Appendix B
Electricity Supply Technologies

On-Grid Electricity Supply Technologies

Table B-1 summarizes key characteristics for on-grid electric generating technologies. Representative values are shown; specific cases may vary considerably from these estimates.

Factors listed in this table include the following:

- Application: Base, intermediate, or peaking. Base load plants provide the slowly varying baseline power demanded by the grid and account for the bulk of the power supplied. Because of the large amount of power they supply, low cost fuels such as coal or—in some cases-nuclear are preferred for these plants. Because of the difficulties inherent in using these fuels, base load plants are generally large and capital intensive. Intermediate and peaking plants are chosen to be successively less capital intensive as they are used for shorter periods, such as for the afternoon peak demand due to air conditioning loads or the early evening peak due to residential lighting demand. To minimize capital costs, more expensive fuels, such as oil or gas, are generally used, and the plants are installed in smaller units.
- Capital Costs. Costs shown are nominal values; these costs will vary widely depending on local conditions, specifics of the technology, and other factors. Many of these cost estimates are from Electric Power Research Institute, *Technical Assessment Guide (TAG),* Report No. EPRI P-6587-L, Palo Alto, CA, September 1989; other cost estimates have been developed by OTA from various sources. All costs are deflated to December 1990 U.S. dollars. Note that the capital costs listed here do not include mining, transmission and distribution, administration, or other overhead capital costs, and are not adjusted for capacity factors as is necessary to account for full systemwide costs as done in appendix A.
- **operating Requirements.** Estimated heat rates (Btu/kWh) are from the Electric Power Research Institute (TAG) where available; other heat rate or thermal efficiency (in percent) estimates have been developed by OTA from various sources. Heat rates or efficiencies will vary depending on specifics of the technology, fuel quality, and other factors.
- Fuel. Plants listed as using ‘‘distillate’ can often use natural gas as well. Fuel costs are from the Electric Power Research Institute (TAG), and are for U.S. delivery in 1990. Availability of petroleum-based fuels varies with world market conditions; if a domestic source is used then availability may be much improved.
- Total Costs. Levelized capital costs assume the discount rate, lifetime, and capacity factors shown; results are sensitive to all these assumptions. O&M costs are estimated by OTA based on information from manufacturers, consultants, utilities, and others. Both fixed ($/kW-yr) and incremental ($/kWh) O&M costs are included; fixed O&M costs are levelized using the capacity factor. Fuel costs are based on given fuel prices and heat rates, Note that these costs are lower than the total systemwide costs estimated in appendix A due to assumed high capacity factors here (70 percent) for individual plants rather than typical system capacity factors of 60 percent or less as assumed in appendix A, and because other cost components such as coal mining, transmission and distribution, and operating overhead are included in appendix A but are not included here.
- Time Requirements. Installation lead times are typical values for the time from decision to build to actual operation. These values are strongly affected by site-specific permitting and other regulatory considerations.
- Environmental Impacts. Air indicates the relative quantity of NO_x, SO_x, and particulate emission, per kWh; it does not include $C0_2$ emissions, which are highest for coal-based technologies, followed by oil, natural gas, and others. Water requirements indicate the relative quantity of water needed to operate the plant. Solid and liquid waste products indicate the volume of waste products which must be handled.
- Infrastructure Requirements. In general, large (over 100 MW) plants will require river or rail access.

The technologies evaluated in table B-1 include the following with the listed parameters:

- **Conventional Combustion Turbine.** Based on an 80 MW unit.
- Conventional Steam Plants. Values for coal plant are based on a 300 MW subcritical plant using West Virginia bituminous pulverized coal without flue gas desulfurization (FGD).
- **Hydroelectric Plants.** Costs may vary widely, depending on local conditions.
- **Advanced Combustion Turbine.** Based on a 140 MW unit.
- **Combined Cycle.** Based on a 120 MW unit using distillate fuel.

