growing on such land (species list is shown in Table AP-C.3.1). Most of them have coppicing characteristic and they are used as firewood. Some of them grow very fast and easy to cultivate according to villagers. Fuel tree cultivation in seasonally waterlogged are is one of the potential methods. *Barringtonia acutangula* (Barringtoniaceae) and *Combretum guadrangulare* (Combretaceae) are most appropriate species for cultivation according to villagers. Other potential species are listed in Table AP-C.3.1.

Table AP-C.3.1 Tree species grow in seasonally waterlogged land

Scientific name	Family	Khmer Name
Barringtonia acutangula	Barringtoniaceae	Reang
Peltophorum dasyrrhachis	Caesalpiniaceae	Trase:k
Combretum quadrangulare	Combretaceae	Sangkae
Combretum trifoliatum	Combretaceae	Trahs
Hymenocardia wallichii	Euphorbiaceae	Phnom Phnaeng
Pithecellobium dulce	Mimosaceae	Ampil tuk
Zizyphus mauritiana	Rhamnaceae	Putrie
Gmelina asiatica	Verbenaceae	Anncha:nh

3.5 Seedling supply

It is preferable that CEC manages nursery and provide seedlings to the members. *Leucaena leucocephala* and *Gliricidia sepium* are suitable species for stump seedling (seedling cut to 20-25 cm without leaves) transplanting. Stump seedling transplanting is the easiest method and therefore recommended. Anlong Ta Mei energy cooperative uses this method for *Leucaena leucocephala* seedling transplant and the survival ratio was high. Small plastic pot seedling method will be used for species not suitable for stump seedling. Forest Administration uses this method to produce seedlings at their nurseries in many locations. Anlong Ta Mei energy cooperative initially purchased *Leucaena leucocephala* seeds from Australia but they currently use collected seeds from the first generation. Tree form does not matter for fuel production and some difference of productivity should not be worried much. After establishment of the first generation, collecting seeds from the established stand would be appropriate for further distribution. Once biomass electrification starts to distribute widely, certain government organization such as Ministry of Agriculture, Forestry and Fishery should set up tree improvement project to supply good quality seeds.

3.6 Ecological sustainability

Increase of nitrogen concentration of soil after planting of nitrogen fixing trees such as *Gliricidia sepium* and *Leucaena leucocephala* are widely reported (Parrotta 1999, Isaac et al.2003 and many others). But harvesting of all branches and leaves in short rotation will likely result the decrease of soil nutrient including nitrogen because the return to soil is too limited. Nutrient concentration in foliage is generally much higher than woody biomass. Leaving foliage on the forest floor after harvesting mitigates the nutrient loss significantly. Bark has high nutrient concentration (especially in calcium) as well but it would be difficult to debark the trees smaller than 10 cm in diameter. Short rotation harvesting will probably result some nutrient loss from the soil. Fertilizer application especially phosphorus and potassium might be necessary for sustainable production. Harvesting of 10t/ha/year woody biomass would probably not cause serious soil nutrient degradation but research of nutrient cycling and necessary fertilizer application should be conducted.

On the other hand, planting trees in degraded land and farming garden will increase organic matter content in the soil by litter fall and roots turn over. This improves soil physical property such as water retainability. Tree planting also prevent from soil erosion and its ability for river water level stabilization is well known.

4. Gasification Electricity Generation Systems

4.1 What is Gasification?

Gasification is thermochemical process for converting solid biomass to combustible producer gas. Gasification technology has a long history. A research for producing gas from wood has been conducted in the 18th century. In 1881, an engine was run by producer gas. The technology was most widely used during the World War II. The war caused severe shortage of oil products. About a million gasifiers were used for running cars, trains and ships and generating electricity in Europe. About 100,000 gasification vehicles were used in Japan and Russia. Convenient oil products became cheaply available after war and gasification was forgotten. The technology was re-spotlighted at the oil shock in 1973. In the last decades, biomass energy utilization has been recognized as one of the most important counter measure against global warning. Development and utilization of biomass gasification technology has been progressing rapidly.

4.2 Comparison of gasification methods

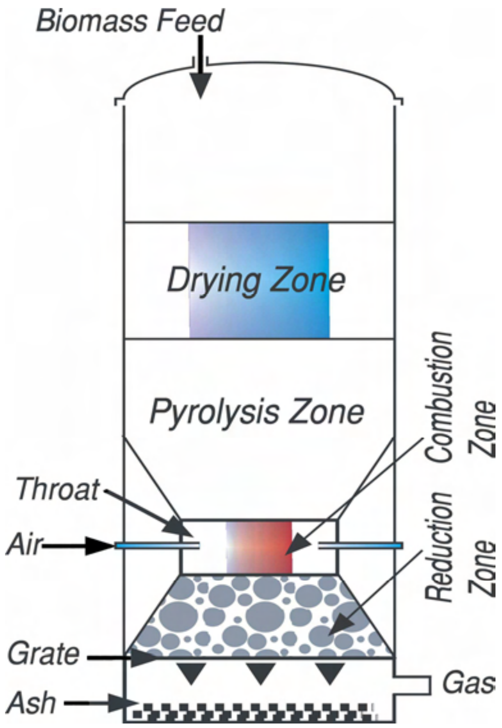
There are two major types of gasifiers, fixed bed gasifiers and fluidized bed gasifiers. Fixed bed gasifiers are divided to updraft type which is heated at the bottom and its producer gas leaves from the upper part, and downdraft type which its oxidation occurs middle of the reactor and the gas leaves at the bottom. The major advantages of updraft type are its simplicity and acceptability of high moisture content biomass (<60%). But the producer gas created by updraft type contains highest amount of tar. This is not very critical in the case of thermal application but extensive gas cleaning is required for power application. On the other hand, producer gas created by downdraft type contains the smallest amount of tar (<100mg/Nm^3) and therefore appropriate for power application. But biomass fuel for downdraft gasifier has to be dried (<20%) and its size has to be relatively uniform (4-10 cm). Downdraft type is not suitable for up sizing. The maximum capacity is thought to be around 500 kWe. Fluidized bed gasifiers were invented to solve the problems of fixed bed type. Fluidized bed gasifier is a vertical reactor vessel filled with sand having a porous bottom. Tar content of the gas is smaller than updraft and biomass of high moisture content can be used. It is suitable for up-scaling as well. But the system is more complicated and expensive, and more difficult to operate. The characteristics of different type of gasifiers are generalized in Table AP-C.4.1. For the rural electrification in Cambodia, downdraft gasifier is the most appropriate reactor type because they are less expensive, produce the lowest amount of tar in the gas and are easy to operate. Most of small-scale gasifier electricity generation systems are downdraft type. The structure of downdraft gasifier is described in Chapter 4.3.

Table AP-C.4.1 General comparison of different type of gasifiers.

