Waste Heat-to-Power Using Scroll Expander for Organic Rankine Bottoming Cycle

DE-EE0005767

TIAX LLC and Keurig Green Mountain (field test site)

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John Dieckmann, TIAX LLC, Principal Investigator (Presenter)

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Project Objective

• Primary objective – develop scroll expander technology for organic Rankine cycle (ORC) for power generation from recovered waste heat, with power outputs from 5kW to 50kW
• Key technical requirements are to obtain high expansion efficiency and long operating life
• Challenges
  • Time variation in temperature and/or flow of waste heat stream
  • Pressure ratio/built-in volume ratio mismatch – larger pressure ratio than practical scroll built-in volume ratio
  • Addressing unanticipated issues arising during development of complex thermodynamic-mechanical hardware
Technical Innovation

• Current ORC expanders
  • Turbo expanders large power output 100 kW up
  • Screw expanders 50kW – 150 kW
  • 5 – 50 kW technology gap
• Scroll well suited to expansion and compression in 5-50kW power range
  • Best efficiency refrigerant compressors from 3kW to 50kW power input (~3 to 50 ton cooling capacity for air conditioning), with proven life and reliability
• Advantages for ORC expander
  • Self-porting
  • Tolerant of two phase flow/liquid slugs
  • In 5 – 50 kW range, good combination of low flow losses, low internal leakage/bypass losses, and high mechanical efficiency
• Advantages for ORC expander (continued)
  • Most ORC working fluids similar to refrigerants, compatible with lubricants

• What is innovative about your project and approach?
  • Applying TIAX-developed radial compliance method and pressure balance and thrust bearing methods to provide axial compliance with low sliding friction loss. Radial and axial compliance minimizes the flank and tip clearances, respectively, between the scrolls, minimizing pocket to pocket leakage loss
  • TIAX and predecessor Arthur D. Little Technology Group have 40 years of experience developing scroll machinery for a wide range of applications
Technical Approach

• Develop scroll ORC expander and ORC balance of plant, sized for Keurig Green Mountain waste heat source
  • Follow normal process for sizing scroll components and implementing mechanical design
  • Use coil sizing software to design condenser and boiler
  • Then test-modify as needed-retest

• TIAAX has been the system developer; Keurig Green Mountain is providing the field test site with waste heat stream

• Primary risk mitigation measure is extended test run at TIAAX facility prior to installation at Keurig Green Mountain facility in Vermont
Transition and Deployment

- Who cares? -- Many medium temperature (150°C to 500°C), modest capacity waste heat streams could be utilized with suitable expander technology
- End users – industries with waste heat streams with recoverable heat between 100,000 Btu/hr and 1½ million Btu/hr
  - Thermal oxidizers (used in a variety of industries)
  - Coffee roasting
  - Bakeries
  - Heat treating
- Bottoming cycle for distributed generation and CHP
  - 30 kW – 300 kW
  - Rejected heat from ORC can be high enough temperature for DHW and space heating
Waste heat stream can be recovered by packaged ORC system.

Typically, no direct impact on operations, but generates a good return on investment – saved electricity cost vs. projected installed cost.

Commercialization
- License to ORC system manufacturer or component supplier.
- When the field system is operating, with performance data, will contact ORC manufacturers to initiate technology transfer discussions.

Technology sustainment
- Technology transfer to licensee.
- Long term TIAAX commitment to scroll technology.
Measure of Success

- Successful development and deployment will increase the number of waste heat streams that can be captured and used for electric power generation
  - Measurement of impact ultimately will be kW’s of waste heat powered generating capacity, kWh’s generated, CO₂ emissions avoided
- Energy Impact – very rough preliminary estimate
  - In 2021, installed in 5% of identified potential applications, 60 million kWh of electric energy generated, saving 0.6 trillion Btu/hr of primary energy and avoiding 30,000 metric tonnes of CO₂ emissions
  - Technical potential, at least 20 x this amount, growing as the installed base grows
Measure of Success (continued)

