Materials for Advanced Ultra-supercritical Steam Turbines - Advanced Ultra-supercritical Component Demonstration

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ComTest Project Objectives

- Higher efficiency for new and existing fossil fuel plants
  - 10% above today’s new state-of-the-art coal power plants, and
  - 25% above that of the average power plants in the U.S. existing fleet
- Lower emissions (NOx, SOx, CO₂)
- Minimized risk for utilities desiring to build A-USC plants
- Fabrication of full scale components (850 MWe) for 760°C
- Accelerated development of domestic supply chain for advanced materials and components (greenfield & retrofit)
- Validation of technology applicable to multiple fossil, nuclear, and renewable power generation options, all targeted by the U.S. DOE NETL Cross-Cutting Research Technology Program
Strategic Alignment with DOE Fossil Energy Objectives

Power Plant Efficiency Improvements – Develop cost-effective, reliable technologies to improve the efficiency of new and existing coal-fired power plants.

- Project aims to close gaps to achieve readiness for commercial scale demonstration of Advanced Ultra-Supercritical (AUSC) technology
- Completion scheduled for September 2021
- Supports increase in power plant steam temperatures for higher cycle efficiency
  - Average efficiency of US coal-fired fleet = 33% HHV
  - A-USC plant efficiency over 45% HHV at 1,400°F (760°C) steam temperature
Increasing Steam Conditions to Dramatically Improve Efficiency

Plant Efficiency (HHV) as a Function of Steam Temperature

- **Studies: Sub-Bit/Lignite**
- **Studies: Bit.**
- **Plant Data: Sub-Bit/Lig.**
- **Plant Data: Bit.**
- **US Fleet Average 2010 (NETL)**

Notes: Studies are a summary for DOE/NETL, EPRI, and IEA Reports (pulverized coal with no carbon capture and storage)

Efficiency is plant design, location, and site specific

Factors include: temperature, pressure, cycle configuration, plant size, cooling water temperature, auxiliary loads, environmental requirements

- **<600°C (SC)**
- **600-650°C (USC)**
- **700-760°C (A-USC)**
Materials Limit the Current Technology

Today’s State-of-the-Art (USC) Coal-Fired Power Plants are defined by steel technology.

- Steels = USC
  - Solid Soln’ = A-USC
    - Age Hardenable = A-USC
      - 760°C (1400°F)

- 9-12Cr Creep-Strength Enhanced Ferritic Steels
  (Gr. 91, 92)

- Advanced Austenitic Alloys (Super 304H, 347HFG, NF709, etc.)

Minimum Desired Strength at Application Temperature
ComTest Project Status

- ComTest is a $27M DOE-funded project
- Phase 1, which began in November 2015, served to identify the technology gaps, as well as the scope and cost of required testing
- Phase 2, which was awarded in December 2018, will perform an advanced manufacturing effort to complete US-based supply chain development for full commercial scale (800-850 MWe) A-USC components made of nickel-based alloys, components operating at up to 760°C.

Close gaps to achieve readiness for commercial scale demonstration
# AUSC Commercialization Roadmap

## Technology Readiness Levels

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<td>concept TRL 4</td>
<td>Test TRL 4-5</td>
<td>TRL 4-7</td>
<td>TRL 8-9</td>
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## Recently completed DOE-sponsored projects achieved TRL = 4/5
AUSC ComTest will achieve TRL = 7 (ready for full scale demo)
ComTest Phase I - Key Accomplishments

- Evaluated multiple potential host sites for test facility
- Identified viable host sites (Ohio and Alabama)
- Completed Pre-FEED and FEED tasks
- Optimized project scope – Closed budget gap
- Prepared preliminary capital cost estimates
- Worked with suppliers to develop supply chain
- Determined that operational testing of the steam turbine and the A-USC superheater were not required
- Revised scope of Phase II to focus on full-scale component manufacturing capability readiness
- Completed Detailed Engineering effort for revised Phase II scope
ComTest Phase II will achieve...

