Micropower Database: Methodology

Title	Micropower Methodology (Sep 2010).doc
URL	http://www.rmi.org/rmi/Library/2010-06_MicropowerDatabase
Date modified	3 Sep 2010
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This paper summarizes the methodology behind the data posted in Rocky Mountain Institute's database of global micropower, posted at http://www.rmi.org/rmi/Library/2010-06_MicropowerDatabase and maintained by RMI's technical staff. The purpose of the database is to present a clear, rigorous, and independent assessment of the global capacity and electrical output of micropower, showing its development over time and documenting all data and assumptions. With minor exceptions, this information is based on bottom-up, transaction-by-transaction equipment counts reported by the relevant suppliers and operators, cross-checked against assessments by reputable governmental and intergovernmental technical agencies.

Following *The Economist*'s convention, "micropower" is defined here as the electricity-producing portion of combined-heat-and-power (known in the U.S. as "cogeneration"), plus all renewable sources of electricity except big hydroelectric stations (which are conservatively defined as units larger than 10 MWe). The term "micropower" occasionally confuses novices, and we recognize that some cogeneration units and some aggregations of wind turbines, photovoltaics, etc. are relatively large (see below). "Micropower," however, is not confined to tiny units on your roof or in your backyard, but generically embraces many kinds of generators that are not large central thermal (or hydro) stations. Micropower's generating units are distinguished by having relatively short lead times and gaining their principal economies from production scale rather than from unit scale. Other terms such as "decentralized" or "distributed" generation are discussed on pp. 2–67 (especially around p. 43) of *Small Is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size* (RMI, 2002, www.smallisprofitable.org), an *Economist* book of the year that describes micropower's economics.

Electric capacity ratings, expressed in GW (10^9 watts) or MW (10^6 watts), are nameplate ratings for nominal output to the grid or local user, net of in-plant consumption, and are not derated for high condensing temperatures in summer.

All years are calendar years. Each year is assumed to have 8,766 hours, smoothing out the quadrennial effect of Leap Day. For all micropower technologies, we have accounted for rapid growth by calculating annual output in a way that doesn't assume all the capacity installed by year-end was installed and commissioned by the beginning of the same year. Assuming continuous exponential growth, we calculated that half of a given year's annual installations would be installed in the last 30.6% of the year:

$$\int_0^a e^x = \int_a^1 e^x$$

$$a = \ln(e/2) = 0.306$$

In practice, definitions of commercial operating date vary, and commissioning and power ascension are not instantaneous. To allow for these effects we have, as a conservatism, assumed that any micropower technology in its year of commissioning achieves only 1/4 of the capacity factor that it will achieve in the following year.

NUCLEAR

1. Annual Connections, Shutdowns, and Construction Starts: Most of the historical data came directly from the International Atomic Energy Agency report *Nuclear Power Reactors in the World (2009)*, available at http://www.iaea.org/programmes/a2/. This IAEA publication lists, by year, annual connections to the grid in MWe. It also details all the nuclear power reactors shut down and construction starts by country; with a little work one can sort these out by date. The 2009 *Nuclear Power Reactors in the World* includes data only through 2008. For 2009 data, we queried IAEA's dynamic *Power Reactor Information System* (PRIS) database on 26 May 2010. This seems safely after the 6 February deadline by which member States are to report the previous calendar year's final data to the IAEA; such reporting sometimes causes significant revisions to data that the IAEA has previously posted in anticipation.

We adopt the IAEA's convention of including in operating capacity units that are in long-term shutdown, so the Shut Downs column counts only units permanently removed from service, based (per IAEA convention) on their date of disconnection from the grid. Conversely, following the IAEA's reporting, we count new connections from their operator-reported date of first grid connection, even though this may precede normally defined commercial operation.

