Natural Gas Combined Cycle Combustion Turbine

Solar PV Utility-Scale

Reference Plants & Levelized Costs

Steven Simmons
Northwest Power and Conservation Council
May 28 2014
REFERENCE PLANTS
# CCCT Reference Plant 1

**Model & Technology**
Based on Siemens H-Class (SCC6 8000H – SGT6)

<table>
<thead>
<tr>
<th>Location</th>
<th>Baseload Capacity</th>
<th>Output &amp; Costs with Augmentation</th>
<th>Life Cycle Costs</th>
<th>Operation</th>
<th>Normalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boardman OR</td>
<td>392 MW</td>
<td>Capacity with 20MW Duct Firing Augmentation 412 MW</td>
<td>Economic Life 30 years</td>
<td>Ramp Rate 35 MW/min</td>
<td>Capacity Adjustments</td>
</tr>
<tr>
<td>Earliest In-Service 2014</td>
<td>Heat Rate 6,471 btu/kWh</td>
<td>Heat Rate with Duct Firing 6,531 btu/kWh</td>
<td>Fixed O&amp;M 15.37 $/kW/year</td>
<td>CO2 Emission Rate 792 lb/MWh</td>
<td>Heat Rate Adjustments</td>
</tr>
<tr>
<td>1x1</td>
<td>Capital Cost 425 $mm</td>
<td>Capital Cost with Duct Firing 433 $mm</td>
<td>Variable O&amp;M 3.27 $/MWh</td>
<td>Water Usage 2,629 gpm* (*for 2x1)</td>
<td>Capital Cost Adjustments</td>
</tr>
<tr>
<td>Cooling Wet</td>
<td>Capital Cost per kW 1,084 $/kW</td>
<td>Capital Cost with Duct Firing per MW 1,052 $/kW</td>
<td>Annual Life Cycle Degradation 0.39% Capacity 0.31% Heat Rate</td>
<td>Levelized Cost of Energy (2015) 56.88 $/MWh</td>
<td></td>
</tr>
</tbody>
</table>

Fuel
Natural Gas – GTN pipeline

Capital Costs are Overnight and all costs in 2012 dollars
# CCCT Reference Plant 2

**Model & Technology**
Based on Mitsubishi Heavy Industries J-Class (MPCP1 - M501J)

<table>
<thead>
<tr>
<th>Plant</th>
<th>Output &amp; Costs</th>
<th>Output &amp; Costs with Augmentation</th>
<th>Life Cycle Costs</th>
<th>Operation</th>
<th>Normalization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong>&lt;br&gt;Boardman&lt;br&gt;OR</td>
<td>Baseload Capacity&lt;br&gt;449 MW</td>
<td>Capacity with&lt;br&gt;20MW Duct Firing&lt;br&gt;Augmentation&lt;br&gt;469 MW</td>
<td>Economic Life&lt;br&gt;30 years</td>
<td>Ramp Rate&lt;br&gt;20 MW/min</td>
<td>Capacity Adjustments&lt;br&gt;• Elevation (-)&lt;br&gt;• Elec./Mech. Auxiliaries (-)&lt;br&gt;• Inlet &amp; Exhaust Losses (-)&lt;br&gt;• Duct Firing Aug (+)</td>
</tr>
<tr>
<td><strong>Earliest In-Service</strong>&lt;br&gt;2018</td>
<td>Heat Rate&lt;br&gt;6,408 btu/kWh</td>
<td>Heat Rate with Duct Firing&lt;br&gt;6,459 btu/kWh</td>
<td>Fixed O&amp;M&lt;br&gt;15.37 $/kW/year</td>
<td>CO2 Emission Rate&lt;br&gt;784 lb/MWh</td>
<td>Heat Rate Adjustments&lt;br&gt;• Lower Heating to Higher Heating Value (+)&lt;br&gt;• Elec./Mech. Auxiliaries (-)&lt;br&gt;• Inlet &amp; Exhaust Losses (-)&lt;br&gt;• Duct Firing Aug (+)</td>
</tr>
<tr>
<td><strong>Configuration</strong>&lt;br&gt;1x1</td>
<td>Capital Cost&lt;br&gt;547 $mm</td>
<td>Capital Cost with Duct Firing&lt;br&gt;556 $mm</td>
<td>Variable O&amp;M&lt;br&gt;3.27 $/MWh</td>
<td>Water Usage&lt;br&gt;137.2 gpm*&lt;br&gt;(*for 2x1)</td>
<td>Capital Cost Adjustments&lt;br&gt;• Conversion to 2012 $ (-)&lt;br&gt;• Cost of Labor OR (+)&lt;br&gt;• Plant Accessories (+)&lt;br&gt;• Duct Firing (+)</td>
</tr>
<tr>
<td><strong>Cooling Dry</strong></td>
<td>Capital Cost per kW&lt;br&gt;1,217 $/kW</td>
<td>Capital Cost with Duct Firing per MW&lt;br&gt;1,186 $/kW</td>
<td>Annual Life Cycle Degradation&lt;br&gt;0.39 % Capacity&lt;br&gt;0.31 % Heat Rate</td>
<td>Levelized Cost of Energy (2018)&lt;br&gt;60.32 $/MWh</td>
<td></td>
</tr>
<tr>
<td><strong>Fuel Natural Gas – GTN pipeline</strong></td>
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</table>

