Reciprocating Engine or Combustion Turbine?

Coauthors: Kurt Koenig
Grant Ericson
AGENDA

► Installations
► Technology Overview
► Footprint
► Performance
► Power to Heat Ratio
► Thermal Load Following
► Fuel Flexibility
► Emissions & Permitting
► Vibrations & Acoustics
► Capital Costs
► O&M Costs
► Decision Matrix
► Case Study
TECHNOLOGY OVERVIEW

- Gas turbines (4-50+ MW)
- Reciprocating engines (2-18 MW)
CTG/REG INSTALLATION

- CTG installation more abundant
- Large REG installation popularity growing, still significant number of installations
- CHP market in US dominated by turbines

CTG/REG Purchases by Size (MW)
FOOTPRINT

- For smaller applications footprints are similar
- For larger applications, footprint of CTG smaller than REG

7.5MW Recip
7.5MW CTG

17MW Recip
15MW CTG

51MW Recip
50MW CTG
PERFORMANCE

Considering the previous REG/CTG comparisons:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Power Output (MW)</th>
<th>Heat Rate (BTU/kWh, LHV)</th>
<th>Exhaust Gas Flow (lb/hr)</th>
<th>Exhaust Gas Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 MW REG</td>
<td>7.5</td>
<td>7,400</td>
<td>94,000</td>
<td>734</td>
</tr>
<tr>
<td>7.5 MW CTG</td>
<td>7.5</td>
<td>10,100</td>
<td>214,000</td>
<td>960</td>
</tr>
<tr>
<td>17 MW REG</td>
<td>17</td>
<td>7,100</td>
<td>246,000</td>
<td>707</td>
</tr>
<tr>
<td>15 MW CTG</td>
<td>15</td>
<td>9,700</td>
<td>395,000</td>
<td>940</td>
</tr>
<tr>
<td>3 x 17 MW REG</td>
<td>51</td>
<td>7,100</td>
<td>737,000</td>
<td>707</td>
</tr>
<tr>
<td>50 MW CTG</td>
<td>50</td>
<td>7,100</td>
<td>1,100,000</td>
<td>890</td>
</tr>
</tbody>
</table>

*Heat rate of REGs generally much lower than CTG counterpart

*Thermal (exhaust) output of REGs generally much lower than CTG counterpart
PERFORMANCE

- Power to heat ratio
- Selecting the appropriate prime mover allows the best utilization of capital with the ability to base load the equipment.

<table>
<thead>
<tr>
<th>REG</th>
<th>MW</th>
<th>Total Heat MWt</th>
<th>Power / Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.0</td>
<td>3.8</td>
<td>1.041</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>4.2</td>
<td>1.071</td>
</tr>
<tr>
<td></td>
<td>5.4</td>
<td>3.7</td>
<td>1.456</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>5.8</td>
<td>1.123</td>
</tr>
<tr>
<td></td>
<td>7.4</td>
<td>4.9</td>
<td>1.523</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CTG</th>
<th>MW</th>
<th>Total Heat MWt</th>
<th>Power / Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.5</td>
<td>6.3</td>
<td>0.553</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>7.8</td>
<td>0.590</td>
</tr>
<tr>
<td></td>
<td>5.7</td>
<td>8.9</td>
<td>0.638</td>
</tr>
<tr>
<td></td>
<td>6.3</td>
<td>9.5</td>
<td>0.666</td>
</tr>
<tr>
<td></td>
<td>8.0</td>
<td>10.9</td>
<td>0.736</td>
</tr>
</tbody>
</table>
PERFORMANCE: THERMAL LOAD FOLLOWING

- Exhaust gas bypass damper:
- CTG: on/off, REG: modulating
PERFORMANCE: THERMAL LOAD
FOLLOWING CTG

Thermally limited: add steam drive chiller (or other steam sink)
Modulating exhaust gas bypass damper prevents shutdown due to lack of thermal load.
Generally, REG’s only operate on gaseous or liquid fuel; fuel type specifies machine type.