Table B-1—Nom nal Parameters for Selected On-Grid Generating Technologies—Part

	Existing reference technologies					
	Conventional combustion turbine	Conventional steam, fueled by: Gas	Oil	Coal	Diesel engine	Hydropower
Application (base, intermediate, peaking)	I,P	B,I	B,	[illegible]	I,P	B,I,P
Capital cost ($/kW)	400	1,100	1,200	1,500	1,000	1,500
Operating requirements:						
Efficiency (Btu/kWh or percent)	14,500	10,000	10,000	0,000	8,800	NA
Fuel:	natural gas	natural gas	residual	coal	diesel	water
Cost, $/million Btu (1990)	$2.72	$2.72	$2.72	$2.00	$4.10	$0.00
Total costs:						
Discount rate (percent)	7	7	7	7	7	7
Lifetime (years)	30	30	30	30	30	30
Capacity factor	15	70	70	70	40	40
Levelized capital costs (cents/kWh)	2.50	1.50	1.60	2.00	2.30	3.50
O&M costs (cents/kWh)	0.90	0.50	0.60	1.00	0.80	0.30
Fuel costs (cents/kWh)	3.90	2.70	2.70	2.00	3.50	0.00
Total (cents/kWh)	7.30	4.70	4.90	5.00	6.60	3.80
Sizes of available units (MW)						
Minimum	4	20	20	50	4	1
Typical	80	300	300	300	8	200
Time requirements						
Installation lead time (years)	2-3	6-8	6-8	7-9	2	10
Expected year of commercial availability	available	available	available	available	available	available
Environmental impacts						
Air	low	low	[illegible]	high	medium	none
Water requirements (gallons/MW-day)	low	medium	[illegible]	medium	low	high
Solid and liquid waste products	low	low	[illegible]	high	low	none
Land requirements (per MW)	low	medium	[illegible]	high	medium	high
Infrastructure requirements: rail or river access	useful	required	required	required	none	useful

NA = not available, not applicable, or too variable to quantify.

SOURCE: Office of Technology Assessment, 1992.

Table B-1—Nominal Parameters for Selected On-Grid Generating Technologies—Part 2

	Improvements in existing technologies					
	Advanced combustion turbine	Combined cycle	Fluidized bed	Life extension	Municipal solid waste	Steam-injected gas turbine
Application (base, intermediate, peaking)	I,P	B,I	B,I	NA	NA	B,I,P
Capital cost ($/kW)	400	600	1,700	50-1,000	5,000	600
Operating Requirements						
Efficiency (Btu/kWh or	13,800	8,100	10,000	NA	17,000	9,400
Fuel:	natural ga	distillate	coal	NA	MSW	natural gas
Cost, $/million Btu (1990)	$2.72	$4.10	$2.00	NA	(varies)	$2.72
Total costs:						
Discount rate (percent)	7	7	7	7	7	7
Lifetime (years)	30	30	30	30	30	30
Capacity factor (percent)	15	70	70	NA	70	40
Levelized capital costs (cents/kWh)	2.50	0.80	2.20	NA	11.50	1.40
O&M costs (cents/kWh)	0.90	0.50	1.30	NA	NA	0.80
Fuel costs (cents/kWh)	3.70	3.20	2.00	NA	NA	2.50
Total (cents/kWh)	7.10	4.50	5.50	NA	NA	4.70
Sizes of available units MW)						
Minimum	4	50	100	NA	40	NA
Typical	80	150	300	NA	50	100
Time requirements						
Installation lead time (years)	2-3	5-6	7-8	1-4	7-8	2-3
Expected year of commercial availability	1992	available	1994	available	available	available
Environmental impacts						
Air	low	medium	medium	NA	NA	low
Water requirements (gallons/MW-day)	low	medium	medium	NA	high	medium
Solid and liquid waste products	low	low	high	NA	NA	low
Land requirements (per MW)	low	low	medium	none	NA	low
Infrastructure requirements: rail or river access	useful	required	required	NA	useful	none

NA = Not available, not applicable, or too variable to quantify.

SOURCE: Office of Technology Assessment, 1992.

