Combined Heat and Power (CHP) Technology Development

Project 19864, Agreement 19128
Oak Ridge National Laboratory
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Objective of the ORNL CHP R&D program

The project objectives are to improve the efficiency and viability of Combined Heat and Power systems and high-efficiency electrical generation systems, while supporting the U.S. manufacturing base.

- Advance the state-of-the-art of CHP
- CHP offers great benefits and potential savings but is under-utilized due to barriers including high capital costs and lack of flexibility to match the electrical and thermal loads
- Address the complications of a wide range of demands, geography, complexity of equipment, grid interface, and utility policy

Technical Approach – Conduct R&D along Three Main Thrusts

- High efficiency power generation

  Novel combustion regimes for power generation and integration of CHP into the industrial sector

  - Directed toward 1 - 5 MW reciprocating engines but applicable to other systems as well

- Materials development and characterization

  Investigating lower cost, high temperature materials for critical components to enable higher efficiency

  - Higher temperature heat exchangers are critical to turbine efficiency and other applications

- Additive Manufacturing for CHP Components

  Removing traditional manufacturing constraints from the design of heat exchangers and engines

  - Initial focus on small-scale engines and compressors

Technical Approach – Task Description

- High efficiency power generation through advanced thermodynamics
  - Modeling of high efficiency engine combustion regimes and heat exchanger approaches
  - Software tool that allows users to examine hourly energy usage for each industrial sub-sector to identify CHP opportunities
- Materials development and characterization
  - Higher temperature heat exchangers drive efficiency gains
  - Lower cost materials and coatings enable CHP market penetration
  - Recovery of waste heat from hostile industrial environments e.g. Electric Arc Furnaces
- Additive Manufacturing for Components
  - Fabricate and evaluate a working engine with additive manufacturing
  - Design and fabricate novel CHP components with additive manufacturing

The technical approach connects advanced manufacturing to energy efficiency

ORNL Manufacturing Demonstration Facility

Additive Manufacturing: Novel devices not limited by traditional fabrication

High Temperature Materials Laboratory

High Efficiency through advanced thermodynamics: Design & evaluate new energy conversion devices & materials

Materials: High temperature and AM-specific alloy development & component characterization

Transition and Deployment

- This is pre-competitive research: results being published and presented
  - 8 publications and 12 presentations since June 2012
- Working with industry in all three thrusts
- End users are equipment manufacturers, facilities
- CHP can improve the bottom line for industry through reduced energy use
- Built and demonstrated a small-scale engine using additive manufacturing for the critical components.

Technology Sustainment Model:
Applying advanced technologies to CHP from a variety of disciplines including materials, thermodynamics, and additive manufacturing

Impact of Existing and Future Research

- Modeling suggests reciprocating engine efficiency of > **50%** is possible with turbine-like NOx emissions using a dual fuel combustion strategy

- IGATE-E CHP Software tool will evaluate the CHP potential at the manufacturing plant and locality – e.g. the steam needs of the top 20 boiler industries represents **0.5 quad** annually. The utility of CHP on an hourly basis can be assessed.

