Near-Term Practical and Ultimate Technical Potential for Renewable Resources
DRAFT – 1/16/06 – DRAFT

INTRODUCTION AND PURPOSE

This table represents near-term and ultimate technical potential for renewable electricity and fuel resources – economic and market considerations are not taken into account. The representation for near term is given in percentage of electric generation in the United States in 2020 and is restricted by near-term challenges, such as infrastructure and reliability problems, electricity storage, and technological ability to use the resource. The ultimate technical potential is a compilation of estimates made by others of the total resource potential. While it assumes near-term challenges will be overcome, the ultimate potential does account for constraints on technologically insurmountable goals, such as generally accepted restrictions on offshore wind facility distance from shore (200 nautical miles), and on drilling capability for enhanced geothermal systems (10 km of depth). The resulting estimates are intended to offer rough estimates of the potential contributions from renewable resources, not economically or market=feasible projections.

This is a draft in progress and your constructive feedback, additional data, and/or suggestions for future work are welcome. Please direct comments to elizabeth_brown@nrel.gov in the National Renewable Energy Laboratory's (NREL) Energy Analysis Office (EAO). For more information on the EAO or NREL, visit http://www.nrel.gov/analysis

METHODOLOGY

Current Renewable Resource Use

Currently used renewable energy resources are drawn from a variety of sources. The current installed nameplate capacity total is a summation of verified, functioning, electric-generation facilities [Renewable Electric Plant Information System (REPIS) 2005]. Delivered electricity is based on 2004 electricity production [Energy Information Administration (EIA) 2005a]. For all the renewable electric technologies except biomass, primary energy required to produce electricity is calculated based on an average heat rate of 10,000 Btu/kWh for existing thermal power plants (EIA 2005b). For biomass, a measured heat rate for power plants, 9,000 btu/kwh, is used (EIA 2005b). For those renewable energy forms that also contribute to heat and fuels markets, total primary energy shown in the table is larger than the thermal energy required to produce only electricity (EIA 2005a).

Near-term Practical Potential

The amount of electricity potentially produced by renewables is shown as a percentage of the total projected U.S. generation in 2020: 5,085 billion kWh (EIA 2005b).

Biomass

Biomass is the only renewable energy form cited that can be used as either electricity or fuel. Because we cannot predict the distribution of biomass use between electricity and fuel, we make two estimates. The first assumes 100% of biomass is used for electricity, and the second assumes that 100% of biomass is used for fuel. The baseline amount of energy for these is the same, because it is limited by physical availability of biomass. Perlack (2005) estimates 1.3 billion dry tons of biomass is possible with the use of non-food cropland and forestland in the long term. To determine the near term potential the mid-range scenarios from Perlack (2005) to identify a near term range of 593 million to 968 million dry tons. The biomass-to-energy conversion used is an average of energy from biomass types of just more than 13 million btus per ton (NREL 2005c). This range yielded a potential of between 8 and 13 quads of energy in the near term. To estimate the amount of electricity that can be generated from the range, we assume a power plant heat rate of 9,000 Btu/kWh (EIA 2005b). The result is 17-28% of total U.S. electric generation. Biomass as a fuel potential is expressed as a percentage of projected 2020 petroleum demand: 26 million barrels per day (EIA 2005b). Using 8-13 quads of available biomass energy, and a 49% fuel plant conversion efficiency, biomass could contribute 9-14% of the national petroleum demand in 2020.

Geothermal
Because of technology limitations, only hydrothermal energy is considered in the short term. In 1979, the United States Geological Survey (USGS) estimated that there were about 22 GW of discovered hydrothermal resources (USGS 1979). While this estimate is dated, there has been no authoritative study of the potential since that time. Using a 95% capacity factor (NREL 2005c), 22 GWs represents 2 quads of energy (or 4% of U.S. electric generation) in 2020.

Hydroelectric
Full hydroelectric potential is 140 GW (Hall et al 2003), which would provide 9.4% of electric generation in 2020, assuming today's national average capacity factor of 0.39 (NREL 2005c). Assuming a 10,000 Btu/kWh power plant heat rate conversion, this is equal to about 5.0 quads of primary energy.

Ocean
In the short term, the full potential of mechanical (wave, tidal, and current) electrical generation is assumed. This resource is estimated to have a full potential of 30 GW installed nameplate capacity. Assuming constant power and a power plant conversion heat rate of 10,000 Btu/kWh, this translates to 2.3 quads of primary energy (or 4.5% of the electric generation) projected for 2020.

Solar
For the near-term technical photovoltaic potential, it is assumed that there will be no storage for solar energy, and no PV generation will be wasted. This implies that none of the nighttime loads can be met by solar, and much of the load at dawn and dusk cannot be met (if PV capacity were sufficient to meet such loads, PV output at midday would exceed loads, wasting energy). These assumptions severely limit the impact of PV on the electric system. The PV impact would be even more limited if one also took into account the many conventional fossil and nuclear plants that must run all the time. In this case, the PV capacity would have to be even smaller to keep from wasting PV generation.

