Technologies for Next Generation Turbine Systems

Turbine Power Systems Conference and Condition Monitoring Workshop
February 25-27, 2002
Galveston, Texas

Alfonso (Al) Wei
Combined Cycle Performance
at
Simple Cycle Cost and Flexibility
Approach to “economically viable” NGT

High P.R. Simple Cycle
- 52 MW Industrial Trent
- Low 40’s % eff’y. Higher PR & temp to improve - risky technologies; very difficult fuel flexible DLE.

Parallel Shaft WIWR
- Wet Recuperated RB211 + 501-K Power Section
- Less development but compromised performance; complicated arrangement; increased unit cost.

ICR
- 25 MW WR-21
- Mid 40’s % eff’y. Only small additional improvements in efficiency possible.

Wet I.C. Wet Recuperated (WIWR)
- Modified Trent Engine
- Low 50’s % eff’y. Large development; high recuperator durability risk; difficult to control.

Super Steam Injection
- Modified Trent Engine
- Low 50’s % eff’y. Large but lower risk development (integration of known technologies); slight compromise in performance vs. WIWR.
R-R NGT Concept #1 - Wet Intercooled Wet Recuperated

Power: 50-80 MWe
Elect’l Efficiency: >50%
Turnkey Price: $400-450/kW
Emissions: <10 ppm NOx
<10 ppm CO
Start-up Time: <15 min
Water System: Closed loop
R-R NGT Concept #2 - Super Steam Injection

- **Power:** 50-80 MWe
- **Elect’l Efficiency:** >50%
- **Turnkey Price:** $400-450/kW
- **Emissions:** <10 ppm NOx
- **Start-up Time:** <15 min
- **Water System:** Closed loop

The diagram shows a modified R-R Trent Engine with an exhaust gas recovery system. The engine is connected to a water recovery unit and a water tank, indicating a closed-loop water system. The efficiency, power, and emissions are highlighted, making this concept attractive for energy production applications.
Similar Plant Layouts

1 Generator Skid
2 Gas Turbine Skid
3 GTG Auxiliary Module
4 Control Room
5 High Voltage Module
6 Utility Tie
7 Gas Compressor
8 Water Recovery Tank

9 Water Recovery Sys
10 Once Thru Steam Generator
11 Fin Fan Cooler
12 Demin water storage
13 Polishing Unit
14 Demin Unit
15 Make up water
# R-R’s NGT - Comparison to Current Products

<table>
<thead>
<tr>
<th></th>
<th>Simple Cycle</th>
<th>Wet Cycle</th>
<th>Combined Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power (MW)</strong></td>
<td>43.1</td>
<td>50-80</td>
<td>56.4</td>
</tr>
<tr>
<td><strong>Efficiency (%)</strong></td>
<td>41.4%</td>
<td>&gt;50%</td>
<td>52.5%</td>
</tr>
<tr>
<td><strong>Turbogenerator Price ($/kW)</strong></td>
<td>$366</td>
<td>$430</td>
<td>$400-450</td>
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<tr>
<td><strong>Turnkey Price ($/kW)</strong></td>
<td>~$560</td>
<td>~$480</td>
<td>~$400-450</td>
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<tr>
<td><strong>Flexibility</strong></td>
<td>High</td>
<td>High -</td>
<td>Med/Lo</td>
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</table>

Source: Gas Turbine World Handbook

**R-R’s NGT Solution:**
- ~25% improvement in efficiency of simple cycle machines
- ~30% improvement in capital cost ($/kW) of combined cycle plants
- Maintains operational flexibility of simple cycle machines
**R-R’s NGT Concept Meets The DOE Goals**

Determine the feasibility of developing flexible gas turbine systems with a greater than 30 MW power rating. Compared to 1999 state-of-the-art systems, the proposed systems shall include:

- 15% or higher improvement in net system efficiency;  
- improvement in turndown ratios;  
- 15% or higher reduction in COE;  
- improved service life;  
- reduction of emissions (carbon and NOx);  
- 15% or higher reduction in operations & maintenance costs;  
- 15% or higher reduction in and capital costs;  
- increased flexibility (min. 400 starts/year);  
- improvement in RAM; and  
- capability to use multiple fuels.

