Distributed Generation Renewable Energy
Estimate of Costs and Useful Life

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Overview

Estimates of total installed costs and operation and maintenance costs are for distributed generation (DG) scale systems appropriate for federal buildings and campuses. Technologies considered are technically proven and commercially available. Technologies included are wind energy, solar photovoltaic (PV) systems, biomass heat, biomass combined heat and power (CHP), solar water heating (SWH), and solar ventilation preheat (SVP), also known as transpired solar collectors. Values provided are not to be interpreted as statistically significant. They are meant only to provide rule-of-thumb guidance, accurate enough for a first pass screen of economic viability.

Table 1 - Costs for Electricity Producing Technologies

	Mean installed cost ($/kW)	**Installed cost range (+/- $/kW)**	**Fixed O&M ($/kW-yr)**	**Fixed O&M (+/- $/kW-yr)**	**Variable O&M ($/kWh)**	**Variable O&M (+/- $/kWh)**	**Annual degrad-ation rate (%/yr)**
PV	$6200	$1200	$21	$6			0.5 to .8 %
Wind 1 to 19 kW	$7500	$2300			$0.02	$0.01	
Wind 20 to 100 kW	$5200	$1800	$50	$20			
Wind 100 to 1000 kW	$2500	$1000	$50	$20			
Biomass Combustion Combined Heat and Power*	$5500	$2000			$0.09	$0.05	

*Unit cost is per unit kilowatt is of the electrical generator, not the boiler heat capacity

Table 2 - Costs for Solar Water Heat (SWH) and Solar Vent Preheat (SVP)

	Mean installed cost ($\$/\text{ft}^2$)	**Installed cost range (+/- $\$/\text{ft}^2$)**	**O&M**
SWH, flat plate & evacuated tube	$150	$50	0.5 to 1.0 % initial installed cost
SWH, plastic collector	$55	$15	0.5 to 1.0 % initial installed cost
SVP	$30	$6	1 Watt/ft2 extra fan power

Table 3 - Costs for wood-fired heat system

	Installed cost ($/kW)	Installed cost range (+/- $/kW)	Fixed O&M ($/kW)	Fixed O&M (+/- $/kW)
Biomass wood heat	$1000	$500	$45	$25

General Discussion

Many often-cited cost studies and reports for renewable energy focus on systems deployed at utility scale. Both initial capital costs and operations and maintenance (O&M) costs can vary significantly with project size, more significantly with some technologies (e.g. wind) and less so with others (e.g. PV). In states and regions with strong financial incentives (e.g. PV in Colorado, New Jersey, and California) or particularly suited for a given technology (e.g. SWH in Florida), there are certainly cost differences that result due to local market maturity and competition. This study reports cost guidance at a national level; regional differences are captured in the ranges provided.

DG electrical generation scale was set somewhat arbitrarily at 10 MW and less for this study, a fairly large upper limit that may be appropriate for large, multi-building sites like a military base or Federal laboratory.

In general, O&M costs are more difficult to find than project total installed costs.

Cost and useful life information was gathered from the following reference types.

1. Published document
2. Actual project information – publically available in an on-line case study, public presentation, database, or article
3. Actual project information – internal, not publically available
4. Discussion with or quote from vendor
5. Informed opinion or experience of NREL expert Screening or assessment report by NREL expert that relies on some or all of the above reference types

Photovolatics (PV)

PV was the easiest technology to characterize in terms of costs because it is a widely deployed technology. Among the references listed in the bibliography, two are DOE Energy Information Agency publications that characterize costs for utility scale central plant technologies: *Assumptions to the Annual Energy Outlook* and *Updated Capital Cost Estimates for Electricity Generating Plants*. Although they are not DG, they are cited here since they include cost estimates for systems less than 10 MW in size.

Wind

There is significant cost spread and a steep unit cost curve ($/kW) versus size for smaller machines. For this reason, wind turbine costs are broken down by ranges of total project size. References show a wide range of O&M costs for wind systems, and O&M costs do not necessarily decrease with increased installed project size at the DG scale. Older installations tend to have higher costs. The expectation is that newer machines are better designed and therefore will have lower O&M costs than machines deployed 10 years ago. Total installed costs for wind turbines are readily available but more challenging for smaller systems. O&M cost for wind systems < 20 kW comes from an in-house expert's rule-of-thumb.