The near-term potential for concentrated solar power is assumed to be the minimum of the projected in-state electrical load and the actual CSP resource in that state. In all cases, the projected state electrical load is the minimum. Therefore, the near-term CSP potential is the electric load of the state in which the CSP resource resides. In 2020, the projected load for states with CSP potential is expected to be 12% of the total U.S. generation, creating an upper bound for CSP electrical generation. Assuming a 10,000 Btu/kWh heat rate for power plants, the estimated primary energy to create this electricity is 6 quads/year.

Wind
The short-term wind potential is limited by grid reliability/stability concerns to be 20% of total generation [based on Wan and Parsons (1993) estimate of between 4% and 50%]. Assuming a power plant heat rate of 10,000 Btu/kWh, the primary energy equivalent is 10 quads.

Ultimate Technical Potential
Ultimate potential differs from the short-term potential by a set of general assumptions for each resource type and one more general assumption. The general assumption is that the electricity grid can adjust to the diverse electricity fed into it by adding storage, transmission, ancillary services, etc. Moreover, the ultimate assumptions do not limit the amount of renewable electricity as a function of total projected electricity demand. As with the short-term assumptions, economic and market constraints are not accounted for in this long-term technical potential.

Biomass

Biomass is the only renewable energy form cited that can be used as either electricity or fuel. Because we cannot predict the distribution of biomass use between electricity and fuel, we make no assumption regarding the differences between the use of biomass for electricity and biomass for fuel. The baseline amount of energy for these is the same, because it is limited by physical availability of biomass. Perlack (2005) estimates 1.3 billion dry tons of biomass is possible with the use of non-food cropland and forestland. The biomass-to-energy conversion used is an average of energy from biomass types of just more than 13 million btus per ton (NREL 2005c). The total energy potential for biomass is 17 quads. To estimate the amount of electricity that can be generated from 17 quads, we assume a power plant heat rate of 9,000 Btu/kWh.

Geothermal

The hydrothermal estimate includes approximately 72-127 GW of as yet-undiscovered resource (USGS 1979). The enhanced geothermal systems estimate is based on an estimate of 42 TW, which includes the entire potential heat source (Tester 1994).

Hydroelectric

The ultimate potential is assumed to be the same as the near-term potential.

Ocean

The ultimate potential estimate for ocean-based power expands the near-term potential to include power from ocean thermal energy of 0.11 TW (Sands 1980). The primary energy required for electricity generation, assuming a heat rate of 10,000 Btu/kWh, is 9 quads.

Solar

Unlike the near-term potential, the ultimate potentials for both PV and CSP are not assumed to be constrained by grid limitations, e.g. storage is assumed, transmission is assumed available, etc. For PV, the total resource potential (NREL 2003b) was restricted by excluding federal and sensitive lands, assuming only 30% of land area can be covered with PV, allowing only slopes that are less than 5 degrees, and requiring a minimum resource of 6 kwh/ m^2 /day. This results in an ultimate technical potential of about 219 TW or 4,200 quads/year for PV systems, assuming a 22% capacity factor.

The CSP resource is restricted to areas with resource potential – the southwestern United States. The potential reduces that amount of land that can be used for CSP by federal and sensitive lands, land with a slope greater than a 5% gradient, major urban areas and features, and parcels less than 5 km^2 in area. The remaining area determined the technical potential for CSP, assuming 50 MW/ km^2 (Price et al 2003).

Wind

The ultimate wind potential is not limited to 20% for intermittency and grid stability reasons, as battery storage is assumed. Instead, wind potential is limited by appropriate land selection (exclusions for federal land, etc.) and technical feasibility. For onshore wind potential, using estimated future capacity factors (NREL 2005b), and assuming complete use of Class 3 winds and better, the result is 324 quads of primary energy from wind. For offshore wind, Class 5 and better with a distance between 5 and 200 nautical miles (nm) were assumed. Between 5-20 nautical miles, only one-third of wind energy in Class 5 and better is captured, between 20 and 50 nautical miles, two-thirds; and between 50 and 200 nautical miles, the entirety. Assuming future capacity factors, the potential for offshore wind primary energy is found to be 272 quads.

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Energy Source		Current					Near-term Practical		Ultimate Technical Potential	
		Installed Electric Nameplate Capacity (TW)[a]	Delivered Electricity (2004)[b]		Primary Energy Required to Produce Delivered Electricity 2004 (Quads)	Primary Energy (Quads /yr)[c]	Percent U.S. Electricity Generation in 2020[d]	Primary Energy (Quads /yr)	Installed Electric Nameplate Capacity (TW)	Primary Energy (Quads /yr)
			TWh	Quads						
Biomass	Electricity	0.01	12	0.04	0.12	2.85	17-28%	8-13[e]	N/A[f]	17[g]
	Fuel	--					9-14%[h]			
Geothermal	Hydrothermal	0.003	17	0.06	0.18	0.34	4%	2[i]	0.09[j]	8[k]
	EGS	--	--	--	--	--	N/E[l]	--	42[m]	3,679[n]
Hydroelectric		0.09	267	0.91	2.73	2.73	9.4%	5[o]	0.14[p]	5[q]
Ocean	Mechanical	0	00	0	0	0	5%	2[r]	0.03[s]	2[t]
	Thermal	0	0	0	0	0	N/E[u]		0.11[v]	9[w]
Solar	PV	0.00038[x]	0.51	0.0017	0.005	0.063	10-25%	5-13[y]	219[z]	4,213[aa]
	CSP	0.000354[bb]	0.47	0.0016	0.005		12%	6[cc]	39[dd]	1,383[ee]
	Heat	--	--	--	--		--	--	--	--
Wind	Onshore	0.0073[ff]	14	0.05	0.143	0.143	20%	10[gg]	8[hh]	324[ii]
	Offshore	0.0				N/A			6[jj]	272[kk]
TOTAL		--	311	1	3	6	99–124%	47-55[ll]		8,529