Table B-1—Nominal Parameters for Selected On-Grid Generating Technologies—Part 3

	New or innovative technologies					
	Advanced batteries	Advanced small nuclear	Binary geothermal	Compressed air energy storage	Fuel cell	Integrated gasification combined cycle
Application (base, intermediate, peaking)	P	B	B,I	P	B,I,P	B
Capital cost ($/kW)	600	1,900	2,000	650	3,000	1,650
Operating requirements						
Efficiency (Btu/kWh or percent)	86%	10,500	29,000	52%	8,500	9,200
Fuel:	electricity	nuclear	warm brine	electricity	distillate	coal
Costs, $/million Btu (1990)	NA	$0.80	variable	NA	$4.10	$2.00
Total costs						
Discount rate (percent)	7	7	7	7	7	7
Lifetime (years)	30	30	30	30	30	30
Capacity factor (percent)	15	70	70	15	40	70
Levelized capital costs (cents/kWh)	3.80	2.50	2.60	4.00	6.90	2.20
O&M costs (cents/kWh)	NA	1.40	1.60	NA	0.80	1.20
Fuel costs (cents/kWh)	NA	0.80	NA	NA	3.40	1.80
Total (cents/kWh)	NA	4.70	4.20	NA	11.10	5.20
Sizes of available units (MW)						
Minimum	NA	150	5	50	10	50
Average	20	350	50	110	25	75
Time requirements						
Installation lead time (years)	2	10-12	5-6	6-8	NA	8-9
Expected year of commercial availability	1997	2002	available	1993	NA	1994
Environmental impacts						
Air	low		high	low	low	medium
Water requirements (gallons/MW-day)	low	medium	high	low	low	medium
Solid and liquid waste products	medium	medium/high	varies	low	low	high
Land requirements (per MW)	low	medium	low-medium	medium	low	high
Infrastructure requirements: rail or river access	none	required	required	none	none	required

NA = not available, not applicable, or too variable to quantify.

SOURCE: Office of Technology Assessment, 1992.

Table B-1—Nominal Parameters for Selected On-Grid Generating Technologies—Part 4

	New or innovative technologies			
	Pumped hydro	Solar photovoltaic	Wind turbines	Solar-thermal electric/natural gas hybrid
Application (base, intermediate, peaking)	P	NA	NA	NA
Capital cost ($/kW)	1,100	6,000	1,100	3,000
Operating requirements				
Efficiency (Btu/kWh or percent)	75%	10%	NA	3,300
Fuel:	electricity	sunlight	wind	sunlight/Gas
Costs, $/million Btu (1990)	NA	0	0	$2.72
Total costs				
Discount rate (percent)	7	7	7	7
Lifetime (years)	30	30	30	30
Capacity factor (percent)	15	20	15	40
Levelized capital costs (cents/kWh)	6.80	36.80	6.80	6.90
O&M costs (cents/kWh)	NA	0.70	1.50	1.50
Fuel costs (cents/kWh)	NA	0.00	0.00	0.90
Total (cents/kWh)	NA	37.50	8.30	9.30
Sizes of available units MW)				
Minimum	NA	NA	0.25	NA
Average	1,000	NA	75	80
Time requirements				
Installation lead time (years)	11	2	2	2
Expected year of commercial availability	available	available	available	available
Environmental impacts				
Air	low	none	none	low
Water requirements (Gallons/MW-day)	high	none	none	high
Solid and liquid waste products	low	none	none	low
Land requirements (per MW)	high	high	high	high
Infrastructure requirements: rail river access	useful	none	none	none

NA = not available, not applicable, or too variable to quantify.

SOURCE: Office of Technology Assessment, 1992.

Table B-2—Nominal Parameters for Selected Off-Grid Generating Technologies

	Diesel	Micro-hydro	Photovoltaics	Wind
Capital cost ($/kW)	700	2,000	1 0,000[a]	5,000[b]
Lifetime (years)	10	20	30	20
Discount rate (percent)	7	7	7	7
Levelized capital cost ($/kW)	100	190	800	470
Capacity factor[c] (percent)	20	20	20	20
Capital cost ($k/Wh)	0.06	0.11	0.46	0.27
O&M ($/kWh)	0.02	0.02	0.005	0.01
Fuel ($/kWh)[d]	0.23	0.00	0.00	0.00
System losses[e] (percent)	5	5	10	10
Total cost ($/kWh)	0.33	0.14	0.51	0.31

NOTE: Numbers may not add due coextensive rounding.