Biomass

The most technically mature and widely deployed biomass systems are direct combustion units that use woody biomass as their fuel. A wood-fired boiler can generate hot water or steam. Water and steam can be used in heat only applications or steam can be used to turn a turbine generator for production of electrical power. When considering biomass renewable energy, it is important to identify a reliable fuel source and take a hard look at fuel costs over a number of years as part of an economic viability assessment. Non-fuel O&M costs can be significant, so any challenges in fuel supply will drive fuel costs upwards and quickly impact project viability.

Other feedstocks and plant technologies exist; however, they are not yet commercial, widely deployed, and/or economically viable at DG scale. Anaerobic digestion is a commercial technology used to create methane from wet feedstocks, including solids from wastewater treatment plants, however wastewater loads need to be on the order of 5 million gallons/day (or approximately the wastewater load of 50,000 people) to consider developing an economically viable digester and power plant (Ref: *Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities*; Eastern Research Group and Energy and Environmental Analysis, U.S. Environmental Protection Agency: Washington, DC, USA, 2007; pp. ii–10).

There are some commercially operating gasification and pyrolysis systems in Europe, but there is no significant capacity installed in the US to gather good rules-of-thumb on costs. A few domestic vendors are currently developing kilowatt-sized gasification systems to generate a renewable fuel (liquid or gas) from waste, wood, or other feedstocks. The resultant fuel could then be used in conventional engines, gas turbines, or fuel cells. Although these DG-sized systems show promise, they are still in the research and development phase with a few units deployed as test beds. No standardized costs are available.

Biomass Combined Heat and Power (CHP)

By review of the literature, the most common biomass generators at the DG scale make use of the power plant's waste heat to provide needed thermal energy, allowing projects to be economically viable. CHP is described in some of the references as a technically sound and economically competitive technology that has not yet experienced wide-scale deployment. In the US, most CHP systems are installed in large industrial facilities with both significant electrical and thermal loads. CHP is also often installed at facilities that have a significant waste stream (like a lumber or paper mill) that serves as a free fuel that would otherwise incur a disposal cost. Cost information for renewable wood-fired steam systems is reported here for system sizes between 100 kW and 10 MW.

Biomass Heat

Wood fired heat systems are technically mature and their costs are readily available.

Solar Water Heat (SWH)

Significant installed cost data on SWH systems were found in the references identified in the bibliography and NREL engineers also have access to a significant number of system costs. However, O&M costs are difficult to find. Two references (Bircher, Perlman) provided O&M estimates for residential sized systems only in $/system. O&M as a percent of initial cost was estimated from these reports (1% and 0.9%, respectively). For commercial systems, economy of scale is assumed to achieve a minimum O&M of 0.5% of capital cost. O&M for systems with plastic collectors is assumed to be the same.

Solar Ventilation Preheat (SVP)

SVP, also known as transpired solar collectors, seems to be the least deployed, or least published, technology of those included in this study. Actual project cost information is difficult to acquire. The values reported in the table include only three actual projects. The ranges are supported by discussions with a vendor. In general, systems installed in new construction would be at the lower end of the cost range, while retrofit systems that have significant integration costs (e.g. additional ductwork and fans) would price at the higher end of the range. Maintenance costs are assumed to be $0, however there is an operation cost of the additional fan power required to draw intake air through the collector. This is estimated to be 1 Watt/ft^2 of collector when the system is operational (collector is operated only when useful energy is available; collector is bypassed at all other times).

