Combined Heat and Power R&D

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 for CHP systems
- 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

- ***Lower Cost Manufacturing through Advanced Materials***
  - Investigating lower cost, high performance, high temperature materials for critical components to enable higher efficiency
    - - Higher temperature heat exchangers are critical to micro-turbine efficiency and other applications
- ***Manufacturing Support for Grid Modernization***
  - Identifying the potential role that the manufacturing sector might have in broadly supporting the next generation grid
  - - Manufacturing sites with CHP can provide power and ancillary services
- ***Employing Additive Manufacturing for DG and CHP Systems***
  - Removing traditional manufacturing constraints from the design of heat exchangers and engines
    - - Geometry of engine components and heat exchangers can be limited by current manufacturing processes

Technical Approach – Task Description

- ***Lower Cost Manufacturing through Advanced Materials***
  - High temperature materials for prime movers
    - Enable high efficiency operation
  - High performance coatings for prime movers
    - Allows the use of lower cost materials
- ***Manufacturing Support for Grid Modernization***
  - Industrial Geospatial Analysis Tool for Energy Evaluations
    - (IGATE-E CHP) categorizes thermal and electrical loads for U.S. plants
  - Distributed Generation R&D Analysis and Planning Support
- ***Employing Additive Manufacturing for DG and CHP Systems***
  - Collaboration with Argonne National Lab on Engine Components
    - Fabricate and evaluate a NG engine cylinder head with additive manufacturing
  - Novel Heat Pipe Design
    - Heat pipes are well-suited to additive manufacturing and offer higher performance than conventional heat exchangers.

The technical approach connects advanced manufacturing to energy efficiency

ORNL Manufacturing Demonstration Facility

High Temperature Materials – advanced characterization

Additive Manufacturing:
Enable novel features and structures currently limited by traditional fabrication

Manufacturing Support through Grid Modernization:
Analyze role of manufacturing sector in grid support

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

Transition and Deployment

- This is pre-competitive research: results being published and presented
  - 12 publications and 18 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

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

Measures of Success

- High temperature ORNL alloy increases operating temperatures of micro-turbines leading to increased efficiency. Micro-turbine installed at ORNL for long-term demonstration of alloys. Goal is **10% improvement in efficiency**

- IGATE-E CHP Software tool has identified the CHP potential at the manufacturing plant and locality level – 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

- Analysis of distributed generation/CHP at manufacturing sites will **identify the value proposition** to the manufacturer and the capacity value to the grid

Project Management & Budget

- Project is ongoing: June 2015 – May 2016 being reviewed

- ***Thrust 1: High Efficiency through Advanced Thermodynamics***

  Milestone: IGATE-CHP: Completion of Web-based Geospatial Representation for all of the Continental U.S. *due 9/30/2015, complete*

- ***Thrust 2: Materials Development and Characterization***

  Milestone: Complete characterization of alumina-forming austenitic (AFA) steel air cells after 3000h microturbine test and compare to performance of current commercial alloy *due 9/30/2015, completed 1/30/2016*

- ***Thrust 3: Additive Manufacturing for Components***

  Milestone: Manufacture and demonstrate the operation of a full size cylinder head for an NG engine *due 9/30/2016, on schedule*

Total Project Budget	
DOE Investment	$1,900
Cost Share	This a pre-competitive program
Project Total	$1,900K

