2015 Procurement Plan
Thermal Resource Specifications

Presentation to: NorthWestern Energy ETAC

June 4, 2015
What Has Changed Since 2013 Plan?

- Strong dollar handicaps GE gas turbine sales when compared to Siemens and Mitsubishi
- Western resource development moving from wind to solar
- Portland General Electric use of Wärtsilä 18V50SG reciprocating engines at Port Westward 2 for load/resource following
- Hydro may be able to provide some load/resource following capability currently performed by gas-fired units
What Hasn’t Changed Since 2013 Plan?

- World economic growth still slow
- Interest rates still low
- Thermal resource costs the same (or declining)
- Similar gas turbine product offerings – product development effort focused on higher capacity models (250 MW or more capacity)
Thermal Resource Basics

Three ways to spin a turbine in a thermal generation project:

- Compression of air and addition of energy to the air from fuel combustion – **Simple cycle combustion turbine (SCCT)**
- Creation of pressurized steam – either through direct heating of water by burning fuel, or use of waste heat created by combustion of fuel for other purposes – **Steam turbine**
- Sequential ignition of fuel that creates an explosion that drives a piston – **Reciprocating Engine**
Heat Rates

- The “heat rate” of a thermal resource is a measure of the amount of fuel required to produce a kWh of power.
- Turbine manufacturers often specify “lower heating value” (LHV) heat rates in product brochures.
- However, the higher heating value (HHV) heat rate for a thermal resource allows direct multiplication of the heat rate times the cost of gas (in $/MMBtu) to calculate a fuel cost expressed in $/MWH.
- The HHV heat rate of a gas turbine equals 1.108x the LHV heat rate.
Combined Cycle CT Basics

- CCCT utilizes two turbine generator sets, usually with separate shaft for each T-G:
  - Gas-turbine generator (GE Frame 7, MHI, or Siemens) – thermal energy from fuel combustion directly spins the turbine
  - Steam-turbine generator – uses heat energy from gas-turbine exhaust to create steam to spin a second turbine
- Add additional combustion capability after combustion turbine to increase steam-turbine output (duct-firing)
CCCT Duct-firing

- Standard GE Frame 7F CCCT GT-STG package allows for duct-firing – could be as much as 60 MW for a 1x1 CCCT configuration
- Duct-firing looks like a quick-start SCCT with 8400 Btu/kWh HR
- Duct-burner start and ramp to full output takes about 10 minutes due to need to have plant operator configure equipment
- On the ragged-edge of fast enough to use for spinning reserve.
How a Combined Cycle Plant works

Duct-burner

Electricity out

Air Intake

Gas Turbine

Combustion Chamber

Fuel

Heat Recovery Steam Generator

Exhaust Stack

Generator

Compressor

Steam Turbine

Condenser

Water

Steam

Warm Water

Cooling Water
CCCT Math

- Large gas turbines have a “heat rate” under 7000 Btu/kWh - describes the conversion of thermal energy into electrical energy.
- Natural gas generally priced in $/MMBtu
- Incremental cost of production = Heat Rate/1000 x (Gas Price + Variable Transportation) x (1+ End Use Gas Tax Rate) + Variable O&M
- Depending on location of unit, may need to factor incremental transmission and losses into the calculation
CCCT Incremental Cost Example

Heat Rate = 6600 Btu/kWh
Gas Price = $3/MMBtu
Variable Gas Transportation = $.10/MMBtu
Variable O&M = $2.5/MWH
Incremental Cost = (6600 Btu/kwh) /1000 x
($3/MMBtu +$.10/MMBtu) + $2.5/MWH = $23.0/MWH

Note: No end-use gas tax in Montana
But CCCT Dispatch Decisions Rarely Straight-forward

- NW CCCT fleet usually sets daily market-clearing price – wind and hydro push CCCTs in/out of the money
- CCCTs often economic HLH but uneconomic LLH - $5.0/MWH in-the-money HLH, -1.0/MWH LLH on 1/14/15
- Start-up requires multi-hour ramp-up/ramp-down – quick start package can shorten the ramp-up
- Maintenance contracts charge for starts after some maximum (around 50/yr) - $3000-$5000/start
- Best CCCT heat rate at full load
  - Heat rate increases 1% for every 5% of output reduction between 80% and 100% of rated capacity
  - Heat rate increases 2.7% for every 5% of output reduction thereafter to maximum turn-down of 50%
Pipeline Capacity Requirements

- Firm gas pipeline transportation reserved on a “Maximum Daily Delivery Quantity” (MDDQ) basis
- Transportation reservation charge calculated based on MDDQ multiplied by rate and number of days in billing period – effectively a demand charge
- Also pay monthly fixed charge and variable charge for pipeline incremental costs
- May pay 2-4 separate sets of pipeline charges between source of natural gas and delivery point (e.g. AECO-TransCanada-NWE)
Types of Open Cycle Gas Turbines

- Frame SCCTs - Primarily capacity (large/fast w/controls)
  - GE 7EA, GE 7F, Siemens 501G, etc.
  - 85-350 MW
  - Heat Rate = 9400-11,400 Btu/kWh – rarely dispatch (under 2% of hours)