	Fixed bed		Fluidized bed
	Updraft	Downdraft	
Biomass fuel with high moisture content (25-50%)	○	×	○
Uniformity of fuel size	Less critical	Critical	Not critical
Tar content in the gas	High	Low	Moderate
Small scale（<100kWe）electricity generation commercial products	△	○	×

4.3 Downdraft gasifier

Biomass is fed from top and move through drying, pyrolysis, oxidation and reduction zones and producer gas leaves from the bottom part in downdraft gasifier (Figure AP-C.4.1). Most of downdraft gasifiers have V shaped throat. This narrow part is the oxidation zone and air is directly sent to this oxidation zone. Most of tar produced at the pyrolysis zone is cracked while moving through the oxidation zone where the temperature is over 1000 °C. This is the reason tar production of downdraft gasifiers are so low. But it is difficult to maintain such high temperature uniformly in the oxidization zone of large capacity reactors. Unavoidably cold zones appear in the throat. As the results, the tar content of gas will increase and therefore the maximum capacity is thought to be around 500 kWe for downdraft gasification power generation systems. Biomass fed to downdraft gasifier should not be too large or too small (4-10 cm). This is because biomass has to be moving downwards smoothly and enough space is required for gas flow to downward and heat transport to upward.



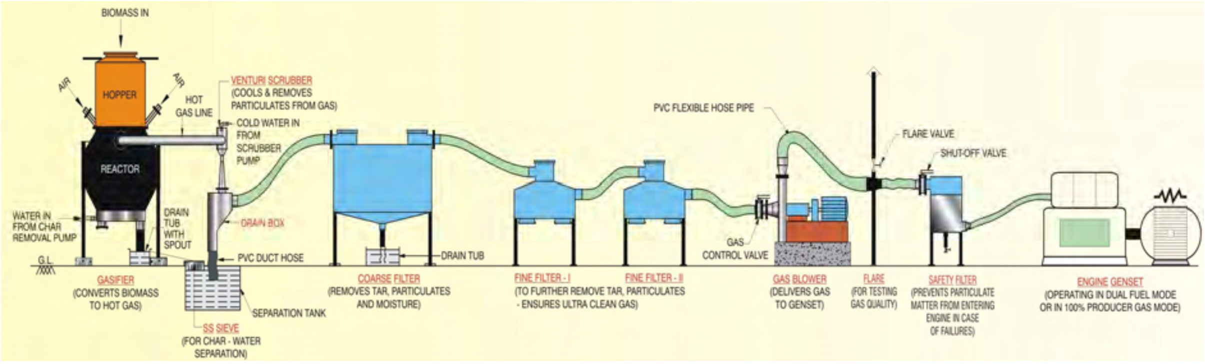
Source : Ankur Pvt. Ltd.

Figure AP-C.4.1 Downdraft biomass gasification reactor

The gas produced by downdraft gasifiers generally consist of combustible gasses about 20% of H_2, 20% of CO and a few percent of CH_4, and non-combustible gasses such as CO_2 and N_2. The producer gas contains 70% or more of energy of biomass in the case of power application.

4.4 Electricity generation by biomass gasification

The gas produced by gasifier is cooled and purified by sent through several filters to remove tar and other particles. The producer gas is then sent to engine to generate power (Figure AP-C.4.2). Diesel engines can be run by duel fuel mode (70% producer gas and 30% of diesel) or by 100% producer gas with minor modification. The gas duct needs to be connected to the engine for duel fuel operation and an ignition spark plug needs to be installed for 100% producer gas operation.



(Source: Ankur Pvt. Ltd)

Figure AP-C.4.2 Schematic flow of biomass gasification electricity generation system

4.5 Gasification in Asia

European and other developed countries have been mainly installing larger gasification electricity generation systems. There is a 75 MWe plant currently operating in Germany. Where small scale gasifiers are commercially available and distributed widely is in Asian countries.

During World War II, gasification was widely used in Japan and other Asian countries. The technology was forgotten after the war but re-spotlighted at the oil shock in 1973. Technology development and installation was progressed in many countries such as India, China, Thailand and Philippines. At present, India and China are the advanced countries in both technology and implementation. In India, a total 55 MWe of gasification power operation systems have been installed by 2003. Between 2004 and 2005, *A*-organization of India itself installed a total 20 MWe electricity generation systems. The total installation would be increased largely by now. In China, thermal application has been the majority installations but currently about 100 gasifiers fuelled by rice husk are generating electricity (Bhattacharya 2005).

4.6 Safety and Environmental Impacts[11]

(1) Carbon Monoxide

Small scale biomass gasifier of downdraft type includes about 20% CO in its producer gas.

A potential leakage of produced gas including CO from gas pipes can be avoided by employing atmospheric pressure (actually a little negative pressure due to suction by engine and blower) in the design of gasifier. (However, this negative pressure will, in case cracks take place on gas pipes, suck air inside the pipe to the contrary, resulting in combustion/explosion of producer gas inside the pipe. It has been devised that excessive pressure at such gas explosion will be released from spring-pressed safety cover or water seals at bottom of filters, etc.)

It is required to carry out gas leakage tests upon installation of a gasifier system.

Some unburnt CO will be exhausted from engine. It is suggested that a practical and appropriate standard of CO emission from biomass gas engine be set at 2,000 mg/m^3 under 5% O (p.297, Handbook, Biomass Gasification, Gasnet, 2005).

Gas engine should preferably be installed outdoor. In many biomass power stations in Asia, a powerhouse is well ventilated by adopting such house design as having only roof and some partial walls.

[11] Handbooks of Biomass Downdraft Gasifier Engine Systems. T.B. Reed. The Biomass Energy Foundation Press, etc

Gas detector/alarm should be installed inside the powerhouse or operator should carry a portable type while in duty.

Ventilation will be important at the time of start and stop in particular since there is a risk of more CO might leak.

(2) Tar and Phenol

Since the tar and phenol included therein generated in a gasifier has the following toxicity, a careful treatment is required:

- Some tars are reported to be carcinogenic.
- Tar includes phenol. Phenol is also called as carbolic acid. It has no color but has unique odor. It is waster-soluble. A wastewater standard of Japan sets a level at 5 mg/l. Phenol has an acute toxicity of medium intent to mammals. The toxicity of phenol is reported to be higher to fresh water life.
- It is reported that condensates of small gasifier has phenol concentration of 1,500-3,000 mg. These should not be disposed to ground or water body.
- The best countermeasure is to minimize creation of tar. In this context, the downdraft type that has the least tar among the small scale fixed bed gasifiers is suitable. There is a treatment method of cleaning remaining tar with sawdust filters and the used filters are back to and reburnt in the gasifier. In the case of water filter, tar is dried with waste heat of engine exhaust gas and then reburnt in the gasifier together with fuel wood. It is possible to minimize the production of condensates by well drying fuel wood before use.
- It will be required to confirm the treatment method of wastewater within an acceptable environmental standard by testing these measures through implementation of the pilot projects proposed in the Master Plan.

(3) Fire

There is a risk for producer gas contained inside the gasifier to contact air and get fire upon opening of top cover for loading fuel wood, which ignites inflammables around.

The producer gas would remain inside gasifier and gas pipes also after stop operation. Upon ignition to restart the gasifier, this remaining gas might explode.

The following countermeasure should be taken to avoid these fires:

- To fill the gas pipes with fresh are by discharging the remaining producer gas inside pipes with blower before igniting the gasifier;
- Not to look into a nozzle upon ignitions by standing not in front of the nozzle but beside it;
- To provide a safety valve if a gasifier is attached with a fixed top cover;
- To attach a flame arrester to a gas-air mixer.