- Few units available to operate on gaseous and liquid fuel
- Propane operation requires 25%+ electrical derate

Generally, CTG’s capable of consuming wide variety of gaseous/liquid fuels

- Certain fuels may dictate higher emissions combustors

<table>
<thead>
<tr>
<th>Gaseous</th>
<th>Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>Light Fuel Oil</td>
</tr>
<tr>
<td>Propane</td>
<td>Heavy Fuel Oil</td>
</tr>
<tr>
<td>Syngas</td>
<td>Crude Oil</td>
</tr>
<tr>
<td>Landfill Gas</td>
<td>Fuel Water Emulsion</td>
</tr>
<tr>
<td>Process Off Gas</td>
<td>Liquid Biofuel</td>
</tr>
<tr>
<td>Digester Gas</td>
<td></td>
</tr>
</tbody>
</table>
EMISSIONS & PERMITTING

- Generally, CTGs offer lower emissions than REG counterparts
- SCR can reduce CO, \( \text{NO}_x \) by 80-90%

Peerless SCR
VIBRATIONAL & ACOUSTICAL

► CTG Vibration
  • Typically manageable
► Sound
  • Sound-attenuating enclosures
  • Intake air silencers
  • Exhaust gas silencers

► REG Vibration
  • Anti-vibration mounts
  • Isolating pads
► Sound
  • Smaller units enclosed
  • Intake air silencers
  • Exhaust gas silencers

Anti-vibration mount  IAC Exhaust Silencer  CTG Enclosure
CAPITAL COSTS

- Among smaller options (<5 MW), capital costs are similar between CTGs, REGs (no BOP considered).
- Among larger options, capital costs of CTGs are less.
O&M COSTS

- Variable O&M
  - Minor maintenance
  - Lube Oil Consumption (REGs)
  - SCR Reagent Consumption
  - Major Maintenance
- Fixed O&M
  - Plant Operations
O&M COSTS

O&M Cost Differences

- Variable O&M
  - Overhaul may fall under separate contract for REGs
  - Trained plant operators may perform minor REG maintenance
  - REG O&M costs vary largely between manufacturers

- Variable O&M costs:
  - REG $0.005/kWh-$0.010/kWh
  - CTG $0.007/kWh-$0.011/kWh
## DECISION MATRIX

<table>
<thead>
<tr>
<th>Points</th>
<th>Criteria</th>
<th>REG</th>
<th>CTG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight: [ 5 ] Range: 0-5</td>
<td>Q: What is the power to heat ratio? (kW * 3412) / (BTU/H). Score: Ratio of 1.0 to 1.5+, all points to REG. Ratio of &lt;0.55 to 0.74, all points to CTG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight: [ ] Range: 0-5</td>
<td>Q: What is the impact of space? Score: If greenfield site or size &lt; 20 MW REG &amp; CTG = 50% * Weight. If existing site, size &gt; 20 MW, tight plant arrangement REG = 25% * Weight, CTG = 75% * Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight: [ ] Range: 0-5</td>
<td>Q: What fuel diversity is required? Score: If gaseous and liquid fuel desired REG = 25% * Weight, CTG = 75% * Weight. Else REG &amp; CTG = 50% * Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight: [ ] Range: 0-5</td>
<td>Q: What startup time is required? Score: If less than five minutes all points to REG. Else REG &amp; CTG = 50% * Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight: [ ] Range: 0-5</td>
<td>Q: What level of emissions is desired? Score: If permitting process difficult and tight emission tolerances required CTG = 75% * Weight. Else REG &amp; CTG = 50% * Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight: [ ] Range: 0-5</td>
<td>What concern is plant vibration and acoustics? Score: If plant vibration and acoustics are major concerns CTG = 75% * Weight. Else REG &amp; CTG = 50% * Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
QUESTIONS

Kurt Koenig
Associate, Senior Project Manager
P 919-900-1864
E kkoenig@burnsmcd.com