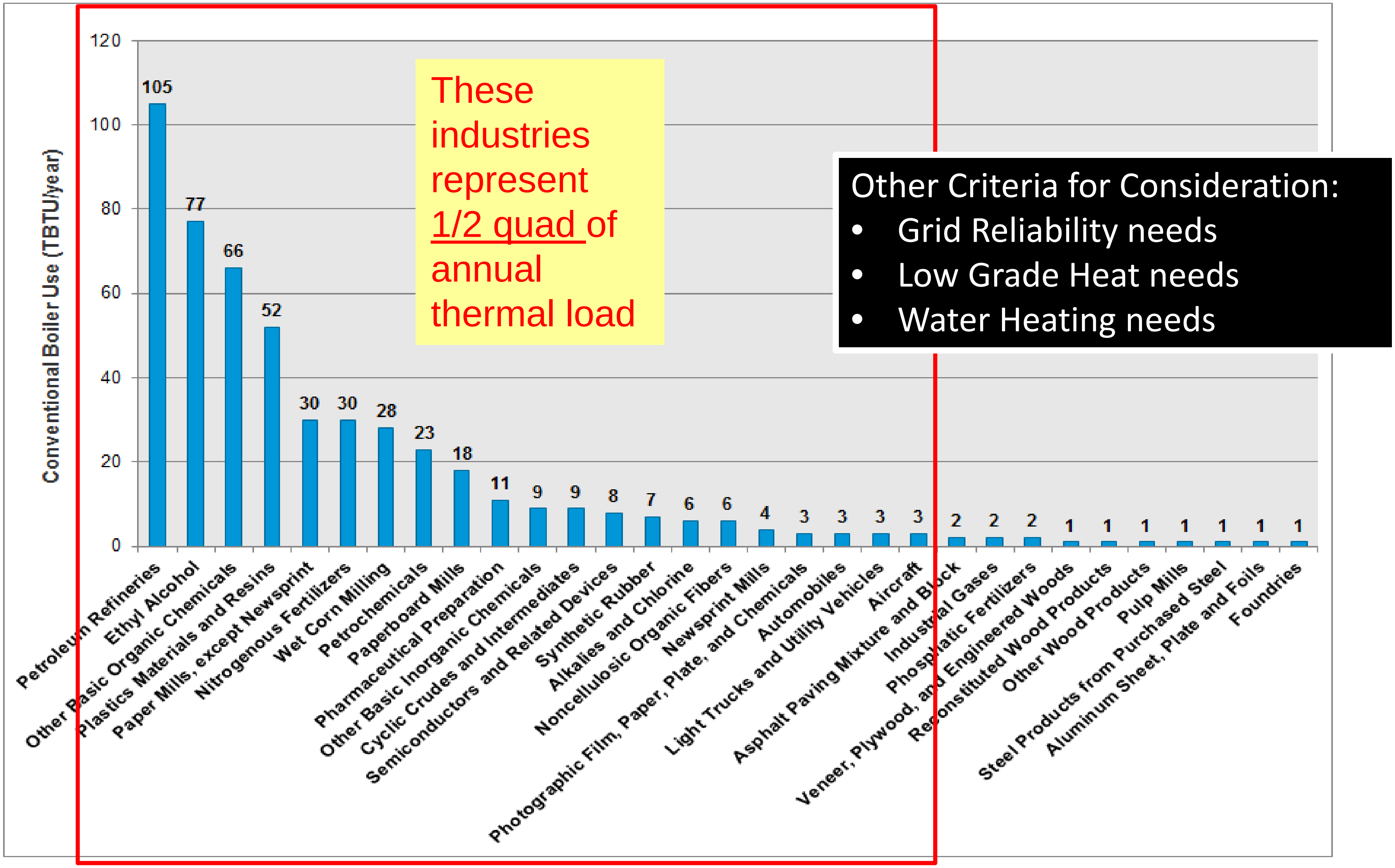
- Low cost, high temperature **ORNL alloy deployed** to two turbine manufacturers.

- Waste heat from existing domestic Electric Arc Furnaces represents **1/3 of a quad.**

- Modelling of compressor design, produced using additive manufacturing, shows up to **75% more efficiency** due to reduced leakage

Impact: Top Manufacturing Subsectors with Highest CHP Potential

6-Digit NAICS (4-Digit SIC) - Based on Conventional Boiler Use



Future Measures of Success

- 10% improvement in engine efficiency for advanced reciprocating and turbine systems
- Adoption of an Electric Arc Furnace waste heat recovery system
- Utilization of one or more advanced alloys or additive manufacturing techniques by an equipment manufacturer
- Software tool in use by industry and regional application centers to identify new opportunities for industrial CHP
- Build CHP system component not currently manufactured using Additive Manufacturing as a final or prototyping step

