High Efficiency Microturbine with Integral Heat Recovery

Contract  DE-EE 0004258

Capstone Turbine Corporation, Oak Ridge National Laboratory, NASA Glenn

John Nourse
Capstone Turbine Corporation
jnourse@capstoneturbine.com
818-734-5144

U.S. DOE Industrial Distributed Energy Portfolio Review Meeting
Washington, D.C.
June 1-2, 2011
C250 / C370 Engine – Capstone/DOE Program

- Current Technology at 33% efficiency
- Potential Products
  - C250 at 250kW and 35% Efficiency
  - C370 at 370kW and 42%+ Efficiency

- Key Technical Developments
  - Dual Property High Temperature Turbine
  - High Pressure Compressors & Recuperator – 11:1
  - Dual Generators – both LP and HP spool
  - Dual Spool Control Development
  - High Temperature Low Emissions Combustor
  - Inter Stage Compressor Cooling
C250 Engine System

- C250 Development
  - Existing Technology
    - Turbine and recuperator common to current C200 product
    - Same rotor speed as C200
  - New Technology
    - 3D Aerodynamics
      - Compressor Diffuser
      - Turbine Nozzle
    - High Flow/PR Compressor
    - Engine Sealing Improvements
    - Generator Design with longer magnet & improved cooling
    - Integration as C370 LP rotor spool

Design for 270kW Nominal Power Output and 35% Efficiency
C250/C370 Engine Design

- Compressor Aero Design
  - 3D Aerodynamic Design - +2.2 % Component Efficiency
  - \( PR = 5.0 \quad m = 3.6 \text{ lb/sec} \)

- Status
  - Design underway - Periodic reviews held
  - Design Completion – June, 2011

Design Release planned for June procurement of first components
C250 Aero Design Flowpath

Vista TF
C250 Engine Design

- Turbine Nozzle Aero Redesign
  - 3D Aerodynamic Design - +1.0 % Component Efficiency
  - C200 Mech. Interfaces

- Status
  - Design well underway - Periodic reviews held
  - Design Completion – July 2011

Design Release planned for June procurement of first castings
C250 Turbine Nozzle Aero Design

C250 Cycle-Match Conjugate Stage – Vane Pressure Contours

- Vane Pressure Side Ps (with streamlines)
- Vane Suction Side Ps (with streamlines)
- Midspan Vane Loading
- Absolute Mach Number on Midspan Vane Section A-A

→ C250 baseline vane predicts more SS acceleration than in C200

Capstone Turbines Proprietary Information
C250 Generator Design Concept

- C250 requires more powerful generator
  - Increase of 25% or more power capability
  - Simple growth version of C200 generator section involves a 125% length magnet shaft
    - Current C200 (100%) is 6.60”
    - Proposed C250 (125%) is 8.25”
  - Larger diameter magnet violates magnet design stress requirements at 60 krpm, leading to potential for magnet cracking

- Longer Magnet Design Validation
  - Critical Speed of Magnet Shaft will be lower
  - Need rig testing to validate Critical Speed margin
The C370 HP turbine utilizes a radial turbine wheel

Approximately the same size and geometry as the C65 turbine wheel (~5.5” dia.)

Current C65 turbine wheel is MAR-M-247

MAR-M-247 is not feasible for the C370 HP wheel due to the higher rotor inlet temperature

Options for the high-temperature wheel:

- Multi-alloy metallic wheel
- Ceramic (Silicon-Nitride) wheel
NASA SOW:
Task 1. Develop misalignment guidelines to lower fabrication costs
   a) Approach: Impose a known misalignment and evaluate bearing performance
   b) Test Rig(s): Rotor simulator test rig, Low speed foil bearing test rig

• NASA responsibilities: Facilities, test journals, PS400 solid lubricant coating, labor
• Capstone responsibilities: Bearings and other required hardware
## Transition and Deployment

<table>
<thead>
<tr>
<th>Desirable Attribute</th>
<th>Importance to End Users</th>
<th>Importance to Government</th>
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<tbody>
<tr>
<td>Lower Operating Costs</td>
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<td>Increase Security of Power</td>
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<td>Reduce Greenhouse Gas Emissions</td>
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<td>●</td>
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<td>Increase Energy Independence</td>
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<td>Reduce Criteria Pollutants</td>
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<td>○</td>
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<tr>
<td>Improve Fuel Economy</td>
<td>□</td>
<td>○</td>
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<tr>
<td>Ensure US Leadership</td>
<td>□</td>
<td>●</td>
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</table>

• Technology advantage can be sustained using
  - Patent Protection (Capstone has 100 worldwide today)
  - Market Leadership (Capstone has worldwide distribution)
  - The Right Incentives (need Government support)
## Transition and Deployment