(4) Environmental Hazard

There are 6,328 villages in Cambodia that are technically suitable for biomass power generation. The fuel wood required to electrify these villages will amount to 186,000 dry ton. This is only 0.4% of the annual production of biomass of 52 million tones in the forests countrywide (refer to Sub-section 1.4.4, Part 2). Accordingly, impacts on sustainable growth of forest are considered small even if all the fuel wood is sourced to the forests. However, there are such risks that forests get deteriorated due to local over-cutting nearby power stations. Therefore, it is set as a principle of the Master Plan to arrange required fuel wood through fuel wood farming.

Even with fuel tree farming, over production and harvesting of fuel trees would not only consume nutrients in soil but also would reportedly lower water permeability and capacity to store water in soil. It has been planned in the Master Plan that particular tree species that has ability to fix nitrogen inside soil are adopted for fuel tree farming and unit tree production is planned on the conservative side at 10 t/ha/yr.

It is required to confirm the sustainable production and harvesting of biomass through implementation and monitoring of the proposed pilot projects.

4.7 Case study of biomass gasification mini-grid rural electrification (India and Cambodia)

(1) India, Gosaba Island

Figure AP-C.4.3 5 x 100 kW biomass gasifier at Gosaba Rural Energy Cooperative, West Bengal State, India

About three million people inhabit the Delta Region of Sunderbans, West Bengal State. Two million of them do not have access to electricity. It is not economically feasible to extend grids to many islands wide spread in the Delta Region. The 500 kW (5 x 100 kW) biomass gasifier duel fuel power generation system (70% biomass + 30% diesel) was installed at Gosaba Island, Sunderbans in June, 1997 (Figure AP-C.4.3). Gosaba Island located about 80 km south west of Kolkata. It takes 1.5 hours by boat from the nearest port of mainland. There were only 16 customers when the operation started because people did not believe the system really works. But customer increased very quickly and currently 1150 HH are connected. The plant is currently operating 16 hours a day (9:00 am to 1:00 am next day). The island developed dramatically since the power station installed. There are so many commercial stores and more than 10 hotels, and people from near by islands come to Gosaba for shopping. There is a bank (State of India Bank) opened and support economical activities. Telecommunication system is available. Internet is available and there is a PC training centre. The hospital can conduct basic operations. The electricity is also used for public purposes such as street lights, school lighting, drinking water supply and irrigation.

The project is 100% funded by government since this is a pilot project but owned and operated by Gosaba Rural Energy Cooperative. The cooperative organises 75 ha of energy plantation. Biomass fuel is supplied by both from farmers and the plantation. The details of operation is summarised below.

Another 500 kW biomass gasifier duel fuel power generation system was commissioned in the remote Island of Chhotomollakhali in the Sunderbans in June 2001. There are numbers of smaller scale of biomass gasifier electrification units has been installed in West Bengal State.

Table AP-C.4.2 Summary of Gosaba Island Biomass Electrification

Plant capacity:	5 x 100 kW
No. of consumers:	1150 HH
Operation hours:	16 hours (9:00 am to 1:00 am next day)
Tariff structure:	Rs. 5.6 / kWh ($0.12) for domestic
	Rs. 6.75 / kWh ($0.15) for commercial
	Rs. 8 / kWh ($0.18) for industrial (telephone exchange, hospital X-ray, bank and soil analysis equipment of NGO)
No. of labourers:	22
Fuel efficiency:	90 cc diesel + 850-900 g of wood / kWh
Cost of fuel:	Rs. 35 ($0.78) / 40 kg half dry wood (one container) - $19.50/t

(2) Anlong Ta Mei Energy Cooperative, Battambang Province, Cambodia

There is one biomass mini grid electricity supply system operated by CEC in Cambodia. Anlong Ta Mei village (Bannan District, Battambang Province) has recently (February 2005) started its operation of community energy cooperative project. Currently electricity is supplied 7 hours (16:30-23:30) a day to 70 households. The project is organized by a NGO, Small and Medium Enterprise Cambodia (SMEC). SMEC received a grant ($24,000) from CIDA (Canadian International Development Agency) for the project. The initial cost for setting up a biomass gasification, electricity generation and distribution system are covered by the grant. The community energy cooperative will own, operate, maintain and manage the system on a non-subsidized, sustainable basis after the initial operational testing period. SMEC provide technical and supervisory input during the implementation period of the project (18-24 months).

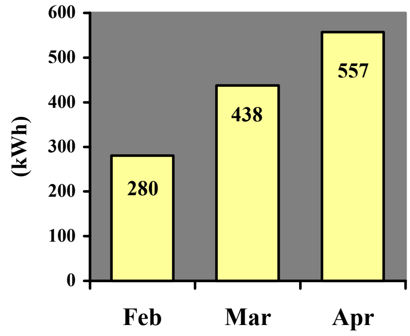


Figure AP-C.4.4 Monthly electricity consumption of Anlong Ta Mei Energy Cooperative.

The project introduced a 9 kWe biomass gasification electricity generation system (imported from India). Wooden posts are used for distribution line system. A meter is set for each house and customers are charged at kWh rate. Street lights were also installed (Figure AP-C.4.5).

(a) Gasifier electricity generation system.

(b) Electricity generation station.

(c) Distribution lines.

(d) A meter box.

(e) Street lights.

Figure AP-C.4.5 Woody biomass gasification electricity generation and distribution facilities at Anlong Ta Mei community energy cooperative project, Battambang Province

The total cost for initial establishment is about $23,436 which consists of a building ($1,500), a gasifier ($10,130), an engine ($4,342) and distribution lines $7,464 (Table 3.7.1). Community provided labour for the establishment. Customers are charged R50,000 ($12.50) for initial connection and the tariff is at R1,200/kWh ($0.30). Monthly electricity consumption has been increased since the operation started (Figure AP-C.4.6). The consumption in April was 557 kWh and the average consumption of each household was 7.6 kWh/month. The average electricity charge for each household was about $2.30/month. The tariff covers the future replacement cost of facilities such as gasifier (20 years), engine (8 years) and distribution line (30 years) (Table 3.7.2). The depreciation cost occupies 38% of monthly operational cost (Table 3.7.2). Cooperative members are encouraged to plant Leucaena leucocephala trees. Fuel for electricity generation is supplied by purchasing planted trees at $20/t from cooperative members. Currently 60 families planted *Leucaena* to a total of 8 ha of land. The monthly electricity consumption is presumed as 600 kWe/month. The amount of necessary fuel wood is 11 t and 1 ha of *Leucaena* farm is sufficient to supply continuously.

4.8 Comparison of biomass gasification electricity generation products

Manufacturers of biomass gasification power generation systems are summarized in Table AP-C.4.3 and technical specification of systems are summarized in Table AP-C.4.4. Only those manufacturers who are producing small scale (< 100 kWe) systems are selected and manufacturers who are already supplying commercial products or nearly ready to supply commercial products are listed. Since appropriate biomass fuels for all pre feasibility study sites are farmed tree woody biomass. It is therefore only gasification systems designed for woody biomass as fuel are discussed in this report.