Project Management & Budget

- Project is ongoing: June 2012 – May 2014 being reviewed
- Thrust 1: High efficiency power generation

  Milestone: Model and compare electrical efficiency for a 1 MW gen-set operating in RCCI mode vs. conventional lean operation *due 9/30/2014*

  Milestone: Complete the model of the impact of CHP on grid reliability and resilience using novel, bottom-up approach *due 6/30/2014*
- Thrust 2: Materials development and characterization

  Milestone: Complete creep testing at 2 conditions on Ni-base superalloy made by additive manufacturing *due 6/30/2014*

  Milestone: Complete materials analysis for waste heat recovery/power generation from high temperature, contaminated gases *due 6/30/2014*
- Thrust 3: Additive Manufacturing for Components

  Milestone: Manufacture and demonstrate a functional heat exchanger or heat exchanging part, such as a compressor head *due 9/30/2014*

  Milestone: Manufacture and demonstrate the operation of a miniature engine with embedded sensors *due 6/30/2014*

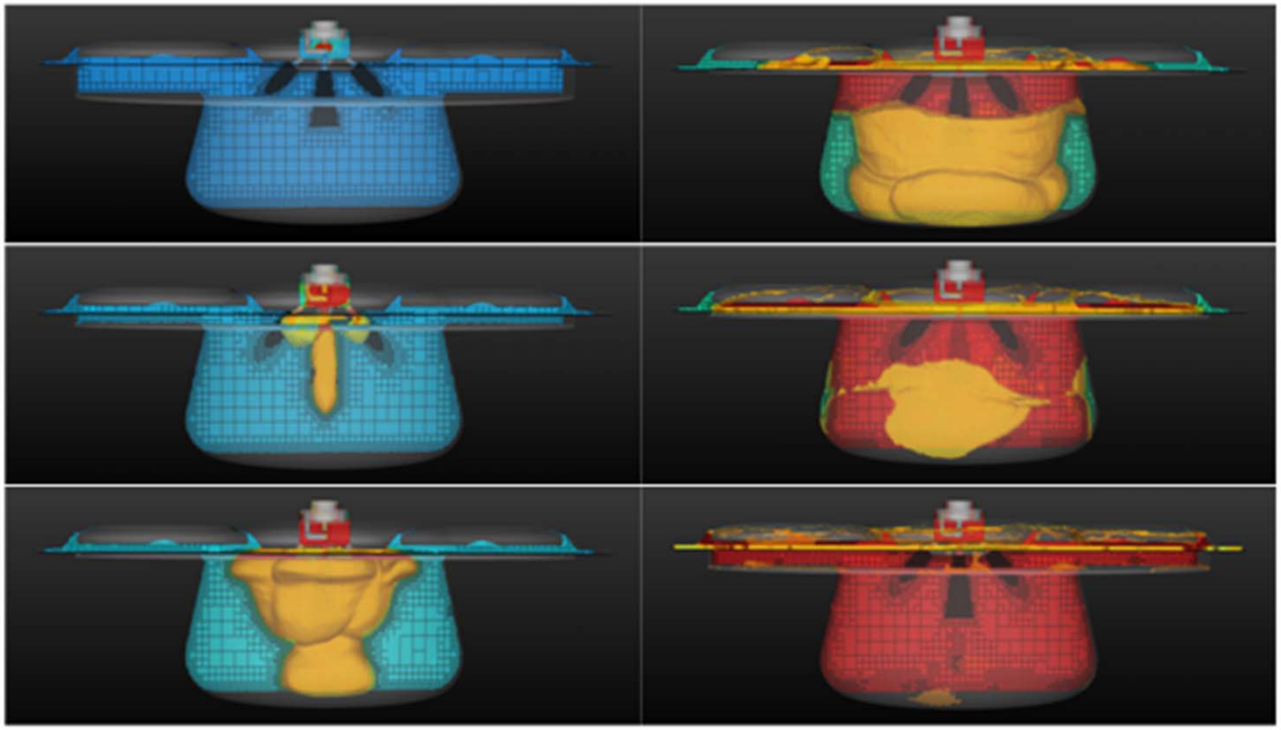
Total Project Budget	
DOE Investment	$2,700K
Cost Share	This a pre-competitive program
Project Total	$2,700K

