ELECTRIC POWER
RESEARCH INSTITUTE

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

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ComTest Project Objectives

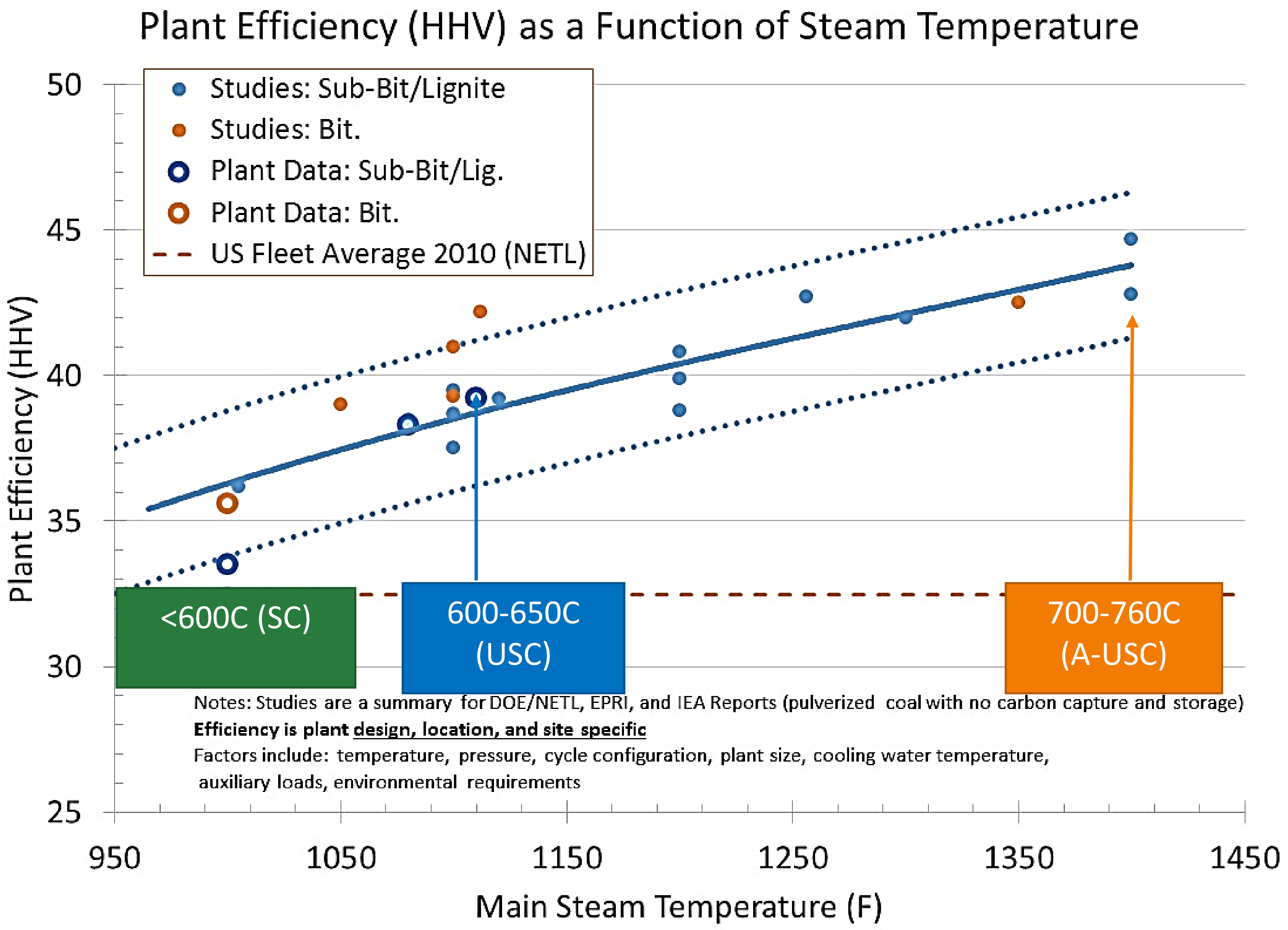
- **Higher efficiency** for new and existing fossil fuel plants
  - 10% above today's new state-of-the-art coal power plants, and
  - 25% above that of the average power plants in the U.S. existing fleet
- **Lower emissions** (NOx, SOx, CO_2)
- **Minimized risk** for utilities desiring to build A-USC 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.

