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

DE-EE0005767

TIAX LLC and Keurig Green Mountain (field test site)

July 1, 2013 – June 30, 2017

John Dieckmann, TIAX LLC, Principal Investigator (Presenter)

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 14-15, 2016

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

Technical Innovation (continued)

- 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
- TIAX 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 TIAX 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

Transition and Deployment (continued)

- 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 TIAX 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, CO_2 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

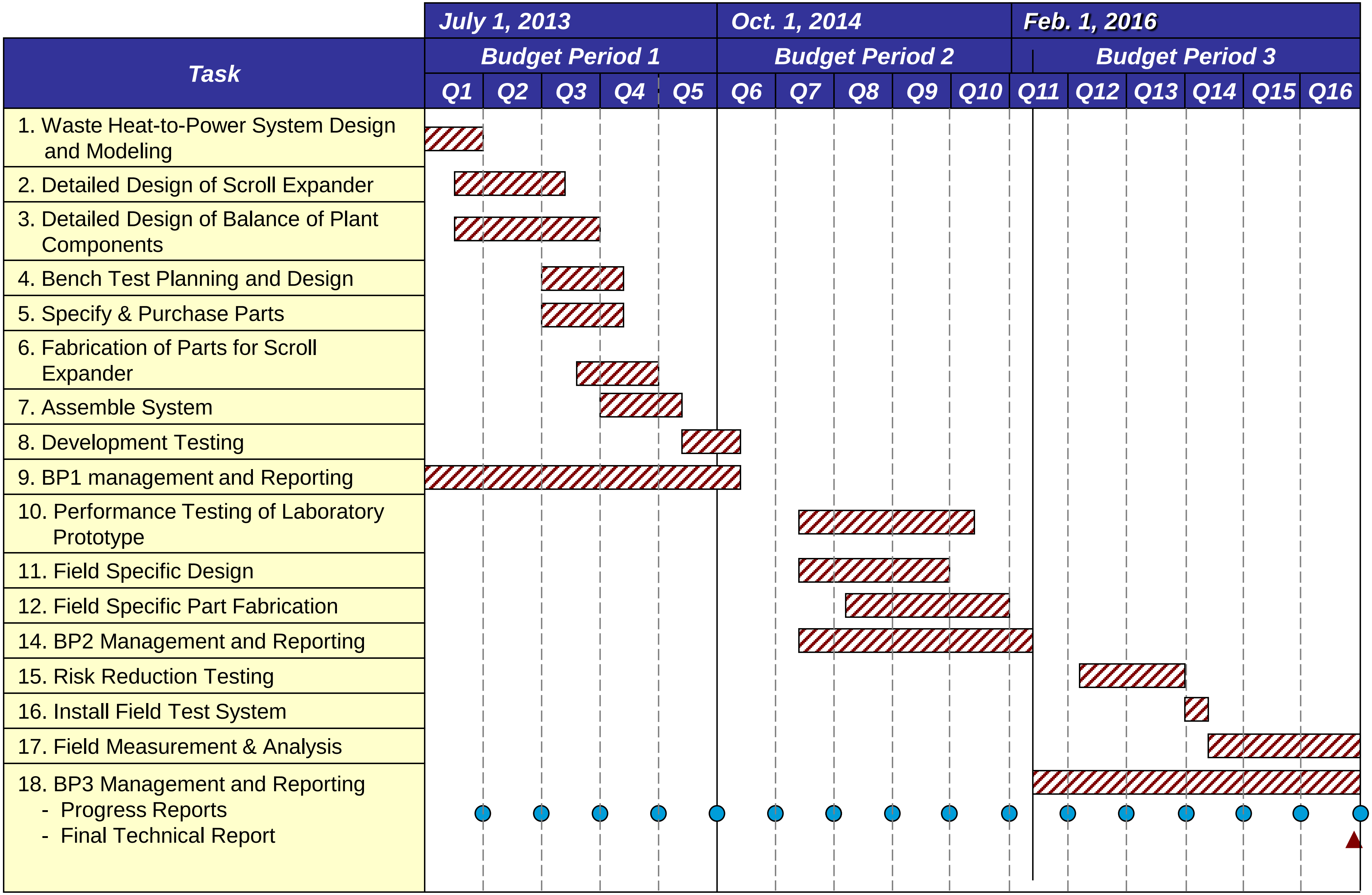
Project Management & Budget

- Project duration 48 months (Gantt chart next page)

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

DOE Investment	***Cost Share***	***Project Total***
$2,816,064	$1,194,716	$4,010,780

Project Management & Budget (continued)



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 TIAX facility in Lexington, MA
- Work to be completed in Budget Period 3
  - Test the field test system at TIAX 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)