In similar fashion to the historical data calculations, we tallied expected connections and shutdowns to find an estimated value for new net capacity (MWe) for each year, and then added expected upratings (see below). Mycle Schneider and Julie Hazemann of Mycle Schneider Consulting, LLC kindly provided data on expected connections and shutdowns. Their data are based on the IAEA PRIS Database and other industry research. We have not included a forecast of construction starts because the available data seem too speculative to be meaningful.

2. Upratings: While upratings—increasing existing nuclear plants' rated output capacity through component retrofits or relaxed regulatory constraints—have become common in recent years because they require investments far lower than for new nuclear construction, there appear to be no published global data that aggregate expected nuclear upratings across countries to arrive at a projection of additional MW/y. The Nuclear Energy Institute does, however, post data on expected U.S. nuclear power uprates (http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/usnuclearexpectedpoweruprates/). To piece together a forecast for the rest of the world, we read the World Nuclear Association's Country Reports (http://www.world-nuclear.com/info/inf84.html) and included, with some uncertainty, the six national uprating plans that included firm dates and magnitudes, using our best judgment to translate date ranges into nominal dates. Some other countries may do upratings too, but their global effect is expected to be minor; the countries with old reactors potentially subject to uprating are seldom the countries with much new nuclear construction.

3. Electrical Output and Capacity Factor: While IAEA's *Nuclear Power Reactors in the World* contains good historical information on capacity net of upgrades, it is missing data on worldwide electrical output. The most complete data on nuclear electrical output were those collected by the U.S. Energy Information Administration, *International Energy Annual 2005* (Table 2.7). While the data extend all the way back to 1990, their most recent year is 2005. We combined IAEA capacity data (as explained above) with EIA output numbers to compute a capacity factor for 1990–2005. (IAEA does publish data similar to capacity factor, but uses slightly different definitions that could cause confusion. The differences are not important.)

For 2006–2009, output data were kindly provided by Jiri Mandula at IAEA, and we computed capacity factor based on these data and our installed capacity data.

For 2010–2015, we assume a continuous 0.80 capacity factor for our expected capacity levels and compute an expected annual output.

NON-BIOMASS COGENERATION, ALSO KNOWN AS NON-BIOMASS COMBINED-HEAT-AND-POWER (CHP)

1. Global Capacity: A recent report by the International Energy Agency, *Combined Heat and Power: Evaluating the Benefits of Greater Global Investment*, (http://www.localpower.org/documents/reporto_iea_chpwademodel.pdf), estimates the 2006 global level of CHP (regardless of its fuel) to be 300 GWe. Actually, the 2006 level may have been higher since the country-level data that this figure aggregates range from 2004 to 2006. Nonetheless, we use this 300-GWe figure as an "anchor" for global CHP capacity, then add and subtract real and expected annual installations to establish a 1999–2012 trend. There are indications that at least in the United States, official data on installed cogeneration capacity may be considerably understated: it was not included in official statistics until recently, so data-gathering techniques and reporting compliance are still maturing.

2. Annual Installations: From 2003 to 2005, the World Alliance for Decentralized Energy (WADE)—the umbrella global trade organization for distributed generation—published an *Annual Survey of Decentralized Energy* (www.localpower.org) presenting, among other things, an analysis of annual global CHP installations. Engine- and motor-based CHP data were extracted from the *Diesel Gas Turbine Worldwide (DGTW) Annual Power Generation Survey*, a supplier-industry compilation of reported equipment sales (http://www.dieselgasturbine.com/surveys.asp) Steam-based CHP data were based on interviews conducted by WADE with its trade-association, vendor, customer, and other partners throughout the world.

While WADE no longer published its survey after 2006, *DGTW* continues to publish its survey and to include more useful data each year. Employing WADE's methodology for extracting engine- and motor-based CHP, we returned to WADE's primary data source and created a trend for 2006–2009 based on the *DGTW* survey. This survey contains data on diesel, dual-fuel, and gas engine orders, and gas turbine power generator orders. For all years up to and including 2009, the survey gathered data on orders placed between June and May, e.g., June 2008 through May 2009. We assumed that orders during this period were installed over the course of the latter year.