Capital Costs are Overnight and all costs in 2012 dollars
Solar PV Update

Proposed Reference Utility Scale Solar PV Plant Update 05.26.14

5 MW ac using flat plate single crystalline modules mounted on single-axis trackers.

individual plants at scattered locations within the better solar resource areas

8.3 acres/MW solar pv (NREL) - so around 40 acres for a 5 MW plant
Solar PV Utility Scale
Capital Cost Estimates & Projections ($/kW ac - 2012 $)

<table>
<thead>
<tr>
<th>Year</th>
<th>Projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>3,107 $/kw ac</td>
</tr>
<tr>
<td>2015</td>
<td>2,654 $/kw ac</td>
</tr>
<tr>
<td>2020</td>
<td>2,098 $/kw ac</td>
</tr>
</tbody>
</table>

Proposed - Seventh Plan Reference
SEPA
LBNL
E3
EIA
NWPC Sixth Plan
Adelanto - 10 MW
Foothills I - 17 MW
Pine Tree - 8.5 MW
Modeled City of Palo Alto Project Low
Modeled City of Palo Alto Project High
LBNL Analyst Projection Low
LBNL Analyst Projection High
Bevans Point - 2 MW
Picture Rocks - 20 MW
SunShot Goal $1/W (dc)
Centinela - 170 MW
Recent Solar PV Power Purchase Agreements

1. Macho Springs Solar by First Solar
   - PPA with El Paso Electric at 57.80 $/MWh
   - Includes New Mexico Production Tax Credit (w/o is approximately 84.90 $/MWh)
   - Uses Thin Film technology

2. Recurrent Energy to build a 150MW solar pv plant in West Texas
   - PPA with Austin Energy for less than 50 $/MWh
   - 2016 operation date – would be largest solar pv plant in Texas
LEVELIZED COST OF ENERGY
Levelized Cost of Energy (LCOE) – a measure to compare costs of different generating technologies over plant life cycles - expressed in $/MWh (or $/kWh).

LCOE reflects the cost per unit of electricity for building, financing, operating, and maintaining a generating plant through the life cycle.

Important assumptions include:

- Capital costs
- Financing costs
- O&M costs
- Fuel costs
- Emission costs
- Utilization
Discussion

Important factors for Solar PV LCOE estimates
1. Capital Cost estimates – the primary cost component for solar projects
2. Financing assumptions – see #1
3. Capacity Factor – based on location, how much electricity can the plant produce?
4. We see some PPA costs lower than published LCOE – why?
   - CA sites on distressed farm land
   - financing options?
   - better locations (capacity factors)

Natural Gas Combined Cycle Combustion Turbine
1. Fuel costs are significant – 30 year foresight of natural gas prices suggests risk
2. Future emission cost?
Discussion

The Council financial model - Micro Fin – was used to calculate LCOE. The model generates annual costs for debt and equity service, taxes (income and property), expenses (O&M, fuel) based on the inputs, calculates NPV and produces a levelized cost for the cost components.

Model assumptions include:

<table>
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<th>Solar PV</th>
<th>Ntrl Gas CCCT</th>
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<td>IOU financed – 9.8% ROE, AT WACC 5.3%</td>
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</tr>
<tr>
<td>Capacity Factor 26.4% (Boise ID area location)</td>
<td>Capacity Factor 85%</td>
</tr>
<tr>
<td>Life cycle degradation</td>
<td>Life cycle degradation</td>
</tr>
<tr>
<td>Investment Tax Credit – 30% until 2017, then 10%</td>
<td>Currently no CO2 emission penalty</td>
</tr>
<tr>
<td>Transmission – point to point, BPA 2014 Trans. Rate Schedule</td>
<td>Transmission – point to point, BPA 2014 Trans. Rate Schedule</td>
</tr>
</tbody>
</table>
Discussion

Compared to recently released LCOE values from

- EIA Annual Energy Outlook 2014
- Black and Veatch Report for NREL (Cost & Performance Data for Power Generation Technologies)
Levelized Cost of Energy $/MWh
Solar PV Utility Scale

IOU financing
Capacity factor – Boise ID area

- Capital
- O&M
- Transm/Losses
- Black & Veatch LCOE
- EIA AEO2014
- Council w/Muni.Fin.
Levelized Cost of Energy $/MWh
Ntrl Gas Combined Cycle CT – Year 2020

- High Fuel
- Low Fuel

- Capital
- Fuel
- O&M
- Trans/Losses
- Council CCCT High Fuel
- Council CCCT Low Fuel
- EIA AEO2014
- Black & Veatch LCOE

No CO2 emission penalty attached
Levelized Cost of Energy $/MWh
Solar PV & Ntrl Gas CCCT – Year 2020

- Council Solar PV
- EIA AEO2014 Solar PV
- Council CCCT Adv 2
- EIA AEO2014 CCCT

- Capital Cost
- Fuel & Var O&M
- Fixed O&M
- Transmission

$/MWh 2012$