All manufacturers use downdraft design which is appropriate for small scale gasifier. Organization *B* uses open top downdraft model. Hot gasses from the bottom of the reactor pass through an annular region transferring back part of the heat into the biomass in the upper zones. This structure allows higher moisture content biomass materials to be fed. Organization *A* has the far highest number and capacity of installation. Organization *A* started producing gasifiers in the late 80's. During last four years (2002-2005), they supplied 29.5 MWe gasification electricity generation systems. They have numbers of installation in twelve countries. They have already installed two systems in Cambodia and have local agent in the country. They are the only manufacturer, which people in Cambodia simply order the systems while other manufacturers prefer to set up a demonstration type installation in Cambodia before commercial installations. Some of the systems of organization *B, C, D* and *E* feature fully automated 24 hours remote controlled operation, which is not necessary for rural electrification in Cambodia. Simplification of the systems may reduce the cost significantly. Organization *C* suggests establishing local manufacturing systems with locally available materials and locally appropriating designs. Such technological transferring project will significantly contribute to lower the gasifier cost and improve local gasification technologies. As the results, rural electrification by biomass will be accelerated. Organization *D* offers low cost high spec and high durability systems but they have lack of past installations and therefore not considered as a reliable supplier yet.

Currently Organization *A* is assumed to be the most appropriate supplier of gasifier systems for rural electrification in Cambodia after taking all aspects (price, past installation records and locally available services) into consideration. The economic analysis of this report is based on the systems of Organization *A*.

Table AP-C.4.3 Summary of Manufacturers of Small Scale Commercial Gasifiers

Manufac turer	Country	Gasifier Type	Capacity	System prices	Installation	Remarks
A	India	Downdraft	4 - 850 kWe	$900 – $2,000/kWe	29.5 MWe (2002-2005) No proper record before 2002. Gasifiers are installed in 12 countries in Asia, Oceania, North and South America, Europe and Africa. There are two installations in Cambodia.	The company has an agent in Cambodia.
B	India	Open top downdraft	20 - 500 kWe	$1,000/kWe	3.3 MWe / 23 electrical installations in India, Chile and Switzerland.	The company has licensees in India, Switzerland and Japan
C	New Zealand	Downdraft	15 - 550 kWe	n.a.	Some recent model systems are installed in Ireland and Canada.	The company also has a licensed manufacturer in Ireland. They provide technical and design service as well. In case of Cambodia, they prefer to provide such service for local gasifier manufacturing.
D	New Zealand	Downdraft	50 kWe-3 MWe	$1,000/kWe	Information is not available.	
E	USA	Downdraft	5 - 50 kWe	$3,000 – $5,000/kWe	There are 10 installations in USA and Philippine	Full automated 24 hrs operation using battery bank.

Table AP-C.4.4 Specification of typical gasifier of each manufacturer appropriate for rural electrification in Cambodia

	A	*B*	*C*	*D*	*E*
Electricity output	64 kWe	80 kWe	34 kWe	100 kWe	50 kWe
Engine system	100 % producer gas, spark ignition	100 % producer gas, spark ignition	100 % producer gas, spark ignition	100 % producer gas, spark ignition	Start-up/Backup fuel; LPG
Operation	Manual wood fuel feeding	Fully automated	Fully automated remote control	Fully automated remote control	Fully automated remote control
Wood fuel conversion	1.5 kg/kWh	1.2 kg/kWh	1.3 kg/kWh	1.5 kg/kWh	1.5 kg/kWh
Continuous operation	> 24hr	*n.a.*	*n.a.*	24hr/7days	24hr/7days
Gasification efficiency	> 75%	80-83%	71%	*n.a.*	*n.a.*
Gasifier durability	10 years	*n.a.*	*n.a.*	30 years	*n.a.*

Note: *n.a.*; not available

Figure AP-C.4.6 A 40 kWe biomass gasification power generation system of *A*- organization

4.9 Domestic manufacturing

Manufacturing of gasifiers is not very complicated technology. In Cambodia, one REE owner produced a gasifier based on the one installed in Anlong Ta Mei CEC. The owner operates duel fuel mode (70% producer gas and 30% diesel) with a modified 75 kW diesel engine to supply electricity to 410 households. The domestic gasifier manufacturing is assumed to be possible. There is another REE owner who is currently trying to produce a gasifier. More people are interested in biomass gasification because of the current diesel price hike. But such copied production might seriously invade a patent right of *A*-organization in India. In addition, such copied systems do not meet safety and environmentally standard. There would be high risk of toxicosis of gasses, explosions and pollutions. The system to support domestic gasifier manufacturing in proper manner is needed. The licensed manufacturing of foreign products is one possible way. For the wide distribution of biomass gasification mini-grid electrification, spare parts supply and maintenance services need to be guaranteed. Domestic manufacturing of gasifiers will reduce the cost dramatically and the back up services will be improved, as the technology becomes locally available.

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Table AP-C.4.5 List of Principal Customers of Gasifier Power Equipments Supplied by "A" Organization in India

Dual Fuel Mode:

Client	Size	Gross output (kW) of system
Forestry Tasmania, Australia	WBG-40	40
Flex Technologies, Russia	WBG-500	500
Bionexx, Madagscar	WBG-40	40
Mozambique Leaf Tobacco, Mozambique	WBG-80	80
M/s Shree Gopal Rice Mill, West Bengal	FBG-120	120
M/s Durgesh Rice Mill, West Bengal	COMBO-175	175
SA Plywood Industries, West Bengal	WBG-400	400
APEDA, Arunachal Pradesh	5 X WBG-100	500
Agrocel Industries, Gujarat	WBG-300	300

100% Producer Gas Mode:

Client	Size	Gross output (kW) of system
James Finlay (Uganda) Ltd Muzizi, Uganda	WBG-400/ GAS-250	250
Dr.Ray Wijewardene, Sri Lanka	WBG-10/ GAS-4	4
CAEMA Srl, Italy	WBG-15/ GAS-9	9
Small and Medium Enterprise Cambodia, Cambodia **Installed at** Community Energy Cooperative, Cambodia	WBG-15/ GAS-9	9
Lanka Transformers Ltd., Sri Lanka	WBG-80/ GAS-40	40
Meghaplast, Meghalaya	WBG-400/ GAS-250	250
KREDL, Karnataka	WBG-400/ GAS-250	250
Agrocel Industries, Gujarat	WBG-300/ GAS-180	180
PMC, Tamil Nadu	WBG-400/ GAS-200	200
Muni Seva Ashram	WBG-80/ GAS-40	40