For all years, DGTW displays data as shown below:

DIESEL, DUAL-FUEL & GAS ENGINE ORDERS, June 2008 – May 2009

Output Range (MW)	Units Ordered	Total Engine Output (MW)	Type of Generating Service			Fuel					Western Europe	Eastern Europe & Russia	Middle East	Far East	Southeast Asia/ Australia	Central Asia	North Africa	Central, W., E., & S. Africa	North America	Central America & Caribbean	South America
			Stand-by	Peak-ing	Contin-uous	Diesel Fuel	Heavy Fuel	Dual-Fuel	Liquid Biofuel	Nat. Gas											
0.50-1.0	17 155	13 013	8174	870	8111	16 429	3	1	0	722	2764	767	2717	1343	1109	2734	75	786	3447	343	1070
1.01-2.0	10 745	15 146	4540	789	5416	9776	27	0	0	942	2540	367	1130	1711	766	791	7	253	2625	152	403
2.01-3.5	2255	5429	1038	148	1069	1594	278	4	3	376	406	52	293	141	132	124	11	35	780	52	229
3.51-5.0	111	444	6	5	100	23	29	2	0	57	26	10	11	3	16	1	0	0	7	33	4
5.01-7.5	153	915	37	6	110	90	35	4	4	20	14	7	24	47	20	10	0	8	10	3	10
7.51-10	155	1342	49	24	82	4	95	0	2	54	5	0	30	4	10	2	0	11	9	0	84
10.01-15	31	359	0	1	30	1	28	2	0	0	2	0	7	0	2	0	0	4	0	2	14
15.01-20	82	1449	0	0	82	0	60	15	2	5	20	0	8	1	0	23	1	15	0	14	0
20.01-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30.01 & above	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	30 687	38 097	13 844	1843	15 000	27 917	555	28	11	2176	5777	1203	4220	3250	2055	3685	94	1112	6878	599	1814

Revised data November 2009

GAS TURBINE POWER GENERATION ORDERS, June 2008 – May 2009																			
Output Range (MW)	Units Ordered	Total Engine Output (MW)	Type of Generating Service			Fuel (Units)				Western Europe	Eastern Europe & Russia	Middle East	Far East	Southeast Asia/ Australia	Central Asia	North Africa	Central, W., E., & S. Africa	North America	Central America & Caribbean	South America
			Stand-by	Peak-ing	Contin-uous	Diesel Fuel	Heavy Fuel	Dual-Fuel	Nat. Gas											
1.00-2.0	112	154	94	0	18	46	49	10	7	1	8	6	95	2	0	0	0	0	0	0
2.01-3.5	56	144	48	0	8	19	24	6	7	2	0	5	47	0	0	1	0	1	0	0
3.51-5.0	61	272	20	0	41	7	13	6	35	6	1	2	23	4	3	0	0	21	0	1
5.01-7.5	54	314	0	0	54	0	0	19	35	5	10	11	10	6	3	0	3	6	0	0
7.51-10	29	219	0	0	29	0	0	10	19	1	8	4	2	6	0	0	0	6	0	2
10.01-15	49	642	1	0	48	2	0	17	30	2	13	8	6	5	2	1	2	10	0	0
15.01-20	8	133	0	0	8	0	0	5	3	1	7	0	0	0	0	0	0	0	0	0
20.01-30	29	761	0	5	24	6	0	0	23	0	5	8	0	5	0	3	0	3	0	5
30.01- 60	94	3880	0	44	50	2	0	33	59	16	9	18	4	7	1	4	5	26	0	4
60.01-120	109	9054	2	82	25	2	67	7	33	7	13	70	0	3	3	0	0	6	0	7
120.01-180	69	10207	0	35	34	2	7	13	47	1	15	27	1	1	10	2	2	10	0	0
180.01 & above	70	17405	0	14	56	2	6	21	41	9	9	17	7	5	2	3	8	10	0	0
Totals	**740**	**43 185**	**165**	**180**	**395**	**88**	**166**	**147**	**339**	**51**	**98**	**176**	**195**	**44**	**24**	**14**	**20**	**99**	**0**	**19**