Results and Accomplishments

- Project tasks on schedule
- Milestones on schedule or have been met for June 30
- Results: High Efficiency through Advanced Thermodynamics
  - High-performance computing model operational for advanced combustion reciprocating engine
  - Incorporated natural gas fuel usage into validated IGATE-E software tool to assess CHP potential across industry subsectors at specific locations
- Results: Materials Development and Characterization
  - Characterized material coupons from additive manufacturing
  - Austenitic stainless steel deployed in turbine engine trials
  - Energy balance calculator for Electric Arc Furnace melts developed
- Results: Additive Manufacturing for Components
  - Fabricated and evaluated engine head with embedded sensors
  - Designed, modelled, and prototyped a novel, low-leakage compressor

Example result: Novel combustion regime modeled in large bore engine (on schedule)

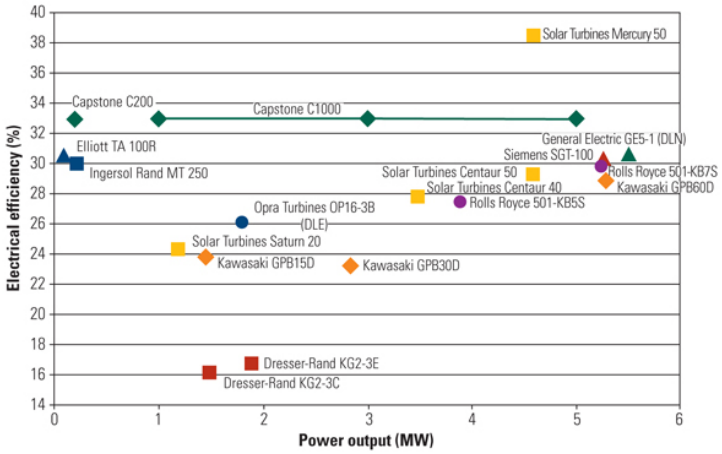
Reactivity Controlled Compression Ignition uses fuels of two reactivities to tailor combustion for efficiency and low emissions



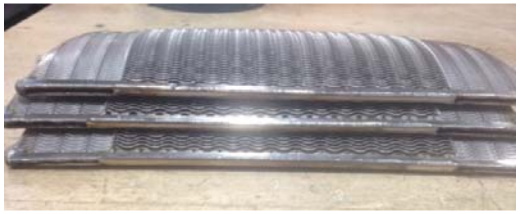
- High Performance Computing model showing ignition in the combustion chamber
- 2 MW natural gas engine used for engine geometry

Example Result: Turbine Manufacturers evaluating High Temperature Recuperator Materials in engines

- Impact: Higher efficiency turbines for less cost
  - Increased market penetration of high efficiency CHP
- Alumina-forming austenitic (AFA) steel invented in 2007
  - Exceptional oxidation resistance with similar creep strength
  - First **demonstrations running in engines**
    - Solar Turbines Mercury 50 (test panels)
    - Capstone C65 (rainbow core with welded cells)
    - 2nd C65 core at ORNL (August 2014 start)
  - Lower cost AFA foils developed in laboratory
    - Laboratory: acceptable creep and oxidation resistance



C200 Primary surface recuperator



8” AFA air cells (~90 made)
for rainbow recuperators

Example result: Additive manufacturing of working engine (completed ahead of schedule)

- Additive manufacturing proven as a feasible means to rapidly prototype critical components and to modify existing designs to enable in-cylinder measurement

Titanium engine head and block printed by the ORNL Additive Manufacturing team. AM enabled a pressure sensor port to be printed in (shown with sensor installed)