Results and Accomplishments

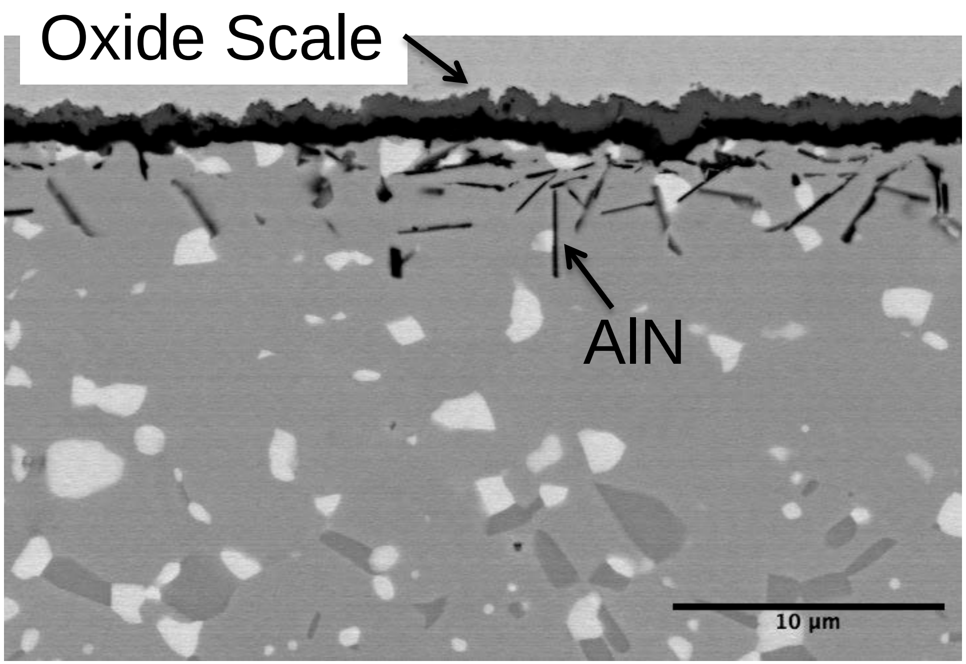
- Project tasks on schedule
- Milestones on schedule or have been met for June 30
- Results: Lower Cost Manufacturing through Advanced Materials
  - ORNL stainless steel deployed in turbine for 1000's of hours
  - Patent submitted on new high temperature alloy
- Results: Manufacturing Support for Grid Modernization
  - IGATE-E CHP Web-based software tool deployed: incorporates geography, thermal base loads, and electrical base loads *by 4-digit SIC code*
- Results: Employing Additive Manufacturing for DG and CHP Systems
  - Fabricated full-size cylinder head with binder jet process
  - Captured image of working fluid while heat pipe is in operation at a heat flux 50 kW/m^2

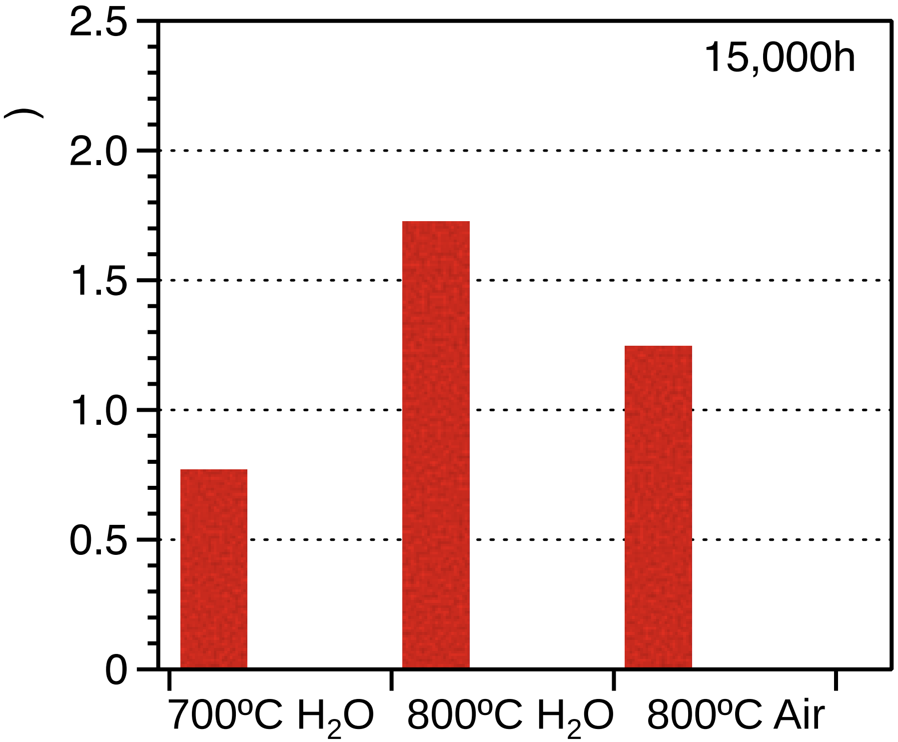
Example: ORNL 65kW Microturbine Engine Test and Test Facility

Folded, crushed and welded AFA 80µm foil air cell

- Capstone engine tests at ORNL with rainbow recuperator made of alumina forming austenitic AFA, 120 (Fe-38Ni-25Cr) and 310 (Fe-20Ni-25Cr) foils
- 3350h in normal operation (65kW, TET~1175ºF)
  - ~1800h at higher temperature ie TET~1272ºF. Goal is 7500h
- Microturbine was modified to allow insertion of pressurized samples and assess new cheaper AFA alloys