These tables show the total capacity of all orders for a given output range, and within that output range, how many units were standby, peaking and continuous. Assuming a constant capacity across generating service types, we omit all standby and peaking capacity from our total CHP number as a major conservatism, since these capacities are large and most could be (and some have probably been) made dispatchable by grid operators. Following WADE's methodology, we include 100% of engines between 0.5 and 30 MW in our overall CHP number, and 60% of engines over 30 MW. For gas turbines, we include 100% of units between 1 and 30 MW, 75% of units between 30.01 and 60 MW, 10% of units between 60.01 and 120 MW, and 5% of units over 120 MW. This methodology ends up concluding that 12–21% of all engine and turbine orders are used in CHP applications.

For 2003–2005, WADE reduced the total level of CHP calculated by this methodology by 10% as an additional conservatism. We follow this approach for 2006–2009.

WADE's 2003–05 surveys showed steam-based CHP as an essentially constant 52.5% of the sum of engine- and motor-based CHP. This fraction reflects WADE's detailed knowledge of the market country-by-country, so we adopt it as authoritative. With no later data to rely on, we also assume that this fraction persisted during 2006–09 and used it also for forecasts to 2012.

With no CHP forecasts to rely on, we assumed a conservative level of engine- and motor-based CHP installation for 2010–2012 (16,700 MW), compared to 2009 (16,791 MW) and 2008 (17,464 MW) calculations. Including steam, we forecast approximately 25.5 GWe of CHP added annually between 2010 and 2012.

The *DGTW* data, and hence our CHP totals, gradually expand in types and sizes over the years, so year-on-year data are not strictly comparable. Specifically, WADE includes steam CHP installations only in China for 2003 and 2004, and only in China and India for 2005. Significant steam CHP, especially European backpressure turbines, probably remains missing from our database.

Starting in 2010, DGTW began reporting orders made within one calendar year, i.e., January-December 2009 as opposed June 2009–May 2010. Because OEMs provide DGTW with the level of orders placed within a 12-month window, there is no monthly data and we could neither standardize the reporting structure nor gain a sense of monthly variations in orders. Since we have been assuming that orders placed by mid-year result in operating generators by year-end, we now assume that all orders placed by end-of-year result in operating generators by midway through the following calendar year. DGTW's Chief Editor, Brent Haight, confirmed that this is a reasonable assumption. We further assume an even distribution of orders across months and forecast that orders placed during the first half or 2010 (and installed by end of 2010) will be equal to half of DGTW's January-December 2009 reported orders, essentially doubling half the 2009 orders and using the 2009 orders to forecast 2010 installations.

3. Biomass adjustments: Since a small percentage of decentralized cogeneration runs on biomass, and all biomass-fired generation is combined with waste-fired generation and listed separately under "Other Renewables," biomass-fired CHP must be subtracted from our CHP total to avoid double-counting. It was hard to establish a firm number for the percentage of biomass-fueled cogeneration. In 2006 personal communications, Michael Brown, director of WADE, estimated that the current biomass-fueled fraction of global generation is 3–5%, potentially rising to 6–8% by 2012. We therefore subtracted from the total decentralized cogeneration 4% of capacity in 2004, rising to 7% in 2012, to reach a reasonable estimate of non-biomass cogeneration.

4. Fuel mix: We could not find global data on CHP's mix of fuels, but most CHP is believed to be gas-fired. A good deal remains coal-fired in China and India (chiefly where gas is unavailable), and some in Germany, all aided by coal subsidies. EIA's partial cogeneration database in *Annual Energy Review 2008*, p. 233, reports preliminarily that in the United States in 2008, 17% of the fossil-fueled commercial and industrial power generation, most but not all of which was cogeneration, was fueled by coal (including culm and other coal wastes), 3% by oil (including waste oil), 73% by natural gas, and 8% by other gases such as blast-furnace gas and refinery offgas. Yet even fossil-fueled cogeneration saves fossil fuel (typically at least half) otherwise burned in the separate production of heat and power, because it displaces the separate fueled boiler(s) otherwise needed to produce the heat that CHP recovers. The resulting carbon saving is smaller than for the predominant gas-fired cogeneration, let alone renewables, but is still substantial, so even coal-fired cogeneration is a significant carbon-saver.