[a] Photovoltaic costs include $6,000 per Peak kW for the panel, $2,000 for the balance of system costs, and $2,000 for batteries and their replacements (every 5 years over the 30 year life of the system).

[b] Wind costs include $3,500 per peak kW for the turbine and balance of system, and $1,500 for batteries and their replacements (every 5 years over the 20 year life of the system).

[c] The capacity factor is listed as percent but might equally well be given in terms of annual kWh output per kW capacity. A capacity factor of 20 percent then corresponds to 1,750 kWh/kW.

[d] For diesel priced at $0.50 per liter.

[e] System losses include battery losses for PV and wind systems, and other system losses for diesel and hydro equipment.

SOURCE: Office of Technology Assessment, 1992. Sources for costs are discussed in chapter 6 and are based primarily on retail quotes from manufacturers and distributors, where available. Developing country costs may be higher due to increased transportation costs, and due to duties and taxes. Costs shown here are for low-volume production, however, and higher volumes may allow for lower per unit costs.

- **Fluidized Bed.** Based on a **200 MW** unit with a circulating atmospheric bed using Illinois bituminous coal.
- **Life Extension.** Costs and other attributes vary widely.
- **Municipal Solid Waste.** Based on a 40 MW mass burn technology.
- Steam **Injected Gas Turbine.** Based on a 100 MW unit.
- **Advanced Batteries.** Based on a 5-hour, 20 MW unit.
- **Advanced Nuclear.** Based on a **600** MW light water reactor with passive safety features.
- Binary **Geothermal.** Based on a 54 MW unit.
- **Compressed Air Energy Storage.** Based on a rock formation cavern, using an electric compressor and a 110 MW combustion turbine. Approximately 10 hours of storage provided. Each kWh of output requires 0.76 kWh electric input plus 4,000 Btu of fuel.
- Fuel Cell. Based on a phosphoric acid fuel cell with 4 units at 25 MW each.
- **Integrated Gasification Combined-Cycle. Based** *on a* 400 MW plant using **bituminous coal.**
- **Pumped Hydro.** Based on a conventional above--ground 3 by 350 MW unit.
- **Solar Photovoltaics.** Based on a flat plate technology. Note that the costs of solar photovoltaic systems are largely scale independent.
- **Wind Turbine.** Based on a farm of three hundred 250 kW units.
- **Solar Thermal.** Based on a parabolic trough/natural gas hybrid. Note that the relatively high capacity factor is due to use of natural gas cofiring to supplement insolation.

Off-Grid Electricity Generating Technologies

A variety of technologies are available that can provide electricity at (remote) sites that are not connected to the electric power grid. Two sets of calculations are of interest. First, how do the costs of these various technologies compare. Four technologies-diesel engine generator sets, micro hydroelectric plants, flat panel photovoltaics, and wind turbines-were selected to illustrate this representative calculation. Second, how do the costs of these technologies (including battery storage, as needed) compare with the cost of extending the grid and providing on-grid generation.

In order to compare the cost of power from these various technologies, estimates were made for the life-cycle costs of a 10 kW peak capacity electricity generating system with storage. Nominal parameters and results are shown in table B-2 and a sensitivity analysis is shown in table B-3. These results are also shown in figures in chapter 6.

As can be seen in table B-2, where available, micro-hydroelectric power can be relatively lower in cost and wind power comparable in cost to diesel systems, Photovoltaic systems tend to be higher in cost for the baseline parameters chosen. The costs of power are highly sensitive, however, to fuel costs in the case of diesel

Table B-3-Sensitivity Analysis for the Cost of Selected Off-Grid Generating Technologies

	Diesel	Micro-hydro	Photovoltaics	Wind
Baseline: total cost ($/kWh)	$0.33/kWh	$0.14/kWh	$0.51/kWh	$0.31/kWh
Variable: fuel cost				
Baseline: $0.50/liter	0.33	0.14	0.51	0.31
$0.75/liter	0.45	0.14	0.51	0.31
$1.00/liter	0.57	0.14	0.51	0.31
Variable: discount rate				
3 percent	0.32	0.10	0.33	0.22
Baseline: 7 percent	0.33	0.14	0.51	0.31
10 percent	0.33	0.16	0.67	0.38
15 percent	0.35	0.21	0.96	0.51

NOTE: Parameters are based on table B-2.