Very limited oxidation of AFA commercial foils after 15,000h at 800ºC





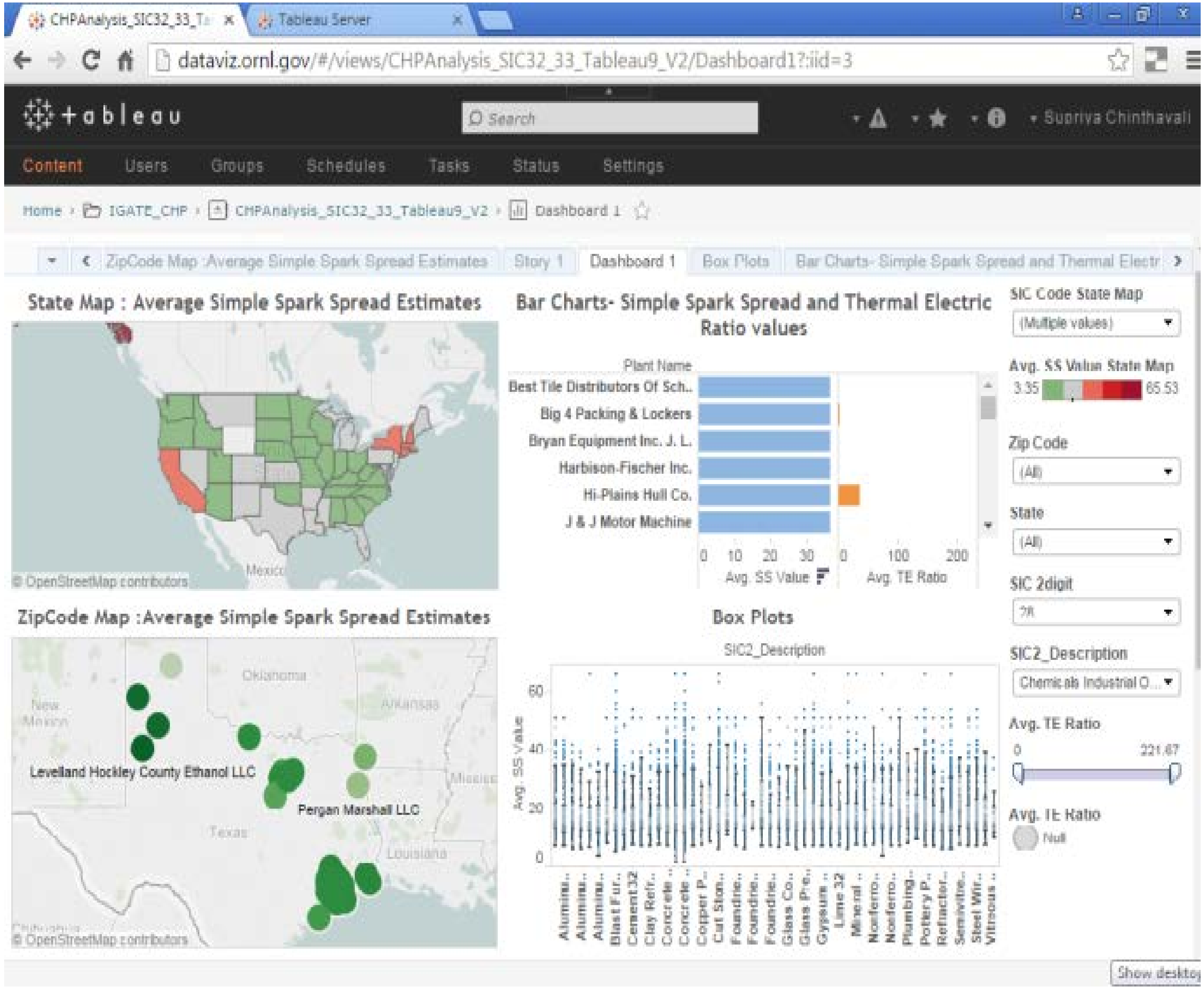
- **Excellent oxidation behavior for all commercial foils at 700-800ºC in air and air +H_2O**
- **No detrimental effect of Aluminum Nitride layer formed during foil processing**