5. Capacity Factor 2000–2012: Having neither electrical output nor capacity factors from any traditional sources, we again turned to help of Michael Brown of WADE. He provided an estimated average capacity factor in terms of hours per year: "7000–7500, possibly more." Running 7,250 hours per year equates to a capacity factor of 82.8%, which we applied uniformly to all years under consideration. Fragmentary data from other sources suggest this may be conservative, but detailed field surveys appear not to have been conducted.

WIND

1. Annual Installations and Cumulative Capacity: Cumulative wind capacity for the period 1990–1995 is taken from the European Wind Energy Association's *Current Status of the Wind Industry (2005)* (http://www.ewea.org/documents/factsheet_industry2.pdf). Cumulative wind capacity for 1996–2008, and a forecast through 2013, are taken from Global Wind Energy Council (GWEC) *Global Wind 2009 Report* (http://www.gwec.net/index.php?id=8), except for 2009 where the value comes from BP's *Statistical Review of World Energy (2010)*. The figure for capacity additions for 1990 is taken from Worldwatch's 2003 *Vital Signs* (http://www.worldwatch.org/pubs/vs/2003/). As a first approximation, lacking reliable data on windpower retirements, we assume that any wind capacity removed from service is roughly offset by upratings from repowering old installations.

2. Capacity Factors 1990–2010: EWEA's *Wind Force 12* estimates the 2003 capacity factor to be 24%, rising to 28% by 2011. From 2004–2010 we interpolated capacity factors based on a linear trend, and extended this back to 1990. GWEC's *Wind Energy Outlook 2008* shows the global wind capacity factor reaching 30% by 2036. For 2013 we interpolated one year of a linear trend from 2012 through

2036.

PHOTOVOLTAICS

1. Annual Installations: For 1990–2003 we used data in Worldwatch's 2005 *Vital Signs* (http://www.worldwatch.org/pubs/vs/2005/). For 2004-2005 we used data from the European Photovoltaic Industry Association's (EPIA) *Photovoltaic Barometer* (http://www.epia.org/03DataFigures/barometer/Barometer_2005_PV_EN.pdf). Production for 2006 comes from Solarbuzz (http://www.solarbuzz.com/FastFactsIndustry.htm).

Production doesn't equal the number of installations because of marketing, delivery, and installation lags and expanding production. For years where installation numbers were not available (1990–2003), we assumed that all panels produced are installed by the end of the *next* calendar year. To find the percentage of PV panels which are produced and installed in the same year, we used Solarbuzz's 2005 Marketbuzz (http://www.solarbuzz.com/Marketbuzz2005-intro.htm) for the 2004 installation data and solved the following equation: $761 * (1–X) + (1194 * X) = 927$. This approximates the percentage of panels that are installed in the same year they are produced. Using this percentage and the aforementioned assumption, we found an estimate for installations for each year (1990–2003). For 2004–2009 installations, we used real installation data from Solarbuzz (see database tab *PV Source Data 2009* for multiple links).

2. Cumulative Installed Capacity 1990–2006: We first found the 1989 cumulative PV production by subtracting the 1990 production from the 1990 cumulative total. Using the assumption that all PV panels produced in 1989 or before were installed by the end of 1990, we then added the annual installations in following years. We assumed the generally accepted 25-year lifespan of the modules (some modern modules now come with a 25-year *warranty*). Therefore, in 1996 we start retiring the first PV modules, which were made in 1971.