- Closing of the remaining gaps and reducing the risks for manufacturing components from advanced materials for commercial demonstration
- Fabrication of full-scale versions of selected key components made of nickel-based alloys
- Validation of a qualified supply chain, to provide greater cost certainty for components
- Obtaining American Society of Mechanical Engineers (ASME) code approval for new materials, components and processes

Additional benefit:

- Manufacturing technology will be applicable to other advanced fossil energy high temperature cycles

Designed to close the remaining gaps to implement A-USC technology
ComTest Phase II Participant Map
ComTest Phase II Work Plan

- Fabrication of components identified as being outside of the proven capabilities of the existing supply chain, including:
  - Steam turbine rotor forging and Haynes 282 nozzle carrier casting
  - Superheater and reheater header and tube assemblies
  - Large diameter pipe extrusions and forgings
  - Test valve articles to support ASME Code approval
- Key fabrication steps will also be done including boiler weld overlays and simulated field repairs
- Extensive inspection and quality assurance testing of the components
- ASME Code approval for key components

Significant fabrication work will be done with lessons learned provided
ComTest Phase II - Statement of Project Objectives

Task 1 – Project management and planning
Task 7 – Procure the AUSC materials that will be fabricated into AUSC components and sub-assemblies in Tasks 8 through 10.
Task 8 – Fabricate AUSC boiler and superheater components and sub-assemblies.
Task 9 – Fabricate a cast nickel-based steam turbine nozzle carrier casing (Haynes 282).
Task 10 – Fabricate forged nickel-based components for an AUSC steam turbine (Haynes 282) and for an AUSC main and reheat steam piping system Inconel 740).
Task 11 – Conduct testing and obtain ASME Code Stamp approval for nickel-based pressure relief valve designs that would be used in AUSC power plants up to approximately 800 MWe size.
Task 12 – Develop a testing matrix for more extensive mechanical testing and metallurgical examination of the fabricated components fabricated in Tasks 8, 9, and 10.
ComTest Schedule

- **Phase I**
  - Pre-FEED
  - NEPA
  - FEED
  - Detailed Engineering

- **Phase II**
  - Negotiations, Sub-awards & POs
  - Turbine Rotor Forging
  - Nozzle Carrier Casting
  - Valve Testing / NB Qualification
  - Superheater Component Fab.
  - Pipe Forgings and tube trials
  - Metallurgical Testing Plan
  - Evaluation & Reporting

Based upon January 7, 2019
Project Management Plan
## ComTest Phase II - Work Scope - Key Areas

<table>
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<tr>
<th>Item</th>
<th>Scope of Work</th>
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<tr>
<td>Boiler / Superheater</td>
<td>Build 800-MWe sized nickel-based alloy parts of superheater and steam piping system – steam headers, boiler tube assemblies, tube membrane panels and weld overlays, large diameter, thick-wall pipe and fittings (up to 25 inch OD x 4 inch thick wall). Field erection and repair simulation.</td>
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<tr>
<td>Nickel-based Alloy Valves</td>
<td>National Board qualification of a scale spring-loaded and power actuated pressure relief valve (PRV/PARV) design for conditions up to 760°C / 345 bar</td>
</tr>
<tr>
<td>ASME Code Cases</td>
<td>Alternate pressure-relief method, flanged fittings, shielded metal-arc welding</td>
</tr>
<tr>
<td>Steam Turbine</td>
<td>Fabricate commercial-scale nozzle carrier casing (10 tons) and rotor disk forging (20 tons) – both from Haynes 282</td>
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Advanced Materials in ComTest Phase II

- Grade 91/92 – membrane panels
- Haynes 282 – tubes, castings, forgings
- HR6W – tubes, pipe/header
- Inconel 617 – safe ends on HR6W tubing
- Inconel 740H – tubes, pipes, forgings
- Sanicro 25 – tubes
- SAVE12AD – pipe/header
- TP347H and Super 304H – lower temperature zones