- Reciprocating Engines - Primarily flexibility (small/fast)
  - 9-20 MW
  - Wärtsilä, Caterpillar (Basin Creek)
  - Heat Rate = 8300-9000 Btu/kWh – higher variable O&M affects dispatch

- Aero derivative SCCTs - Capacity and flexibility (fast)
  - GE LM6000, GE LMS100, P&W FT-8 (DGGS)
  - 10-105 MW
  - Heat Rate = 8700-9500 Btu/kWh – infrequent dispatch (under 5% of hours)
Open Cycle Turbine Dispatch

- Purchase spot market natural gas
- Infrequent dispatch complicates gas pipeline and transmission strategy – Firm transport way too expensive, but interruptible may be interrupted or reduced over winter peak
  - Avista Rathdrum – California storage and exchange via GTN
  - Back-up fuel (DGGS)
- Smaller unit size and flat HR curve may make reciprocating engines a better operational fit for flexibility requirements than other SCCT technologies
- Infrequent CT dispatch increases start-up forced outage risk
## MDDQ by Unit

<table>
<thead>
<tr>
<th>Unit</th>
<th>Capacity (MW)</th>
<th>MDDQ (MMBtu/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE LMS100</td>
<td>93</td>
<td>19,833</td>
</tr>
<tr>
<td>GE 7EA</td>
<td>79</td>
<td>21,452</td>
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<tr>
<td>P&amp;W FT-8</td>
<td>53</td>
<td>13,356</td>
</tr>
<tr>
<td>GE 7F.05 CCCT</td>
<td>308</td>
<td>48,216</td>
</tr>
<tr>
<td>plus Duct Firing</td>
<td>40</td>
<td>8160</td>
</tr>
<tr>
<td>Wärtsilä 18V50SG</td>
<td>18</td>
<td>3669</td>
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</tbody>
</table>

At 65% 7F.05 CCCT capacity factor and 20% duct firing capacity factor, NorthWestern Energy’s Montana system gas load would increase by about 2/3.
Simple Cycle for Peaking

- LMS100 – Intercooled aero-derivative with lower heat rate
- Frame 7EA – relatively inexpensive capital cost, but higher heat rate
- Pratt & Whitney FT-8 – Heat rate between LMS100 and 7EA. Units at Dave Gates Generating Station

All units would operate infrequently – dispatch model results somewhat insensitive to unit chosen for simple cycle duty, since turbines provide little protection against high energy prices.
CCCT – Frame 7F.05

- Modeled the 7F.04 in the last Procurement Plan.
- 7F.05 gradually replacing the 7F.03 and 7F.04 in the GE product line-up
- Larger than predecessor gas turbines with a lower heat rate.
- 307 MW maximum output @59°F at 3100’ – lose 20 MW of capacity for a 5100’ site
- Includes 40 MW of duct-firing (for modeling purposes, no capital cost associated with duct-fired capacity)
- Run analysis assuming air-cooled capacity and heat rate – not much difference from water-cooled
Reciprocating Engine - Wärtsilä 18V50SG

• Largest engine available (18 MW)
• Little performance degradation at higher altitudes – only need to study 5000’ version
• Excellent heat rate (for open cycle) with flat load-heat rate curve, but higher variable O&M due to shorter maintenance intervals than for traditional gas turbines.
Resource Recommendation

CCCT – GE 7F.05
Simple Cycle – GE LMS100, GE 7EA, Pratt & Whitney FT-8
Reciprocating Engine - Wärtsilä 18V50SG
Note: The Northwest Power and Conservation Council plans to use the Wärtsilä 18V50SG as the representative peaking resource in the dispatch modeling for the Seventh Power Plan
## Dispatch Model Inputs

### Key Dispatch Model Inputs

<table>
<thead>
<tr>
<th>Gas Turbine</th>
<th>Capacity (MW)</th>
<th>Heat Rate (Btu/kWh)</th>
<th>Capital Cost ($/kW)</th>
<th>Variable O&amp;M ($/MWH)</th>
<th>Fixed O&amp;M ($/kW-yr)</th>
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<tbody>
<tr>
<td>GE LMS100 (3500’)</td>
<td>93.2</td>
<td>8867</td>
<td>1087</td>
<td>3.47</td>
<td>17.06</td>
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<td>GE LMS100 (5000’)</td>
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<td>1140</td>
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<td>P&amp;W FT-8 (3500’)</td>
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<td>917</td>
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<tr>
<td>P&amp;W FT-8 (5000’)</td>
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<td>962</td>
<td>4.83</td>
<td>6.35</td>
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<tr>
<td>GE 7EA (3500’) – 2 Units</td>
<td>158.4</td>
<td>11,286</td>
<td>897</td>
<td>3.20</td>
<td>11.73</td>
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<tr>
<td>GE 7EA (5000’) – 2 Units</td>
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<tr>
<td>Wärtsilä 18V50SG</td>
<td>18.4</td>
<td>8314</td>
<td>1380</td>
<td>6.00</td>
<td>10.50</td>
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Final Discussion