The Status of Clean Energy in the United States

Tribal Energy Program Review
May 6, 2015

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Lazard’s Levelized Cost of Energy (LCOE) Estimates

Source: Lazard 2013
Lazard’s Capital Cost Estimates

Source: Lazard 2013
## EIA Estimates (2012 data)

### Dispatchable Technologies

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Capacity factor (%)</th>
<th>Levelized capital cost</th>
<th>Fixed O&amp;M (including fuel)</th>
<th>Variable O&amp;M</th>
<th>Transmission investment</th>
<th>Total system LCOE</th>
<th>Subsidy</th>
<th>Total LCOE including Subsidy</th>
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</thead>
<tbody>
<tr>
<td>Conventional Coal</td>
<td>85</td>
<td>60.0</td>
<td>4.2</td>
<td>30.3</td>
<td>1.2</td>
<td>95.6</td>
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<td>Integrated Coal-Gasification Combined Cycle (IGCC)</td>
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<td>31.7</td>
<td>1.2</td>
<td>115.9</td>
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<td>IGCC with CCS</td>
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<td>Natural Gas-fired</td>
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<td>Conventional Combined Cycle</td>
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<td>Advanced Combined Cycle</td>
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<td>1.2</td>
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<tr>
<td>Advanced CC with CCS</td>
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<td>4.2</td>
<td>55.6</td>
<td>1.2</td>
<td>91.3</td>
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<td>Conventional Combustion Turbine</td>
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<td>Geothermal</td>
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<td>Biomass</td>
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<td>47.4</td>
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<td>39.5</td>
<td>1.2</td>
<td>102.6</td>
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</table>

### Non-Dispatchable Technologies

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Capacity factor (%)</th>
<th>Levelized capital cost</th>
<th>Fixed O&amp;M (including fuel)</th>
<th>Variable O&amp;M</th>
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<th>Total system LCOE</th>
<th>Subsidy</th>
<th>Total LCOE including Subsidy</th>
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</thead>
<tbody>
<tr>
<td>Wind</td>
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<td>Wind-Offshore</td>
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<td>Solar PV(^2)</td>
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<td>4.1</td>
<td>130.0</td>
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<td>118.6</td>
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<td>Solar Thermal</td>
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<td>6.0</td>
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<td>Hydro(^3)</td>
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<td>6.4</td>
<td>2.0</td>
<td>84.5</td>
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</table>
Solar PV
Solar PV Installed Capacity and Weighted Average System Cost

Source: GTM/SEIA 2015
• U.S. Installed 6.2 GW of PV in 2014 (4.8 GW in ‘13)

• Cumulative PV 18.3 GW (20 GW including CSP)
Recent Legislative Action for Net-Metering / Rate Design Effecting PV

U.S. Generation Capacity Additions by Source

- U.S. has installed ~19 GW of new capacity per year in past decade
  - Natural gas and wind have been largest contributors but solar is becoming a significant portion of new generation
  - Would take 50-60 years to change entire U.S. fleet
- In 2014, solar was responsible for approximately 1/3 of all new generation capacity in the U.S.
  - Wind and solar combined for 55% of new generation

Note: PV converted to AC using .8333 derate factor.
Average capacity factors for the following projects by technology:

- Single Axis PV: 30%
- Fixed Tilt PV: 29%
- CSP Trough: 22%
- CSP Tower: 13% (Ivanpah)
- CSP Trough + Storage: 28% (Solana)
- CPV: 24% (Alamosa)

PV systems in southwestern states have significantly higher capacity factors:

- PV systems on East Coast: 21%; others 30%
Solar CSP
Technologies

Tower

Parabolic Trough
CSP Installations

Source: GTM/SEIA 2015
Wind
United States - Annual Average Wind Speed at 80 m

Wind Market Update

- 5.1GW of annual installations in 2014
- 65.9 GW of cumulative installations at beginning of 2015

<table>
<thead>
<tr>
<th>State</th>
<th>Capacity, MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas</td>
<td>1,122</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>648</td>
</tr>
<tr>
<td>Iowa</td>
<td>511</td>
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<tr>
<td>Washington</td>
<td>267</td>
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<tr>
<td>Colorado</td>
<td>261</td>
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</tbody>
</table>
Best Uses for Technology (size, installed cost)