Applicable to multiple high-temperature advanced generation options
**Boiler and Steam Piping Scope for Phase I**

- Fabricate A-USC boiler and superheater components and sub-assemblies, membrane panels, SH/RH tubes, headers, pipes
- Bend thick wall large diameter Inconel 740 pipe
- Fabricate forged Inconel 740 wye fitting
- Field erection and repair simulation
  - Waterwall panel butt welds and longitudinal seam welds
  - Inconel 740H thick wall piping – circumferential welds of fittings and plugs
  - Grade 92 tube membrane panel repair – simulated “Dutchman” repair
  - Evaluation of strength of post-weld-heat-treatment (PWHT) vs non-PWHT welds in 740H
  - Determine ability to weld repair and to use innovative repair options such as weld overlays
Steam Turbine Assembly - Nozzle Carrier
A-USC Steam Turbine Nozzle Carrier Casting
(10 tons Haynes 282)
Note: Trial casting is half of lower section
Steam Turbine Rotor Forging in Phase II

- Rotor Forging (Haynes alloy 282)
  - Previous work with 24” diameter triple melt ingot to make 5,000 lb. pancake to simulate disk for bolted rotor turbine design
  - GE’s new welded rotor design uses a much larger shaft forging
    - Requires 36” diameter, 30,000 lb. triple melt ingot (largest possible)
    - Concern for ingot segregation and cracking
    - Challenge to achieve fine grain in forging, sonic test capability in doubt

Alloy 282 pancake forged at Wyman-Gordon

Proposed Phase II rotor forging
ASME Code Case Development for Phase II

- Alternative overpressure protection method vs. spring activated PRV at the superheater outlet
- Expand ASME B16.34 to allow bolted flange design at high temperatures
- Revision of Code Case 2902 for Inconel 740H, to permit the use of shielded metal arc welding (SMAW) process
- Qualification of high temperature PRV design
- Parallel Code Case work (testing separately funded)
  - Code case for wrought H282
    - GE submitted the request to ASME with support by Haynes International
  - Mechanical properties data of Thermanit 263 weld filler wire
    - Add SMAW to ASME Code Case 2902
## Task Areas

### Fabrication of Boiler Components
- Ability to complete fabrication of superheater/reheater assembly, using accepted shop methods (machining, bending and welding)
- Verification that weld overlay may be applied to membrane panels

### Fabrication of Turbine Casting
- Ability to produce nozzle carrier casting that meets specified OEM requirements
- Verification that valid repair methods are available

### Fabrication of Forged Components
- Ability to produce steam turbine rotor forging that meets specified OEM requirements
- Verification that valid repair methods are available

### Pressure Relief Valve (PRV) Qualification
- Production of test valve component
- Completion of National Board qualification test
- Acceptance of valve qualification by ASME for high-temperature PRV valve designs
ComTest Phase II - Current Status and Progress

- ComTest Phase II was awarded by DOE on December 12, 2018
- Submitted Phase I Topical Report
- Completed updated Project Management Plan
- Received vendor input for Risk Management Plan
- Executed key subcontracts
  - Riley
  - GE / Alstom Power
  - EPRI
- Conducted Phase II kickoff meeting with DOE on March 4, 2019
- Planned quarterly meeting for April 10, 2019
  - Co-located with NETL Crosscutting Review meeting (Pittsburgh, PA)
Conclusions

- Identified Phase II project scope to close gaps, to achieve readiness for commercial scale demonstration of AUSC technology
- Focus on full-scale manufacturing technology and supply chain development for advanced materials yields crosscutting benefits:
  - Supercritical CO2 cycles
  - Concentrated solar
  - Nuclear
  - Enhanced flexible operation – even at lower temperatures
- Supports efficiency and flexibility improvements for new and existing generation units
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