3. Annual Installations 2010–2015: Two annual growth rates contained in the European Photovoltaic Industry Association's *Global Market Outlook (2009)* (http://www.epia.org/index.php?id=18) are included. The more conservative scenario portrays 17% annual growth while the more aggressive scenario portrays 32% annual growth. We combined the conservative growth rate with a "conservative" 2010 installation forecast provided by Gartner Research (http://www.pv-tech.org/news/_a/gartner_concerned_about_conflicting_views_of_solar_module_supply_situation/)and the aggressive growth rate with an "aggressive" 2010 installation forecast provided by IMS Research (http://www.pv-tech.org/news/_a/despite_inverter_shortages_ims_research_raises_2010_solar_market_to_14.6gw/) to create conservative and aggressive 2010-2015 trends. We then averaged the resulting levels of installations and output to arrive at an "average" growth scenario that we used for all forecasts.

4. Capacity Factor 1990–2010: The IEA's *World Energy Outlook (2005)* (http://www.iea.org/textbase/npsum/weo2005sum.pdf) contains predictions of PV capacity and output for 2010. From these were able to calculate IEA's implicit PV capacity factor of 0.17. We assume 0.17 was IEA's observed capacity factor in 2004 when the *World Energy Outlook (2005)* was written, and we use it for 1990–2004. EIA's *International Energy Outlook (2009)* (http://www.iea.org/weo/2009.asp) assumes a 0.21 capacity factor for 2012. We assume the EIA observed 0.21 in 2008 when *International Energy Outlook (2009)* was written and drew a linear trend from 2004 to 2008. Professor Mark Jacobson

of Stanford confirmed to us that this is a reasonable assumption. He uses the same 0.21 capacity factor in his paper *Evaluating the Feasibility of Meeting all Global Energy Needs with Wind, Water and Solar Power (2010)* (http://www.stanford.edu/group/efmh/jacobson/PDF%20files/JDEnPolicy24Jan2010.pdf). We held capacity factor constant at 0.21 through 2015 to be conservative. This trend is reasonable for the U.S., where average insolation (averaged over all states of the Earth's rotation and orbit) is ~180 W/m^2. Given the rapid growth of PV capacity in low-latitude countries, and an average insolation of ~230 W/m^2 worldwide, this should be conservative as a global trend.

In the future, we hope to establish a more robust trend by determining average capacity factors for three types of PV installations (rooftop, utility scale, and utility scale with single-axis tracking panels), then modeling each type's relative share of total global capacity over time. We believe that 0.17 is reasonable for nontracking rooftop installations and 0.30 for utility-scale with one-axis tracking panels (currently the least-cost solution for large installations; the 0.30 is the U.S. average reported by SunPower's CTO Tom Dinwoodie in 2010 personal communications), with utility-scale without tracking panels (an increasing rarity) falling somewhere in between. We have not considered two-axis tracking panels because, although they yield an even higher capacity factor than single-axis tracking panels, they also currently yield higher cost per kWh.

SMALL HYDRO

1. Annual Installations 2000–2010: The European Small Hydro Association (ESHA) (http://www.esha.be/) cites a global installed capacity of 37 GWe in 2000, rising to 55 GWe by 2010. We drew a linear trend between 2000 and 2010, and continued it to 2012. As of 2010, REN21 (www.ren21.net) also defines small hydro as installations ≤10MW. Formerly this authoritative global expert group used a different convention (≤10MW throughout the world except China and India, where the upper bound is 50MW and 30MW respectively). Since we only seek to include hydro ≤10MW, we did not include REN21's data until 2009, but a few years ago we confirmed that when adjusted for the different upper size limits, their data are consistent with ours within a few percent. REN21's 2009 small hydro number (60 GW worldwide) is right in line with our trend, which shows 57.44 GW in 2008 and 62.875 GW in 2010.