IGATE-E CHP Web based Application

Role based Authentication

Interactive Visual Analytic Dashboard

Easy Sharing and Collaboration

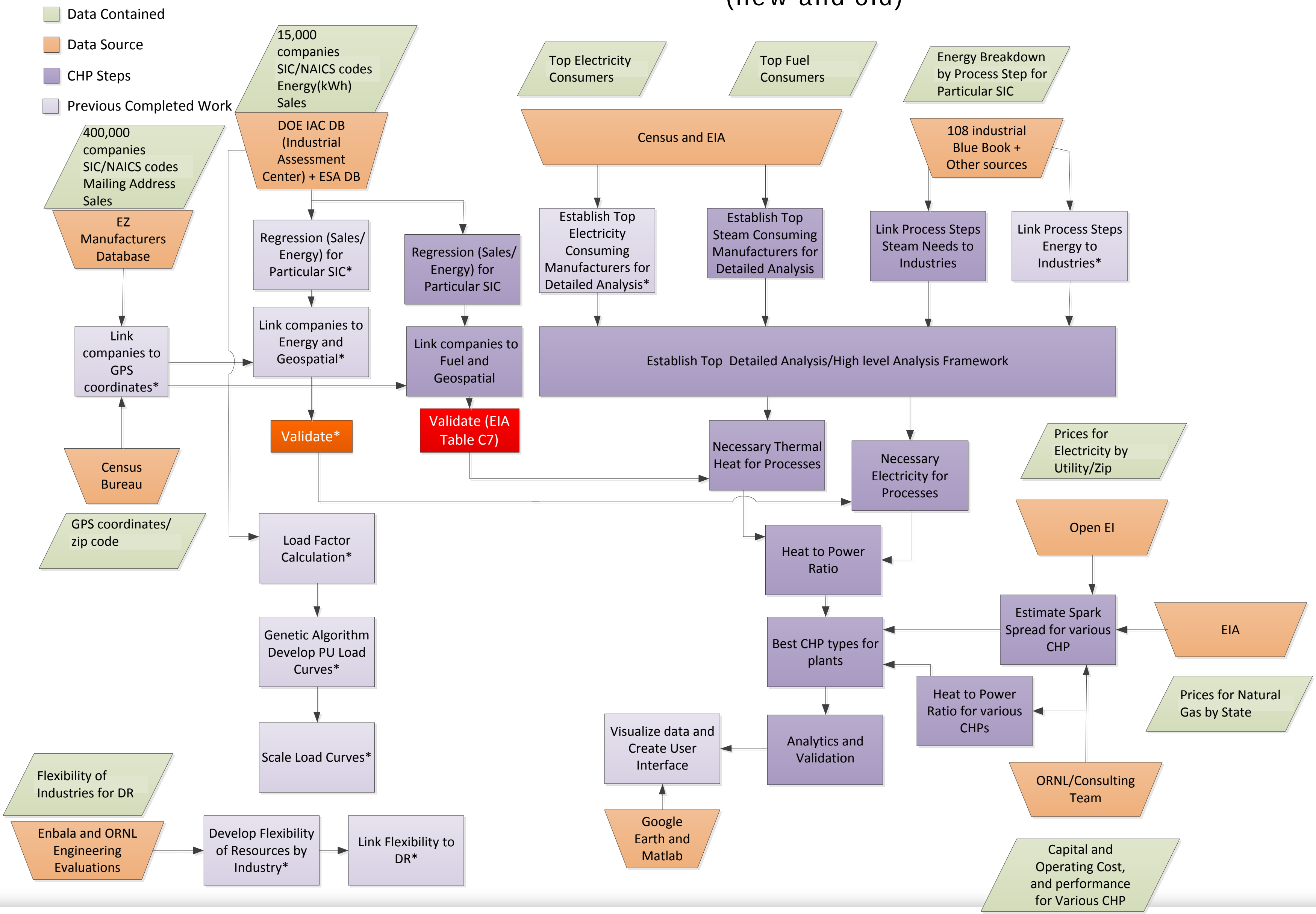


URL: https://dataviz.ornl.gov/

IGATE-E Framework

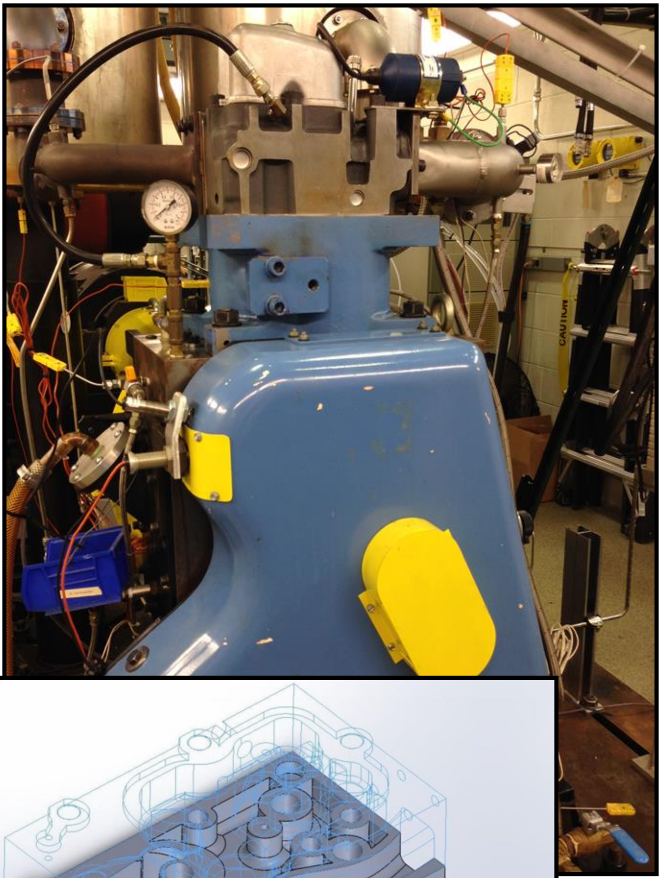
Framework uses many data sources

Full framework is composed of many steps (new and old)

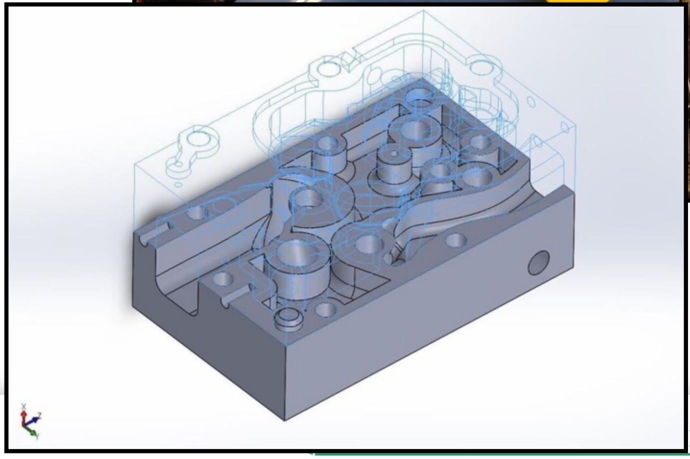


Additive manufacturing (AM) may enable improved engine designs and materials to to improve combustion efficiency by optimization of heat transfer.