60 GAS-9 + GAS-4 Systems sent to Tamil Nadu for rural electrification.

5. BIOMASS GASIFIER POWER GENERATION SYSTEM

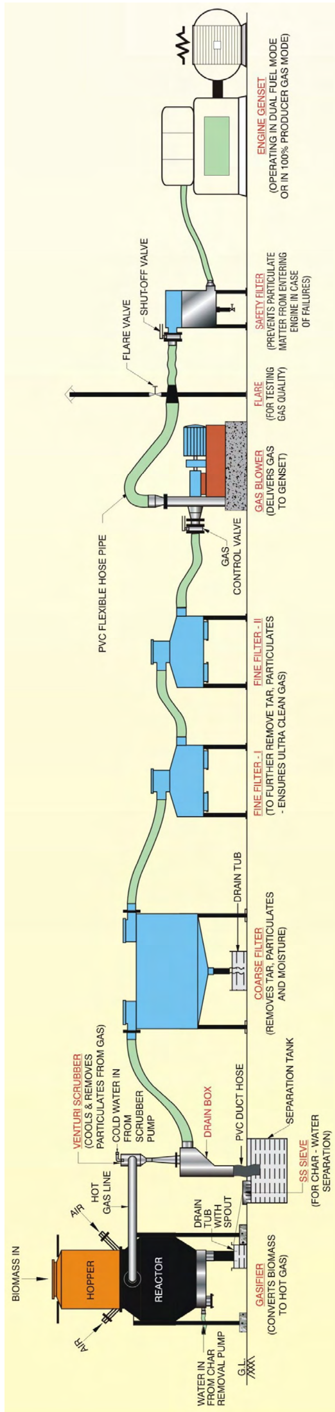

Figure AP-C.5.1 Biomass Gasifier Power Generation System

Source: Ankur Scientific Energy Technologies Pvt. Ltd.

6. REPORT OF PRODUCTIVITY AND SUSTAINABILITY OF BIOMASS FUEL PRODUCTION

Productivity and sustainability of biomass fuel production

—Case study of Meanok Forest Plantation in Kampong Chhnang Province and Anlong Ta Mei Community Energy Cooperative in Battambang Province —

Meanok Forest Plantation

Anlong Ta Mei Tree Farm

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April 2006

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Chemical analysis was conducted under supervision of Dr Nakorn Worasuwannarak in a laboratory of King Mongkut's University of Technology in Thailand. Ms Ung Chan Pisey provided valuable support in logistics and lab analysis.

INTRODUCTION

In Cambodia, about 15% of households have access to electricity (NIS 1999). However, only 9% of households in rural area have access to electricity compared to 54% in urban areas. Cambodia does not have a major inter city main grid connection. Moreover, electricity tariff in rural area is generally much higher, sometimes it exceeds 10 hold differences. Overall, people in rural areas are subject to both expensive and poor quality electricity.

The Royal Government of Cambodia is acutely aware of how rural communities are disadvantaged and have set the target of 70% level of household electrification with grid quality electricity by the year 2030 (JICA 2005a). The government will be working to achieve this target via grid extension and mini-grids establishments and it has been proposed that mini-grid establishment will be based mainly on renewable energy. All oil products are imported in to Cambodia. Consequently, utilization of domestic renewable energy source has both environmental and economic advantages. However, micro-hydro and wind power potential is very limited in Cambodia and solar power generation is not appropriate for stand alone grid systems (JICA 2005a). By contrast, biomass resources such as wood and agricultural residues are abundant in Cambodia and biomass fuel already accounts for some 85% of the national energy consumption (MOE 2002).

In Cambodia, biomass gasification electricity is estimated cheaper than diesel generation when electricity consumption per household exceeds 13 kWh/month. Average electricity consumption per household in rural community is about 10 kWh/month when people use electricity only for lighting and watching TV. With additional daytime electricity use such as water pumping for household and irrigation purpose, rice milling and ice making makes biomass gasification electricity cheaper option than diesel generation. JICA study team for 'The Master Plan Study on Rural Electrification by Renewable Energy in The Kingdom of Cambodia' concluded that over 6000 villages among total 14,000 villages in the country are appropriate candidature for biomass electrification in terms of both economics and biomass resources (JICA 2005a). JICA study team also concluded that tree planting would be the main biomass resource rather than agricultural residues such as rice husk mainly because the difficulty of stable supply.

For the success of biomass electricity systems, sustainability of fuel wood production is one of the most important factors. If sustainable management is to be achieved, management programs need to develop a better understanding of the biological and ecological processes that maintain net primary production and biomass storage (Kimmins 1997), in order to maintain production and minimise nutrient depletion of sites over successive rotations. The history of tree planting is rather short in Cambodia. With the best knowledge of authors, there is no published data of biomass production and nutrient cycling of tree plantation in Cambodia. Biomass estimation of forest stand is important not only for biomass energy use but also for stored carbon estimation as the greenhouse gas sink. JICA study team decided to conduct study of biomass productivity and nutrient sustainability of tree plantation. Although the resources and time we can allocate for such study was very limited as a study team for national rural electrification. We could manage to conduct field sampling survey in both tree farming

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and tree plantation site as well as chemical analysis of plant materials and soils. In this report, we present biomass equation and productivity of *Eucalyptus camaldulensis* and *Acacia auriculiformis* in Meanok Forest Plantation in Kampong Chhnang Province and *Leucaena leucocephala* in tree farming in Anlong Ta Mei Energy Cooperative in Battambang Province. We also present nitrogen and carbon distribution in trees and soils, and provide suggestions and recommendations for the plantation management and further investigations.

Part 1. Meanok Forest Plantation

BACKGROUND

Environment and history of Meanok Forest Plantation is well described in Lic and Shima (2005). We summarize it as follows. Meanok Forest Plantation is located in Sameakki Mean Chey District, Kampong Chhnang Province. The plantation spread at latitude between 11° 50' and 11° 57', and longitude between 104° 30' and 104° 40'. The plantation is owned and managed by Forest Administration. Planting started in 1999 and total 1525 ha have been planted by 2003. Planted species are *Acacia* spp. and *Eucalyptus* spp. Degraded natural forest is cut and bulldozed prior to planting. Average annual rainfall recorded at Pochentong Meteorological Station in Phnom Penh which is about 40 km away from the plantation is 1550 mm. The average temperature in plantation is 27.3°C. Soil type of the area is classified as Ferric Acrisols or Gleyic Acrisols (FAO 1974).

There are several species of *Eucalyptus* and *Acacia* have been planted in Meanok Plantation. We selected *Eucalyptus camaldulensis* and *Acacia auriculiformis* for this study. Eucalyptus camaldulensis is a major *Eucalyptus* species in Meanok Plantation and some tree growth data is published in Lic and Shima (2005). Although no published growth data of Acacia is available, once biomass equation is built, stand biomass can be easily estimated after forest census data is collected. *Acacia auriculiformis* has the oldest stand. Consequently variety of dbh (diameter at breast height) trees is available for sampling. We report volume and biomass equation, carbon and nitrogen concentration of each biomass components of *Eucalyptus camaldulensis* and *Acacia auriculiformis*, stored biomass, carbon and nitrogen content in each biomass components of *E.camaldulensis* stand. Description and, carbon and nitrogen concentration in a soil profile are also reported.

METHOD

Biomass Estimation

We harvested 10 trees each of the species across the range of dbh distribution (4.4 – 20.2 cm). Trees were felled and the stumps cut to ground level. Total tree height and diameter at 2 m intervals, both under and over bark, were recorded along the length of the stem. Stem sections were then weighed both with and without bark. Crown components were sorted and weighed as: branches diameter ≥ 2 cm, < 2 cm and foliage. Sub samples of each component and four sub samples of stems were also weighed fresh and then brought to the Ministry of Industry, Mines and Energy (MIME) in Phnom Penh where they were dried in an oven at 70°C until constant weight. The moisture content was used for estimating total dry weight of each tree.