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<tr>
<th>R-R’s NGT</th>
<th>Achievable</th>
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<td>15% or higher improvement in net system efficiency</td>
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</table>
The Market Opportunity Appears to Exist

Source: Diesel & Gas Turbine Worldwide Annual Power Gen Survey
Customer Survey: R-R Solution Seems Appropriate

Distributed Generation Growth?

- Yes
- No

Future Mid-Merit Market?

- Agree
- Disagree
- Don’t Know

Peaking Market Growth?

- Continued Growth - Rate
- Continued Growth - Reduced Rate
- No Growth
- Don’t Know

Market Perceived for R-R’s NGT?

- Yes
- No

70-80 MW Size?

- Satisfactory
- Too Large
- Too small

How Fast Should Start Time Be?

- <10 Min
- 10-15 min
- 15-20 min
- 20-30 min
- >30 min
R-R’s NGT - Economic Benefits to Operators

**COE Comparison - Mid-Merit Operation**  
NGT vs. Simple Cycle Machines

**IRR Comparison - Spot Market Trading**  
Example

<table>
<thead>
<tr>
<th></th>
<th>New England</th>
<th>PJM</th>
<th>California</th>
<th>UK Pool</th>
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<tbody>
<tr>
<td><strong>Base case</strong></td>
<td>Trent</td>
<td>LM 6000 PD</td>
<td>LM 6000 ES</td>
<td>6FA</td>
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<tr>
<td><strong>Scenario 1</strong></td>
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<td>LM 6000 ES</td>
<td>6FA</td>
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<td><strong>Scenario 2</strong></td>
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<td><strong>Scenario 3</strong></td>
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<td><strong>Scenario 4</strong></td>
<td>Trent</td>
<td>LM 6000 PD</td>
<td>LM 6000 ES</td>
<td>6FA</td>
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Reference Case in EIA Annual Energy Outlook - 2001

**Scenario 1**  
High gas price (2 x base case)

**Scenario 2**  
Gas price 1.5 x base case, CO2 tax in later years

**Scenario 3**  
Low longer-term gas prices, high CO2 taxation
Public Benefits of R-R’s NGT

- **Assuming 34 NGT units (2550 MWs) per year installed in U.S.:**
  - **CO₂ Emissions - Cumulative 15 Year Savings**
    - Compared to Simple Cycle GT, 150 million tonnes savings
    - Compared to Coal Plant, 630 million tonnes savings
    - $3B savings in CO₂ trading credits (assumed @ $20/tonne) cf simple cycle GT
    - $12.6B savings in CO₂ trading credits (assumed @ $20/tonne) cf coal plant
  - **Fuel (natural gas) Consumption - Cumulative 15 Year Savings**
    - Compared to Simple Cycle GT, 2.6 trillion cubic feet savings
    - $8.3B fuel cost savings compared to Simple Cycle GT

- **$2.1 billion/yr potential export sales from 2006 (assumed 54 units/yr)**

- **Lower risk approach allows earlier availability to market**

- **Flexible characteristics allow for viable and efficient operations even in changing market conditions**
Summary

- **R-R’s NGT concepts have been approached from an “economic viability” perspective:**
  - Leveraging available hardware and technologies to lower risk, investment, and time to market; and
  - Applying these in innovative ways to develop a solution that will provide customers with improved return on investment (ensure deployment) while providing extensive public benefits.

- **R-R’s NGT concepts (Wet Intercooled/Wet Recuperated; Super Steam Injection):**
  - Meet DOE NGT goals;
  - Seem to be appropriate for the future marketplace;
  - Provide substantial economic benefits to operators; and
  - Provide substantial public benefits.

- **R-R is encouraged by the results of this study. However, the significant technical & market risks and the large investments required make launching an NGT product very difficult in today’s business environment.**