- AM may enable improved engine designs and materials to minimize thermal losses which lead to combustion instabilities at high dilution.
- ANL has a single-cylinder research engine with multi-fuel capability (including natural gas).
- ANL has provided a head to ORNL to replicate the head using advanced materials via AM.
- Personnel at the Manufacturing Demonstration Facility (MDF) have begun preliminary studies evaluating AM to fabricate high strength bimetallic samples for consideration.
  - Tungsten-steel, tungsten-molybdenum, tungsten-bronze.



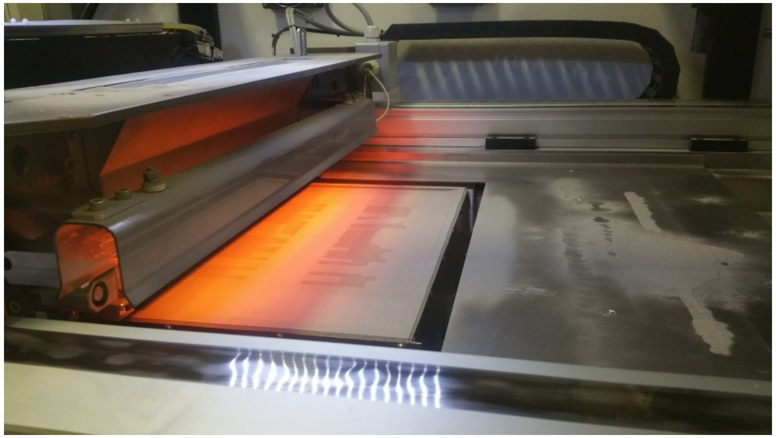
- ORNL has measured the dimensions which were incorporated into a solid works model.