Allometric relationships of estimated component dry matter (y) from diameter at breast height (dbh) were developed using the harvested sample trees for each component separately. Linear and non-linear regressions of several forms relating component weights, stem volumes and leaf area to dbh were examined. Allometrics that best fitted the data were chosen by examining

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residual distributions and maximizing adjusted r^2. The final regression form was as *log* dry matter = a + b *log* dbh, where a and b are constants.

We estimated stand biomass by applying dbh data in Lic and Shima (2005). Among their data in different stands. We only used the 2001 confirmed seed source plot data because one forestry officer pointed out that there would possibly be the confusion of *Eucalyptus camaldulensis* and *Eucalyptus tereticormis* in some other plots.

Leaf areas of sample leaves were measured by leaf area meter to obtain specific leaf area (the area of the leaf as a ratio of its dry weight). Leaf area is calculated as multiply specific leaf area and the dry leaf mass, and then leaf area index (the leaf area per unit land area) was calculated.

Soil Profile

A one-meter depth soil profile was dug and the description was recorded in the *Acacia auriculiformis* stand. Profile description was made according to the standard method of FAO (1990). Soil colour was recorded according to the Standard Soil Color Charts (Research Council for Agriculture, Forestry and Fisheries 1997) Sample soils were collected using soil corers which volume was known. Four samples were collected from each horizon and bulked.

Photo 1. Biomass destructive measurement in Meanok Tree Plantation. (Top left) Stem measurement of *Acacia auriculiformis*. (Top right) Stem weighing of *Eucalyptus camaldulensis*. (Bottom left) Sorting leaves and branches of *E.camaldulensis*. (Bottom right) Studied *E.camaldulensis* stand.

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Chemical Analysis

Oven-dried plant samples were then ground using food grinder. Each biomass components of 3-4 trees were bulked to reduce the number of samples for analysis. Soil samples were air-dried and lightly ground using pestles and mortars. The ground plant and soil samples were then sent to King Mongkut's University of Technology in Thailand. At the laboratory, samples were further ground into fine particles of less than 250 μm in diameter, and dried in vacuo at 70^{o}C for 24 hours prior to analysis. Samples were then analysed using a CHNOS analyser (Thermofinnigan, Flash Ea 1112). Soil pH was measured in a 1:2 mixture of soil:deionized water at MIME.

RESULTS AND DISCUSSION

Soil Profile

Description and a photograph of the one-meter depth soil profile at the *Acacia auriculiformis* stand in Meanok Plantation are shown in Box 1. The profile did not show apparent differences between horizons. Soil textures were sand across the profile. Upper horizons were slightly blackish than sub horizons and this indicates more organic matter contents in upper horizons. Soil colour in A horizon was reddish grey (10R 5/1) then pale reddish orange (2.5YR 7/3) for B1 and light gray (5YR 8/2) for B2 horizons. Some chemical and physical characteristics of the soil profile of Meanok Plantation and Anlong Ta Mei tree farm are shown in Table 1. Soil in Anlong Ta Mei was clayish and very different from the soil in Meanok. Bulk density was higher in Meanok. Higher bulk density is typical characteristics of sandy soil. pH in surface was slightly acidic (5.4 for Meanok and 5.7 for Anlong Ta Mei) and sub soils were closer to neutral (6.3 to 6.9) in both sites. The pH level is in the preferable range (5.5 to 7.0) of most plants growth (Brady and Weil 1999). Soils in Meanok contained very small amount of carbon and nitrogen. Nitrogen concentration in the soil below 70 cm was too small and was not detectable. Total carbon and nitrogen stored in the soils of 1 m depth in Meanok were only 13% (C) and 12% (N) of soil in Anlong Ta Mei. Soil profile survey in Meanok was conducted at *A.auriculiformis* stand. Higher nitrogen concentrated litter fall because of nitrogen fixing characteristics of *A.auriculiformis* likely enrich the nitrogen concentration in surface soil. Nitrogen concentration in the soils in *E.camaldulensis* site would be even lower. Other nutrients are likely to be very limited as well in Meanok soils.

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TABLE 1. Physical and chemical characteristics of soil profiles in Meanok *Acacia auriculiformis* plantation and Anlong Ta Mei *Leucaena leucocephala* tree farming site.

Horizon	Depth	Bulk density	pH	N concentration	C	C/N ratio	N stored amount	C
Meanok	(cm)	(Mg/m^3)		(%)			(kg/ha)	
A	0-12/20	1.57	5.4	0.032	0.41	12.75	798	10175
B1	12/20-70	1.87	6.3	0.007	0.05	6.83	684	4667
B2	70-100	1.87	6.8	0.000	0.03		0	1575
	total						1482	16418
Anlong Ta Mei								
A	0-12	1.26	5.7	0.111	1.22	10.97	1686	18492
B	12-40	1.32	6.9	0.121	1.49	12.29	4454	54745
B	40-70	1.35	6.9	0.077	0.73	9.48	3119	29582
C	70-100	1.48	6.8	0.068	0.61	9.03	3017	27239
	total						12276	130058

BOX 1. Soil profile description of Meanok Forest Plantation.

Profile # 0502 Meanok *Accacia auriculiformis* plantation, Kampong Chhnang Province.

Coordinates: 104^o 35' E, 11^o 50' N. Altitude: 30m, Topography: almost flat. Land form: plain. Land element: plain. Position: intermediate part. Gradient: level. Form: straight. Micro-topography: No micro-relief. Parent material: not known. Erosion: no evidence of erosion. Land use: 6 y old first rotation *Acacia auriculiformis* plantation.

Horizon	Depth (cm)	Color (moist)	Notable features
O	1 - 0		Mostly *Acacia* leaves.
A	0 – 12/20	10R 5/1	No mottling / sand / no rock fragment / very weak structure / loose consistence when dry or moist / non sticky / non plasticity / 14 (Yamanaka method hardness) / no voids / few very fine and very few fine, medium and coarse roots.
B1	12/20 – 70	2.5YR 7/3	No mottling/ sand / no rock fragments / very weak structure / loose consistence when dry or moist / non sticky / non plasticity / 20.5 (Yamanaka method hardness) / no voids / very few very fine, fine and medium roots.
B2	70 +	5YR 8/2	No mottling/ sand / no rock fragment / very weak structure / loose consistence when dry or moist / non sticky / non plasticity / 22 (Yamanaka method hardness) / very few fine and medium roots.

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Biomass and Volume Equations

Tree diameter (over-bark) was a strong predictor of stem volume of trees (Figure 1). Equations for estimating tree volume and biomass of plant components from dbh are shown in Table 2. Stem volume of *Eucalyptus camaldulensis* and *Acacia auriculiformis* can be calculated with following equations.

(*E.camaldulensis*)

log over-bark stem volume (m^3) = 2.375 x *log* dbh (cm) – 8.737 (r^2 = 0.995)

(*A.auriduliformis*)

log over-bark stem volume (m^3) = 2.054 x *log* dbh (cm) – 7.835 (r^2 = 0.984)

d^2h is often used as a parameter for volume equations and volume tables instead of dbh. With using d^2h, following equations were obtained.