On-Site Power ($6-$12/W)
- Remote (<10 kW)
  - Water pumping, electrification
  - Water pump = 1 kW, House = 5 kW, Farm = 10 kW

Grid Connected ($3.50 -$7/W)
- Small (1 kW – 50 kW)
  - Residence, business, farm/ranch
- Mid-Size (100 kW – 1 megawatt [MW])
  - Facility, community, industrial
  - Convenience store = 50 kW, school = 250 kW

Energy for Sale ($2-$3.50/W)
- Utility (>1MW)
  - Wind farm
Biomass
Biomass Resources of the United States
Total Resources by County

This study estimates the biomass resources currently available in the United States by county. It includes the following feedstock categories: crop residues (5-year average: 2003-2007), forest and primary mill residues (2007), secondary mill and urban wood waste (2007), methane emissions from landfills (2006), domestic wastewater treatment (2007), and animal manure (2002). For more information on the data development, please refer to: http://www.nrel.gov/docs/fy10osti/38181.pdf. Although, the document contains the methodology for the development of an older assessment, the information is applicable to this assessment as well. The difference is only in the data's time period.
Bioenergy Pathways

**Thermal**
- **No Oxygen**
  - **Combustion**
    - Heat/power/CHP
    - Boiler, steam turbine
    - Co-fire with coal
  - **Gasification/Plasma**
    - Fuel Gases (producer gas) (CO + H2+CH4)
    - Burn gas for hot water/steam (commercial)
    - Use in IC engine, gas turbine or fuel cell for CHP (pre-commercial)
    - Catalytic conversion to alcohols, chemicals, synthetic diesel (development)
  - **Pyrolysis**
    - Char, gases, liquids (syn gas)
    - Torrefied wood for pellets, coal replacement
    - Pyrolysis oil for boilers and power (early commercial)
    - Specialty chemicals (commercial)
    - Further refining for transportation fuels (in development)

**Biochemical**
- **Pretreatment**
- **Digestion**
  - Ethanol
  - Biodiesel
  - CH4
  - CO2

**Partial Oxygen**
Biomass Costs - Electric

- Installed costs $1,900 - $5,500/kilowatt (kW)
- Larger systems (>5 megawatt [MW]) have better economics
- LCOE = $0.08 - $0.20/kilowatt-hour (kWh)
- A typical biopower scale for a tribal or community application would probably be about 10-MW, and cost ~$40 M
- LCOE could be $0.10 - 0.12/kWh
  - this strongly depends on feedstock cost
Biomass Costs - Thermal

• Heating plants: average $350,000 per MMBtu/hr (*), with smaller plants having a higher cost intensity than larger ones

• Operation and maintenance costs include:
  o Fuel
  o Labor (2-5 hours per week, including fuel ordering and a daily walk-through)
  o Repair and replacement of mechanical parts
  o Ash disposal

(*) MMBtu is one million British thermal units
Biomass Performance Characteristics

• Typical biomass boiler operating on fuel with a moisture content of 40% has a net efficiency of about 60-65%.

• Efficiency influenced by:
  o Moisture content of the biomass
  o Combustion air distribution and amounts (excess air)
  o Operating temperature and pressure
  o Flue gas (exhaust) temperature
Geothermal (non-electric)
Community Scale

Direct Use
Uses low-temperature resources:
- District Heating
- Process Heat
- Agriculture
- Aquaculture
Residential Geothermal Heat Pumps

- Highly efficient method of providing *heating and cooling*
- Work by using ground temperature as a renewable resource for pumping heat in winter and rejecting heat in summer
- Cost effective
- Economic and environmental benefits
Hot Water Facility-Scale Geothermal

• Can provide all or part of a facility’s hot water

• An auxiliary heat exchanger uses waste heat from the geothermal compressor (superheated gases) to heat water

• Uses excess heat that would otherwise be expelled to the loop
Cost of Geothermal

• **Residential (single family)**
  - New Construction $15,000 to $20,000 for heating and cooling
  - Remodel $15,000 to $30,000 for heating and cooling

• **Community**
  - 107,000 ft\(^2\) Middle School (600 students) GSHP built in 2011 $1.3 million
  - Community College: $860,000 GSHP
  - Geothermal Power Plant in Nevada: $4.4 million

• **Note that hybrid systems (coupled with a cooling tower or boiler) can make geothermal more cost effective**
Thank you!

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