• Economic impact
  • By 2021, installed in 5% of identified applications, $13.5 million invested in scroll based ORCs, $4.4 million of electricity costs saved
## Project Management & Budget

- **Project duration 48 months (Gantt chart next page)**

<table>
<thead>
<tr>
<th><strong>Milestone Description</strong></th>
<th><strong>Verification Method</strong></th>
<th><strong>Planned Completion Date</strong></th>
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</thead>
<tbody>
<tr>
<td>Detailed Design of Scroll Expander Completed</td>
<td>Drawing package and solid models reviewed</td>
<td>1/31/2014</td>
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<tr>
<td>Component Fabrication Completed</td>
<td>All components in hand and inspected for conformance with specifications and tolerances</td>
<td>5/30/2014</td>
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<tr>
<td>System Assembly Completed</td>
<td>System assembled</td>
<td>6/30/2014</td>
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<tr>
<td>Scroll Expander Operating</td>
<td>Expander operating</td>
<td>7/15/2014</td>
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<tr>
<td>Scroll Expander Isentropic Efficiency &gt;70%</td>
<td>Laboratory test results</td>
<td>11/04/2014</td>
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<tr>
<td>Scroll Expdr Isentropic Efficiency &gt;75% 200 Operating Hours</td>
<td>Laboratory test results</td>
<td>11/23/2015</td>
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<tr>
<td>Field System Assembled at TIAx</td>
<td>System operating</td>
<td>6/15/2016</td>
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<tr>
<td>Field System Testing at TIAx Facilities Complete</td>
<td>Test results</td>
<td>9/30/2016</td>
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<tr>
<td>Field Test System Installed and Operating at Design Capacity</td>
<td>Physical installation complete and performance test results</td>
<td>10/31/2016</td>
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<tr>
<td>12 Months of Field Test Operation</td>
<td>Results documented and included in quarterly progress report and final report</td>
<td>10/31/2017</td>
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### DOE Investment

- **DOE Investment**: $2,816,064
- **Cost Share**: $1,194,716
- **Project Total**: $4,010,780
### Project Management & Budget

<table>
<thead>
<tr>
<th>Task</th>
<th>Budget Period 1</th>
<th>Budget Period 2</th>
<th>Budget Period 3</th>
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</thead>
<tbody>
<tr>
<td>1. Waste Heat-to-Power System Design and Modeling</td>
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<tr>
<td>2. Detailed Design of Scroll Expander</td>
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<td>3. Detailed Design of Balance of Plant Components</td>
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<td>4. Bench Test Planning and Design</td>
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<td>5. Specify &amp; Purchase Parts</td>
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<td>6. Fabrication of Parts for Scroll Expander</td>
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<td>7. Assemble System</td>
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<td>8. Development Testing</td>
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<td>9. BP1 Management and Reporting</td>
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<td>10. Performance Testing of Laboratory Prototype</td>
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<td>11. Field Specific Design</td>
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<td>12. Field Specific Part Fabrication</td>
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<td>14. BP2 Management and Reporting</td>
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<td>15. Risk Reduction Testing</td>
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<tr>
<td>16. Install Field Test System</td>
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<td>17. Field Measurement &amp; Analysis</td>
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<td>18. BP3 Management and Reporting</td>
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<td>- Progress Reports</td>
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<td>- Final Technical Report</td>
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</tbody>
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- Progress Reports
- Final Technical Report
Results and Accomplishments

- Status – BP1 tasks complete and all milestones and go/no go criteria met
- BP2 tasks complete and all milestones and go/no go criteria met
  - Expander isentropic efficiency 75 – 76%
  - 200 operating hours with no bearing wear
  - Field system set up at TIAAX facility in Lexington, MA
- Work to be completed in Budget Period 3
  - Test the field test system at TIAAX facilities
  - Install field test system at Keurig Green Mountain field test site
  - Run the field test
  - Document the results
Results and Accomplishments (continued)
Results and Accomplishments (continued)