- ORNL is currently evaluating a binder-jet process to print engine components.

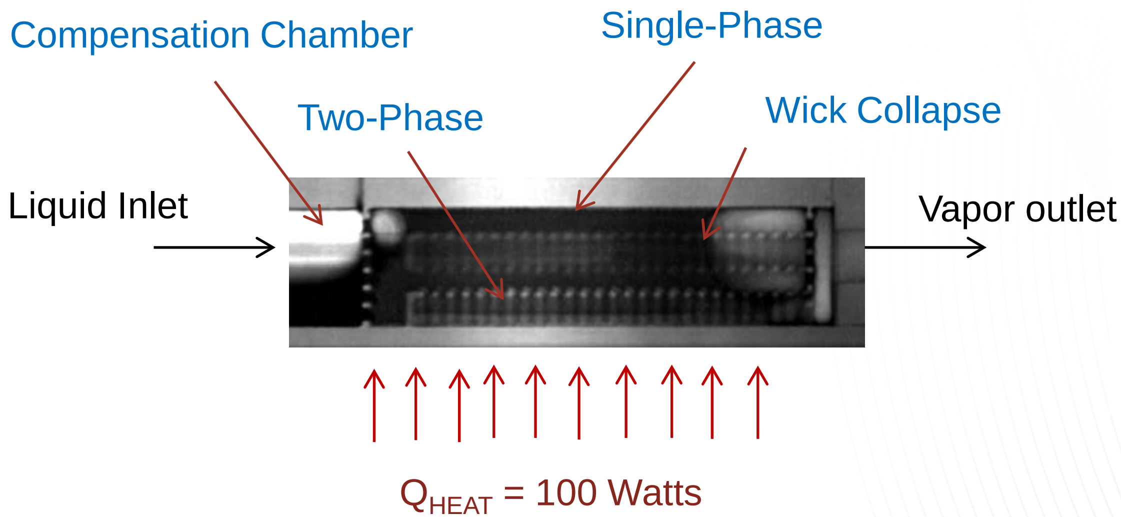
Example: The binder jet process was used to fabricate replicate heads out of tungsten and bronze.

- AM allows for rapid prototyping of engine heads with novel feature and alternate materials
- ORNL has successfully printed engine heads out of steel. Optimization of melt infiltration process is underway
- Inner contours (such as cooling passages) can be modified in-situ for rapid screening
- Materials to be evaluated include tungsten infiltrated with bronze, molybdenum, and steel. Optimization of melt infiltration process is on-going
- Additional port geometries are being considered to facilitate ignition, compression and swirl, and in-situ measurement of combustion behavior and thermal analysis

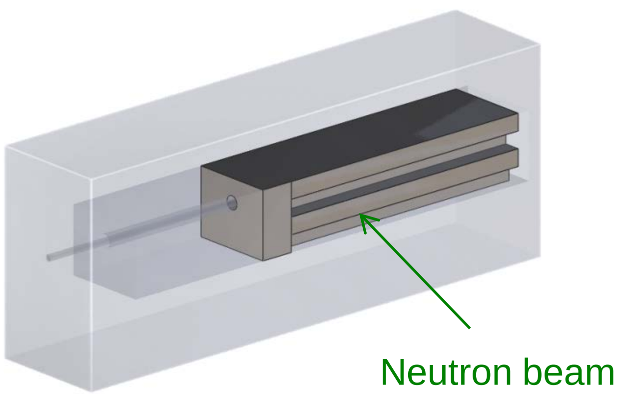


Example: Additive-Printed Heat Pipe

- **Captured image of working fluid while heat pipe is in operation – heat flux 50 kW/m^2**
- **Totally embedded heat transfer capability**
- **Peak temperature maintained below 45 ^{o}C**
- **Next generation designed to be significantly thinner**



Peak Temperature 45^{o}C



Neutron imaging conducted at HFIR

Analysis of 3D-Printed Microchannel Evaporator Flow

- **Non-invasive neutron imaging**
- **Coupled with heat transfer data to provide new heat transfer coefficients correlations**
- **Coupled with pressure drop data to provide new correlations**
- **New understanding of critical heat flux**