Table 4 - Bibliography of publically accessible references for System Costs

	Bibliography of publically available cost references	**Technologies***
1.	Barbose, G., N. Darghouth, et al. (2010). *Tracking the Sun III: Installed Cost of Photovoltaics in the U.S. from 1998-2009*, Lawrence Berkeley National Lab (LBNL).	PV
2.	Bergman, R. and T. Maker (2007). *Fuels for Schools: Case Study in Darby, Montana*.	bHeat
3.	Biocycle Magazine (2008). *Middlebury College Biomass Plant*. BioCycle Magazine. **49**.	bHeat
4.	Bircher, C., J. Curry, et al. (2003). *Utility Success Stories in Solar Water Heating*. ASES 2003 Annual Meeting.	SWH
5.	Bolinger, M., R. Wiser, et al. (2010). *Preliminary Evaluation of the Impact of the Section 1603 Treasury Grant Program on Renewable Energy Deployment in 2009*, LBNL.	wind, PV
6.	California Solar Initiative (CSI) (2011). CSI Solar Thermal Projects Data Review.	SWH
7.	CTA Architects and Engineers et al. (2007). *Exploring Wood Biomass Retrofit Opportunities in Michigan Boiler Operations*.	bHeat
8.	East Harbor Management Services (2005). *Availabilities and Costs of Renewable Sources of Energy for Generating Electricity and Heat: 2005 Edition* (New Zealand), Prepared for New Zealand Ministry of Economic Development.	SWH
9.	EIA (2010). *Assumptions to the Annual Energy Outlook 2010*.	PV
10.	EIA (2010). *Updated Capital Cost Estimates for Electricity Generation Plants*.	PV
11.	EPA (2007). *Biomass Combined Heat and Power Catalog of Technologies*.	bCHP
12.	FEMP (1999) *Showering with the Sun at Chickasaw National Recreation Area*.	SWH
13.	FEMP (2004) *Heating Water with Solar Energy Costs Less at the Phoenix Federal Correctional Institution*.	SWH
14.	FEMP, D. (1998). *Transpired Collectors (Solar Preheaters for Outdoor Ventilation Air)*. D. FEMP.	SVP
15.	GTM Research (2010). *U.S. Solar Energy Trade Assessment 2010: Trade Flows and Domestic Content for Solar Energy-Related Goods and Services in the United States*, Solar Energy Industries Association.	PV, SWH
16.	GTM Research (2010). *U.S. Solar Market Insight 2010 Year-in-Review*, Solar Energy Industries Association.	PV, SWH
17.	International Energy Agency (2008). *Deploying Renewables: Principles for Effective Policies*.	wind, PV
18.	International Energy Agency (2008). *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*.	bCHP
19.	Intron Inc. (2009). *CCSE Solar Water Heating Pilot Program: Interim Evaluation Report*, California Center for Sustainable Energy.	SWH
20.	Kozubal, E., M. Deru, et al. (2008). *Evaluating the Performance and Economics of Transpired Solar Collectors for Commercial Applications*. Preprint. Golden, National Renewable Energy Laboratory (NREL).	SVP
21.	Manwell, J., J. McGowan, et al. (2009). Wind Energy Explained: Theory, Design, and Application, John Wiley & Sons.	wind
22.	OpenPV (2011). The Open PV Project database review.	PV
23.	Perlman, J. and A. McNamara (2008). *Solar Domestic Hot Water Technologies Assessment* (NYSERDA).	SWH
24.	Renewable Energy Policy Network for the 21st Century (REN21) (2010). *Renewables 2010 Global Status Report*.	wind, PV, bCHP
25.	SNL Financial (2011). SNL Financial Database Search of Woody Biomass CHP Systems < 11MW, SNL Financial.	bCHP
26.	University of Oregon Institute for Sustainable Environment (2008). *Wood Heat Solutions: A Community Guide to Biomass Thermal Projects*. University of Oregon.	bHeat
27.	Wiser, R. and M. Bolinger (2010). *Wind Technologies Market Report 2009*.	wind

*PV = photovoltaics, SWH = solar water heat, bCHP = biomass combined heat and power, bHeat = biomass heat, SVP = solar vent preheat

Useful life

Useful life was estimated by interviewing NREL experts familiar with the technologies and also by performing a literature search. Little information on actual lifetime studies was found. The bulk of the literature referenced included an assumed useful life for a given technology. These numbers have value since they provide conventional thinking of experts in each field, however it is important to understand that they do not include lifetime statistical data of actual projects. The bibliography table shows the reports and papers that were reviewed to establish the conventionally accepted lifetimes.