SOURCE: Office of Technology Assessment, 1992.

Table B-4—Nominal Costs and Break-Even Distances for Grid Extension

	Diesel	Micro-hydro	Photovoltaics	Wind	Grid + extension
Baseline: total cost ($/kWh)[a]	$0.33/kWh	$0.14/kWh	$0.51/kWh	$0.31/kWh	$0.07/kWh + $O.032/kWh-km
Break-even distance (kilometers)					
Variable: grid extension					
Baseline: $ 4,500/km	8.1 km	2.1 km	13.9 km	7.5 km	NA
$ 7,000/km	5.2	1.3	8.9	4.8	
$ 9,000/km	4.0	1.0	6.9	3.8	
$10,000/km	3.6	0.9	6.3	3.4	
$13,000/km	2.8	0.7	4.8	2.6	
Variable: discount rate					
3 percent	10.4	1.8	10.8	6,6	NA
Baseline: 7 percent	8.1	2.1	13.9	7.5	
10 percent	6.8	2.2	15.7	8.0	
15 percent	5.3	2.4	17.8	8.6	

NA = not available or not applicable.

[a]Baseline values for remote generation technologies are listed in table B-2; baseline parameters for on-grid generation are$1500/kW capacity, 30 year lifetime, 7 percent discount rate, $0.01/kWh for O&M, $0.02/kWh for fuel (fuel priced at $2.00 per million Btu and a heat rate of 10,000 Btu/kWh), and an actual capacity factor of 60 percent in operations, with power routed to the site at the same rate as generated by the remote technologies; baseline values for grid extension were $4500/km—coresponding to a single-wire earth return (a very low cost system), a lifetime of 20 years, a discount rate of 7 percent, and an annual O&M cost of 3 percent of the initial capital cost.

SOURCE: Office of Technology Assessment, 1992.

systems, and to discount rates in the case of photovoltaic, wind, and hydro systems (see table B-3).

Actual costs may vary considerably from the parameters chosen in tables B-2 and B-3. Other factors are also important in choosing a system for remote generation. Many regions will not have access to good micro-hydro or wind resources. Diesel systems require timely delivery of fuel, spare parts, and competent maintenance for reliable operation; in many areas these factors are not available. Finally, photovoltaic systems, though expensive, may have substantial advantages over diesel systems by not using fuel, having few or no moving parts, and requiring little maintenance.

These systems can also be compared to the cost of extending the electric power grid and providing on-grid generation capacity. There are two components of cost that must then be considered: the cost of conventional on-grid generation as detailed in table B-1, and the cost of the grid extension itself.

As detailed in Chapter 6, the cost of grid extension ranges from $4,600 to nearly $13,000 per kilometer for single phase systems, depending on the terrain, the precise type of system, and a host of other factors. O&M costs range from 2 to 4 percent of the capital cost.

By equating the cost per kWh of the remote generation to the cost of the grid technology plus grid extension, an approximate "break-even" distance can be calculated. For distances less than the break-even distance, it will then be lower cost to extend the grid; for distances greater than the break-even distance, it will be lower cost to install a remote generation technology. Note, however, that there are many caveats to this highly simplified analysis. The capacity of grid extension may be much greater than that assumed here for the remote generation technologies, or may be upgraded more easily. On the other hand, remote generation technologies may be more reliable than extending the grid with lines easily downed during storms. A much more detailed analysis is required for actual implementation of a real system.[1]

Results of such a calculation are shown in table B-4. As seen there, the most sensitive factor is the cost of the grid extension itself. Breakeven distances are not particularly sensitive to the discount rate as both grid extension and remote generation require large upfront capital investments.

1 For a slightly more detailed analysis, see Chandra Shekhar Sinha and Tara Chandra Kandpal, "Decentralized v Grid Electricity for Rural India,' *Energy Policy* June 1991, pp. 441448.

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