2. Capacity Factor 2000–2010: According to ESHA's analysis, the 55 GWe of capacity in 2010 is expected to produce 220,700 GWh. This translates to a capacity factor of 45.8%, which is logically lower than large-scale hydro (large hydro operations are able to rely on their reservoir capacity to smooth power distribution through the season.) We assumed that this capacity factor is a good estimate for all years, smoothed over hydrological variations, as small hydro technology is reasonably mature. Since the equipment is very durable and many once-abandoned sites are being redeveloped, we assume that this trend and the upgrading of old equipment offsets any retirements. We think this assumption is probably conservative.

BIOMASS-FIRED GENERATORS

1. Annual Installations: Navigant Consulting (http://www.navigantconsulting.com, http://www.acore.org/pdfs/Frantzis.pdf) kindly provided data on the incremental capacity additions for 2000–2002. We used IEA's 2002 total global capacity from the *World Energy Outlook (2004)* as a reference value and worked backward and forward to find yearly total capacities. Our 2004–2006 and 2008-2009 capacities came from REN21's *Global Renewable Status Report*. We drew linear trends between 2002 and 2004, and between 2006 and 2008 to fill in missing data. We did not explicitly

account for retirements and renewals of equipment, simply assuming that the process's generally favorable economics will tend to keep old capacity running or renovated (though the global distribution of the plants is shifting; for example, ~3 GW (2005) of bagasse cogeneration is a key to the profitability of Brazil's major sugar-cane ethanol industry). Much biomass-fueled generation is in the forest-products industries such as pulp-and-paper and furniture-making; for example, EIA's *Annual Energy Review 2008* preliminarily reports that in 2008, U.S. industry (excluding the commercial sector) generated 27.9 TWh from wood and 0.7 TWh from "waste" (which after 2000 excludes non-biogenic wastes and tires), plus 548 and 16 trillion BTU of useful thermal energy, respectively. However, considerably more wood and waste was consumed by electricity-only (non-CHP) plants.

IEA provided two global scenarios: a reference scenario (where biomass electricity generation reaches 407 TWh in 2015) and an alternate policy scenario (where it reaches 511 TWh in 2015). We averaged these 2015 generation projections to arrive at a 459 TWh figure, then, based on linear growth and a 70% capacity factor, back-calculated annual installations for 2009–2015.

2. Capacity Factor: Both the 2002 and 2010 capacity factors were calculated from IEA's capacity and output for these years. As the capacity factors were identical at 70%, we adopted this value forall previous, intermediate, and future years.

GEOTHERMAL

1. Annual Installations: Based on global capacity data provided by the *International Geothermal Association* (http://www.iea-gia.org/documents/FridleifssonetalIPCCGeothermalpaper2008FinalRybach20May08_000.pdf) and a linear trend covering missing years (2001–2002), we calculated annual installations for 2000-2008 by simply subtracting each year's global capacity from the following year's. Navigant Consulting provided an annual installation number for 2000 and BP's *Statistical Review of World Energy (2010)* provides a 2009 total capacity number.

An EIA projection contained in the *International Energy Outlook (2009)* shows global geothermal electricity output rising to 75 TWh in 2010 and 93 TWh in 2015. We interpolated a linear trend from 2010 through 2015 (extrapolated to 2009) and based on our assumed capacity factors, calculated annual and cumulative global installations.

2. Capacity Factor: Both the 2002 and 2010 capacity factors were calculated from IEA's capacity and output for these years, 72% and 78% respectively. For intermediate years, we simply assumed a linear increase from 2002 to 2010. Capacity factors for 2000 and 2001, and from 2011 to 2015 were extrapolated using the same linear trend.

TOTAL WORLD ELECTRICAL OUTPUT

1. These data are taken from *BP's Statistical Review of World Energy 2010* "Electricity Generation" section. We use this series to calculate the share of total world electricity generation from micropower, nuclear, large hydroelectric, and non-cogenerating fossil fuel power plants.

LARGE HYDRO

1. We calculate large hydroelectric electricity generation by subtracting our small hydro generation levels from BP's total hydroelectric generation levels as reported in BP's Statistical Review of World

Energy (2010).