<table>
<thead>
<tr>
<th>End User</th>
<th>Application</th>
<th>Key Attributes</th>
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</thead>
<tbody>
<tr>
<td>Commercial (Hotels, Office, Retail) Small Industrial Facilities</td>
<td>CHP/CCHP*</td>
<td>Efficiency, Availability</td>
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<tr>
<td>Electric Utility</td>
<td>Peak Power</td>
<td>Availability, Efficiency</td>
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<tr>
<td>Oil &amp; Gas Production</td>
<td>Remote Power</td>
<td>Stand Alone Capability</td>
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<tr>
<td>Data Centers / Telecom Critical Industrial Processes</td>
<td>Uninterruptible Power</td>
<td>Availability, Efficiency</td>
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<td>Waste Water Treatment Plants Farms with Anaerobic Digesters</td>
<td>Renewable Fuel with CHP</td>
<td>Emissions, Efficiency</td>
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<tr>
<td>Vehicle OEM’s</td>
<td>Series Hybrid Drive Systems</td>
<td>Efficiency, Emissions</td>
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</table>
Measure of Success

- **US Production Opportunity:**
  - Total C370 Market ~ AMTS Market = 31.3 GW
  - Conservative C370 Sales Projections ~ 3% of Total Potential

- **US Leadership Opportunity:**
  - 1,200 new or retained jobs
  - Retain worldwide technology advantage
Benefits

- Example Operating Costs

**C370 Net Power Costs**

- Results in Significant Economic Market Potential

<table>
<thead>
<tr>
<th>State</th>
<th>Retrofit MW</th>
<th>20-Year New MW</th>
<th>Total MW</th>
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<tbody>
<tr>
<td>California</td>
<td>1,034</td>
<td>790</td>
<td>1,824</td>
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<td>Texas</td>
<td>598</td>
<td>408</td>
<td>1,006</td>
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<td>New York</td>
<td>532</td>
<td>352</td>
<td>883</td>
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<td>New Jersey</td>
<td>408</td>
<td>264</td>
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<td>Illinois</td>
<td>330</td>
<td>304</td>
<td>634</td>
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<td>Connecticut</td>
<td>281</td>
<td>191</td>
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## Benefits

- **Energy & Environmental Benefits by 2020**

<table>
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<th>Energy or Emissions Attribute</th>
<th>Annual Reduction</th>
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<tbody>
<tr>
<td>Fuel Consumption</td>
<td>15.4 GWh/year or 526 million Therms/year</td>
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<tr>
<td>NOx</td>
<td>8.8 Tons/year</td>
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<tr>
<td>CO2</td>
<td>2.8 Million Tons/year</td>
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</table>

**Assumptions:**

C370 uses natural gas and is 42% efficiency with 85% total CHP efficiency, 1GW installed operating 8,000 hours/year with NOx of .14lb/MWh. Comparison is to getting electricity from the average US grid at 33% efficiency with 1.79 lb/MWh NOx and 1,300 lb/MWh CO2, and hot water from a boiler that is 80% efficient with NOx of .23lb/MWh using natural gas fuel input.
Commercialization Approach

• Certify to UL, IEEE, CE and other Standards
• Train Sales & Service for Proper Support
• Utilize Capstone’s Existing Distribution Channels
• Quantify Economic/Environmental Benefits
• Promote using Trade Shows/Conferences
• Develop Case Studies/White Papers/Videos
• Leverage Government Incentives/Rebates
Project Management & Budget

- Project task and milestone schedule
  - Schedule Performance - Earned Value will be measured against Planned Value.
  - Cost Performance
    - Earned Value vs Actual Cost
    - Unit cost model vs costed BOM

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<th>FY12</th>
<th>FY13</th>
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<td>DOE Investment</td>
<td>775k+260k</td>
<td>2000k+250k</td>
<td>1255k+250k</td>
<td>150k+60k</td>
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<td>(CPST+ORNL/NASA)</td>
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<td>Cost Share</td>
<td>1010k</td>
<td>5370k</td>
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<td>Project Total</td>
<td>2045k</td>
<td>7620k</td>
<td>6505k</td>
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C250 Schedule

C250 Milestones

System Concept

Engine
  - Generator
  - Turbine Nozzle
  - Compressor
  - Combustor
  - Procurement
  - Engine Assy Test

Fuel System

Electronics/Energy Storage

Enclosure

Software

System Test

C250 Schedule Diagram

- Cycle Model
- Bearing Test
- Model/Analysis/Dwgs
- Gen Design
- Tooling/Proto Parts
- Component Test/Eval
- Engine Test w/ First Article Parts
- Uprate C200
- IGBT/Power Brd

Milestones:
- 3Q10
- 4Q10
- 1Q11
- 2Q11
- 3Q11
- 4Q11
- 1Q12
- 2Q12
- 3Q12

Dates:
- 8/15/11
- 11/20/11
- 8/30/12
- 2/20/12
- 8/30/12

Design Iterations Based on Procure/Test Results

System Components:
- Engine Assy Test
- Tooling/Proto Parts
- Component Test/Eval
- Engine Test w/ First Article Parts
- Uprate C200
## C370 Schedule

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Upcoming Design Activity

- **C250 Engine Design**
  - Bearing housing & shroud-line definition
  - Compressor Impeller Stress & Aeromechanical Analysis Validation
  - Nozzle and Compressor Drawing Release

- **C370 Combustor Conceptual Design**
- **C370 Turbine Rotor Design Concepts**

- **First C250 Engine Test in October 2011**
Questions?