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[a] REPIS 2005.
[b] EIA 2005a. For resources that have other uses than electricity, the primary energy will be larger than the previous column. For resources that are used only for electricity, the entire primary energy is represented in primary power required for electricity production.
[c] EIA 2005a. For resources that have other uses than electricity, the primary energy will be larger than the previous column. For resources that are used only for electricity, the entire primary energy is represented in primary power required for electricity production.
[d] Total U.S. electricity generation in 2020 (EIA 2005a)
[e] Low bound represents mid-yield crop scenario and current forest product yield of 593 million dry tons. High bound represents high yield scenario without land use changes and full forest land potential (968 million dry tons) from Perlack 2005.
[f] No value for biomass is listed, because no assumption is made regarding potential differences between biomass for electricity and biomass for fuel.
[g] 1.3 billion dry tons per/year (Perlack 2005)
[h] Percentage of total petroleum demand (EIA 2005a)
[i] 22 GW estimated discovered resource (USGS 1979)
[j] calculated from ultimate potential quads from (USGS 1979)
[k] Includes estimate of remaining undiscovered potential (USGS 1979)
[l] No estimate; EGS technology uncertain
[m] Tester et al 1994. Assumptions: 1. Resource potential for enhanced geothermal systems (EGS) 2. Assumes drillable depth to 10 km.
[n] Tester 1994
[o] Historical 39% capacity factor (EIA 2005a), 0.14 TW maximum potential (Hall 2003)
[p] Hall et al., 2003. Summation of current and potential capacity in undeveloped areas, dams without power, and dams with power.
[q] Historical 39% capacity factor (EIA 2005a), 0.14 TW maximum potential (Hall 2003)
[r] Wave flux data (Hagerman and Bedard 2005), 10% of U.S. coastline usable (Thresher 2005)
[s]Hagerman and Bedard 2005. Estimate includes actual measurement of wave energy per km of usable coastline. Includes 0.009 TW for tidal energy (Thresher 2005)
[t] Wave flux data (Hagerman and Bedard 2005), 10% of US coastline usable (Thresher 2005)
[u] No estimate; thermal technology uncertain
[v] Sands 1980
[w] Includes offshore potential (Sands 1980)

[x] Land and Water Fund of the Rockies 2005
[y] Assumes no storage and no surplus generation.
[z] NREL 2003. See accompanying documentation for details of areas eliminated from technical potential
[aa] 30% land coverage, 10% panel efficiency, 6 kwh/m^2/day minimum resource (NREL 2005a)
[bb] Morse 2004, Troughnet 2005
[cc] Assumes no out-of-state transmission
[dd] 1.) Includes the southwestern U.S. 2.) Assumes 50 MW/k m^2 (Price et al 2004). 3.) Estimate includes areas with a minimum of 6 kWh/m^2/day annual direct normal solar resource. See accompanying documentation for details of areas eliminated from technical potential.
[ee] 50 MW/k m^2 (Price 2003)
[ff] End-of-year 2004 installed capacity. Direct calculations to electricity would be overestimates because not all capacity was online for the entire year. To avoid this, the electricity numbers are calculated from the EIA 2005 reported primary energy use, assuming all wind used as electricity, and a capacity factor calculated from the installed capacity and generation in 2003.
[gg] Intermittency allows for only 20% generation (Wan and Parsons 1993)
[hh] 1.) Includes the 48 contiguous states. 2.) 5 MW/km^2 is the installed capacity assumption representing a turbine spacing of 10 rotor diameters apart in a row, rows spaced 10 rotor diameters apart. 3.) Estimate includes Class 3 through Class 7 wind (NREL 2005a,b, NREL 2003a). See accompanying documentation for details of areas eliminated from technical potential.
[ii] Class 3 wind and better
[jj] NREL 2005 Major Assumptions: 1.) Estimate includes contiguous United States but excludes the Gulf Coast and southeast coast through South Carolina, due to present data limitations (resource assessment activities are in progress). 2.) 5 MW/km^2 installed capacity (see 10) 3.) Reflects Class 5 or greater wind resource, between 5 and 200 nautical miles from shore. See accompanying documentation for details of areas eliminated from technical potential.
[kk] Class 5 wind and better from 5-200 nm offshore
[ll] Electricity only