(*E.camaldulensis*)

log over-bark stem volume (m^3) = 0.902 x *log* d^2h – 9.501 (r^2 = 0.999)

(*A.auriduliformis*)

log over-bark stem volume (m^3) = 0.870 x *log* d^2h – 9.501 (r^2 = 0.994)

Using d^2h instead of dbh slightly improve the correlation coefficient (r^2 = 0.995 → 0.999 for *E.camaldulensis* and r^2 = 0.984 → 0.994 for *A.auriculiformis*). But standing tree height measurement involves considerable error especially for taller trees. Since the correlation coefficient of equations with dbh is very high, we recommend using only diameter for volume estimation because tree height measurement requires extra labour for less accurate data collection. Further data collection and analysis should be carried out for examining this matter. Volume equations reported here are the first ones in Meanok Forest Plantation. Further data collection from different age stands is recommended to enhance the reliability of the equations. Relationships between dbh and mass of each plant component (stem, stem bark, branches ≥ 2 cm, branches < 2 cm and foliage) were analysed for each age class by regression analysis (Table 2). The total mass (r^2 = 0.99 for both species) and the mass of stem (r^2 = 0.99 for *E.camaldulensis* and r^2 = 0.98 for *A.auriculiformis*) were well predicted on the basis of dbh (Figure 2). The regression of other biomass components were weaker but the correlation coefficient was still very high (r^2 = 0.91 – 0.98) except branches > 2 cm of *A.auriculiformis* (r^2 = 0.76). Total biomass of *A.auriculiformis* is higher than *E.camaldulensis* across the dbh range. This mainly attributes to the higher stem wood density (616 kg/m3 for *A.auriculiformis* and 556 kg/m^3 for *E.camaldulensis*) and more branching characteristics of *A.auriculiformis*. The stem wood density of *E.camaldulensis* is reported as 705 kg/m^3 in Pakistan (Ahmad 1996) and 980 kg/m^3 (FAO 1979). Further investigation is needed to elucidate the reasons for the differences.

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TABLE 2. Allometric equations for estimating stem volume and biomass of each plant component where y is logarithmic stem volume (m3) or biomass (kg) and x is logarithmic dbh (cm).

Component biomass (kg)	*Eucalyptus camaldulensis*	*Acacia auriculiformis*
Over-bark stem volume	y=2.375x-8.737, r^2=0.995	y=2.054x-7.835, r^2=0.984
Under-bark stem volume	y=2.467x-9.214, r^2=0.993	y=2.080x-8.084, r^2=0.984
Total biomass	y=2.452x-2.541, r^2=0.992	y=2.264x-1.571, r^2=0.990
Stem	y=2.470x-2.908, r^2=0.986	y=2.182x-1.899, r^2=0.978
Bark	y=1.987x-3.398, r^2=0.959	y=1.628x-2.387, r^2=0.982
Branch > 2 cm diam	y=4.134x-9.465, r^2=0.972	y=3.428x-6.684, r^2=0.756
Branch < 2 cm diam	y=2.195x-4.127, r^2=0.909	y=2.066x-3.273, r^2=0.929
Foliage	y=2.120x-3.736, r^2=0.973	y=2.153x-3.984, r^2=0.930

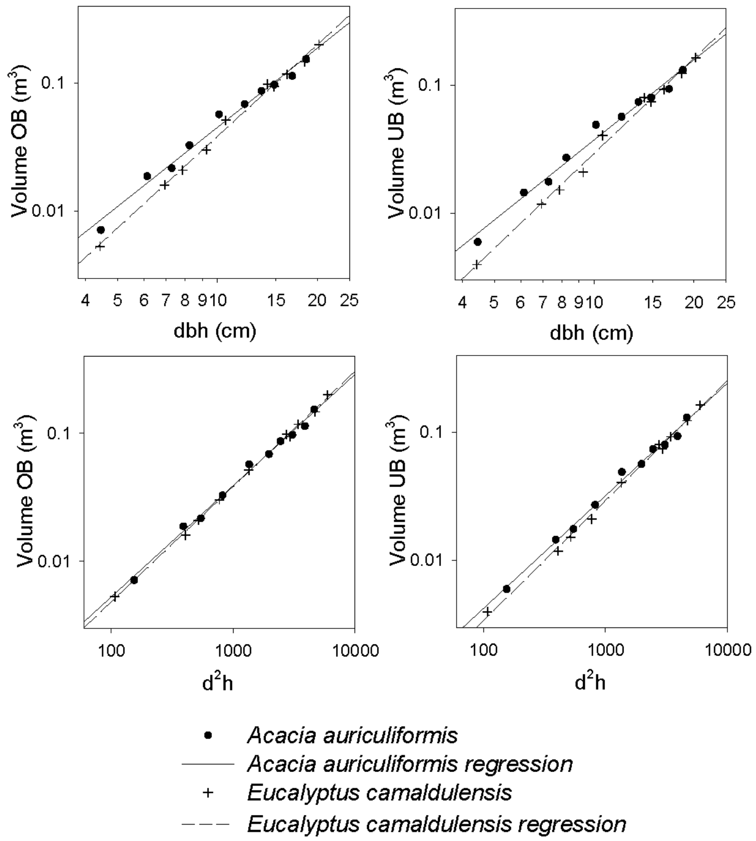

FIGURE 1. Relationship between over-bark (OB) and under-bark (UB) stem volume, dbh and d2h of *Acacia auriculiformis* and *Eucalyptus camaldulensis* trees in Meanok Forest Plantation.

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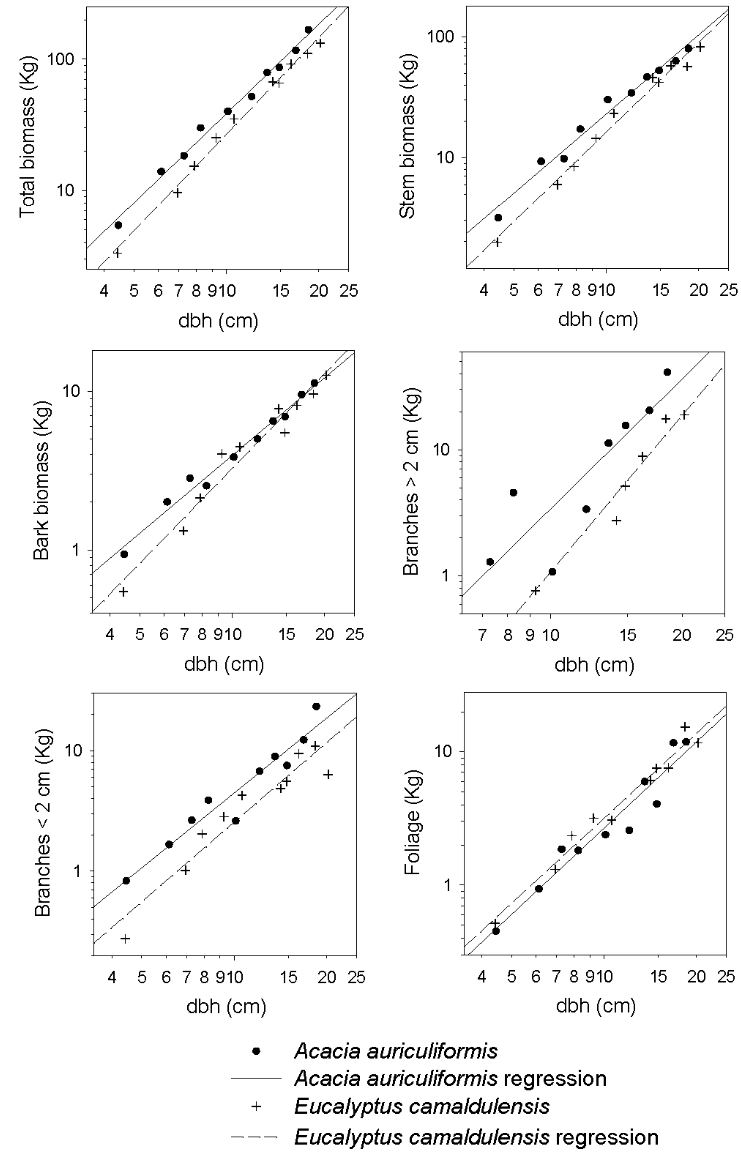