Table 5 - Useful Life

System Useful Life	**Years**
PV	25 to 40
Wind	20
Biomass combustion Combined Heat and Power	20 to 30
Biomass heat	20 to 30
SWH	10 to 25
SVP	30 to 40

Table 6 - Bibliography of publically accessible references for Useful Life

	Bibliography of publically available Useful Life references
1.	Agarwal, P. and L. Manuel, *Empirical wind turbine load distributions using field data.* Journal of Offshore Mechanics and Arctic Engineering, 2008. **130**(1).
2.	Agarwal, P. and L. Manuel, *The influence of the joint wind-wave environment on offshore wind turbine support structure loads.* Journal of Solar Energy Engineering, Transactions of the ASME, 2008. **130**(3): p. 0310101-03101011.
3.	Allen, S.R., et al., *Integrated appraisal of a Solar Hot Water system.* Energy, 2010. **35**(3): p. 1351-1362.
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5.	Ancona, D. and J. McVeigh, *Wind turbine—materials and manufacturing fact sheet*. 2001, Princeton Energy Resources International for the Office of Industrial Technologies. US Department of Energy.
6.	Asif, M., J. Currie, and T. Muneer, *Comparison of aluminium and stainless steel built-in-storage solar water heater.* Building Services Engineering Research and Technology, 2007. **28**(4): p. 337-346.
7.	Azzopardi, B. and J. Mutale, *Life cycle analysis for future photovoltaic systems using hybrid solar cells.* Renewable and Sustainable Energy Reviews, 2010. **14**: p. 1130-1134.
8.	Clyne, R., *Transpired Solar Collectors: Office of Power Technologies (OPT) Success Stories Series Fact Sheet.* 2000, National Renewable Energy Laboratory (NREL): Golden.
9.	Crawford, R.H., *Life cycle energy and greenhouse emissions analysis of wind turbines and the effect of size on energy yield.* Renewable and Sustainable Energy Reviews, 2009. **13**(9): p. 2653-2660.
10.	Crawford, R.H. and G.J. Treloar, *Net energy analysis of solar and conventional domestic hot water systems in Melbourne, Australia.* Solar Energy, 2004. **76**(1-3): p. 159-163.
11.	Czanderna, A.W., *Reliability and lifetime issues for new photovoltaic technologies*, in *Future Generation Photovoltaic Technologies: Proceedings of the First NREL Conference, 24-26 March 1997*. 1997. p. 55-69.
12.	Czanderna, A.W. and F.J. Pern, *Estimating service lifetimes of a polymer encapsulant for photovoltaic*

modules from accelerated testing, in *Conference Record of the Twenty Fifth IEEE Photovoltaic Specialists Conference, 13-17 May 1996*. 1996. p. 1219-1222.

13. Demtsu, S., S. Bansal, and D. Albin, *Intrinsic stability of thin-film CdS/CdTe modules*, in *35th IEEE Photovoltaic Specialists Conference, PVSC 2010, June 20, 2010 - June 25, 2010*. 2010: Honolulu, HI, United states. p. 1161-1165.
14. Dunlop, E.D., *Lifetime performance of crystalline silicon PV modules*, in *Proceedings of 3rd World Conference on Photovoltaic Energy Conversion, 12-16 May 2003*. 2003: Osaka, Japan. p. 2927-30 Vol.3.
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16. Enzenroth, R.A., et al., *Performance of in-line manufactured CdTe thin film photovoltaic devices.* Journal of Solar Energy Engineering, Transactions of the ASME, 2007. **129**(3): p. 327-330.
17. Florides, G.A., et al., *Modelling, simulation and warming impact assessment of a domestic-size absorption solar cooling system.* Applied Thermal Engineering, 2002. **22**(12): p. 1313-1325.
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19. Guinivan, D., *Life expectancy.* Engineering, 2008. **249**(10): p. 32-34.
20. Hammond, G.P., et al., *Integrated appraisal of a building integrated photovoltaic (BIPV) system*, in *1st International Conference on Sustainable Power Generation and Supply, SUPERGEN '09, April 6, 2009 - April 7, 2009*. 2009: Nanjing, China.
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37.	Otanicar, T.P. and J.S. Golden, *Comparative Environmental and Economic Analysis of Conventional and Nanofluid Solar Hot Water Technologies.* Environmental Science & Technology, 2009. **43**(15): p. 6082-6087.
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43.	Saranyasoontorn, K. and L. Manuel, *Design loads for wind turbines using the environmental contour method.* Journal of Solar Energy Engineering, Transactions of the ASME, 2006. **128**(4): p. 554-561.
44.	Schleisner, L., *Life cycle assessment of a wind farm and related externalities.* Renewable Energy, 2000. **20**(3): p. 279-288.
45.	Vazquez, M., et al., *III-V concentrator solar cell reliability prediction based on quantitative LED reliability data.* Progress in Photovoltaics: Research and Applications, 2007. **15**: p. 477-491.
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