FIGURE 2. Relationship between dbh and, total biomass and each biomas components of Acacia auriculiformis and Eucalyptus camaldulensis in Meanok Forest Plantation, plotted with logarithmic scale.

Biomass Productivity and N & C distribution

Nitrogen and carbon concentrations of biomass components of *E.camaldulensis* and *A.auriculiformis* of Meanok Forest Plantation, and *L.leucocephala* of Anlong Ta Mei tree farm is shown in Table 3. Foliage nitrogen concentration of *E.camaldulensis* was only 62% of *A.auriculiformis* and 42% of *L.leucocephala.* Nitrogen fixing characteristics of *A.auriculiformis* and *L.leucocephala* would be the reason for the higher foliage nitrogen concentration. Higher foliage nitrogen concentration of *L.leucocephala* to *A.auriculiformis* probably attributes to the higher nitrogen concentration in soils at Anlong Ta Mei site (Table 1).

Biomass, carbon and nitrogen contents of 3-year-old *E.camaldulensis* stand was estimated by using forest census data in Lic and Shima (2005), biomass equations (Table 2) and, carbon and nitrogen concentration (Table 3). The mean annual biomass increment (MABI) of total biomass was 5.3 Mg/ha. MABI of stem and branch > 2 cm which can be used for gasification electricity generation was 3.4 Mg/ha. This is much smaller than the prospective estimation of biomass production of 10 Mg/ha/year used in the Master Plan (JICA 2005a). MABI of plantation trees usually dramatically increased at several years after planting. MABI of studied *E.camaldulensis* stand is likely to increased in following years but it would not probably reach 10 Mg/ha/year under the current management practice.
Stem wood accounted for 61% of total biomass but only 31% of nitrogen. Harvest only stem wood and leave bark and canopy components at the logged over site would significantly improve nutrient sustainability of plantation compared to whole tree harvesting. Meanok Plantation soils were very poor in nitrogen and probably poor in other nutrients as well. Nitrogen stored in the 3-year-old *E.camaldulensis* trees was 5% of stored in 1 m depth soil. Productivity of successive rotations would be decreased because of nitrogen (and other nutrients) depletion although growth of coppiced regenerated trees usually grows faster than initial planted generation. Conversion to nitrogen fixing tree species or mix planting with them, and fertiliser application should be considered for optimal and sustainable production. Specific leaf area of *E.camaldulensis* and *A.auriculiformis* were 7.42 m^2/kg and 10.43 m^2/kg respectively. Leaf area index (LAI) of the 3-year-old *E.camaldulensis* stand was 1.48. This is much lower than the LAI range of global plantations of 2.2 to 11.6 (Beadle 1997) and it indicates poor capacity of productivity of the stand.

Potential for Biomass Electricity

There are three villages (Srae Mikak, Meanok Lech and Meanok Kaeut) with total 636 households near Meanok Forest Plantation. Those villages are currently not electrified. They are located outside of 40 km circles from Phnom Penh and Campong Chhnang, which is technical limit of medium voltage line (22 kV) extension. Villages are more than 10 km away from National Highway #5 and it will take many years to the area be connected to the future national grid. The prospective selling price of the timber in Meanok Plantation is $15/Mg (Lic and Shima 2005). Prospective wood price for biomass electricity generation is $20/Mg. Fuel cost is minor fragment of electricity generation cost and it is possible to set even higher wood price. Lic and Shima (2005) concluded that operation in Meanok Plantation is possibly bring large financial deficit and is failure in terms of social and environmental aspect as well. Lic

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TABLE 3. Carbon (C), nitrogen (N) concentration and C/N ratio of biomass components of *Eucalyptus camaldulensis*, *Acacia auriculiformis* of Meanok Forest Plantation and *Leucaena leucocephala* of Anlong Ta Mei Energy Cooperative. *n*: number of samples, *SE*: standard error.

		C		N		C/N	
	n	(%)	*SE*	(%)	*SE*		*SE*
Eucalyptus camaldulensis (Meanok)							
Stem	3	48.7	0.06	0.24	0.01	205.8	11.1
Bark	3	43.2	0.73	0.38	0.01	113.5	5.3
Branch > 2cm	3	47.8	0.40	0.43	0.15	137.0	37.3
Branch < 2cm	3	46.9	0.41	0.59	0.05	82.3	7.1
Foliage	3	51.3	0.37	1.61	0.09	32.2	2.1
Acacia auriculiformis (Meanok)							
Stem	3	48.4	0.70	0.26	0.02	188.6	12.5
Bark	3	49.2	0.14	1.48	0.09	33.5	1.9
Branch > 2cm	3	47.6	0.85	0.76	0.15	67.6	12.0
Branch < 2cm	3	48.6	0.32	1.17	0.18	43.4	6.6
Foliage	3	53.9	0.35	2.59	0.11	20.9	1.0
Leucaena leucocephala (Anlong Ta Mei)							
Stem with bark	4	47.0	0.37	0.75	0.07	63.8	4.8
Branch	4	46.7	0.34	0.95	0.06	49.6	3.0
Foliage	4	45.2	0.18	3.82	0.12	11.9	0.4
Fruit	4	45.2	0.21	4.83	0.42	9.6	0.7

TABLE 4. Biomass, carbon and nitrogen content in each plant components of 3-*y*-old *Eucalyptus camaldulensis* stand in Meanok Plantation.

(kg/ha)

	Total	Stem	Bark	Branch > 2cm	Branch < 2cm	Foliage
Biomass	15971.2	9710.3	2115.0	556.3	1590.0	1999.5
C	7679.4	4726.6	913.5	266.1	746.5	1026.7
N	74.9	23.1	8.1	2.4	9.2	32.1

and Shima (2005) also pointed out that involvement of and benefit to the local community is one of the most important aspects for the success of the plantation management. Biomass electrification of the area would significantly improve the living condition of the local community. Once sustainable high biomass production is realized, Meanok also has high potential for establishing megawatt class plants to supply clean renewable electricity to the future national grid.

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