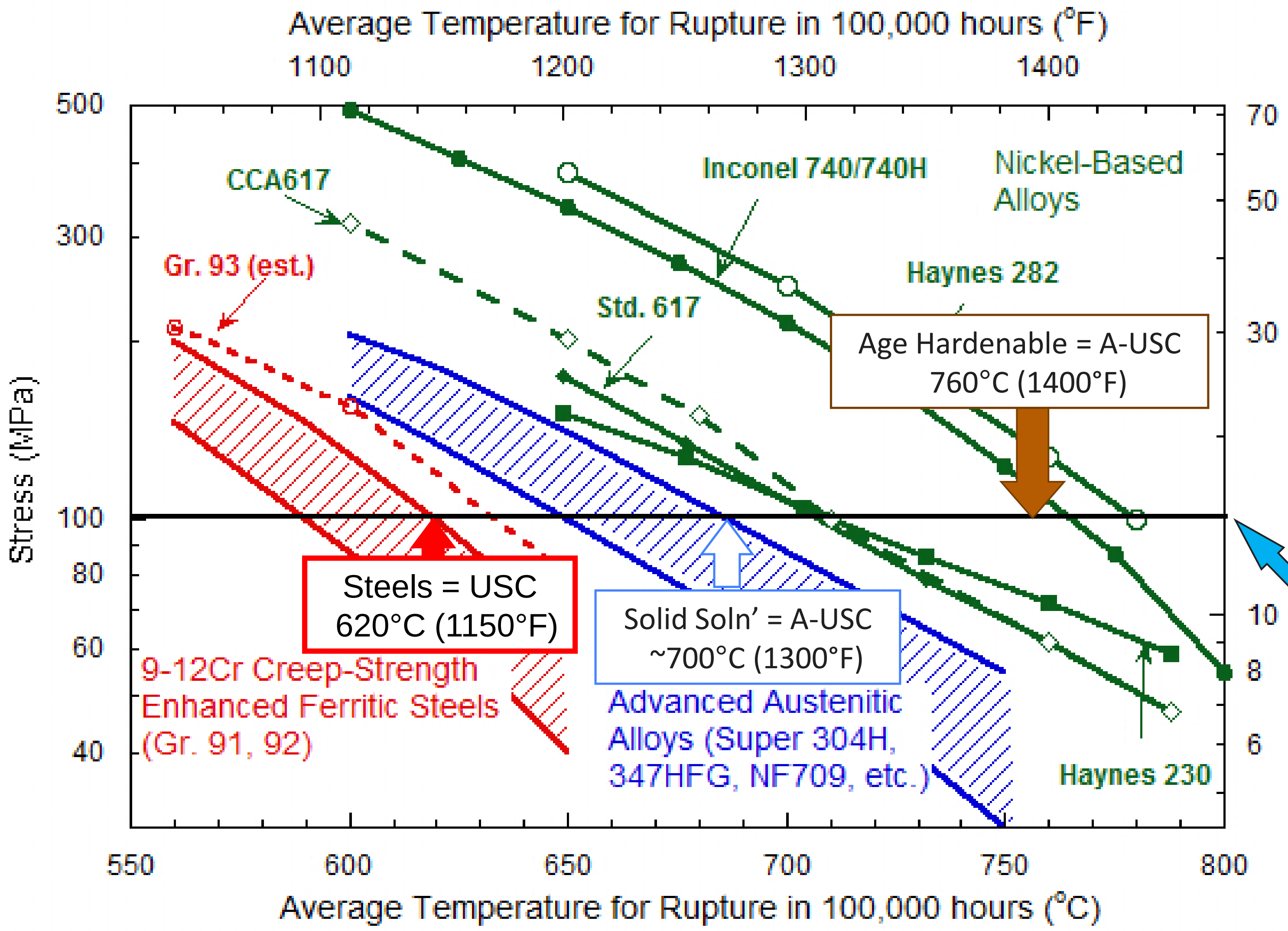
- Project aims to close gaps to achieve readiness for commercial scale demonstration of Advanced Ultra-Supercritical (AUSC) technology
- Completion scheduled for September 2021
- Supports increase in power plant steam temperatures for higher cycle efficiency
  - Average efficiency of US coal-fired fleet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

Increasing Steam Conditions to Dramatically Improve Efficiency



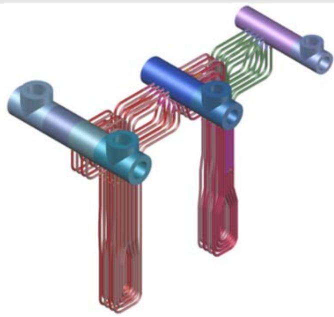
Materials Limit the Current Technology

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



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			Roadmap to AUSC Demo	
2000	2005	2010	2015	2020 / 2025
Materials Evaluation (Nickel Superalloy Focus)	Component Mockup	Steam Loop at Plant Barry. Large forgings & castings	AUSC Component Test (ComTest)	AUSC Demonstration
Laboratory TRL 2-3	Proof of concept TRL 4	Component Test TRL 4-5	System TRL 4-7	Overall TRL 8-9

Components	TRL
Tube Membrane Panel	4
Superheater	5
Turbine	4
Desuperheater	4
Header	4
Valves	4

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

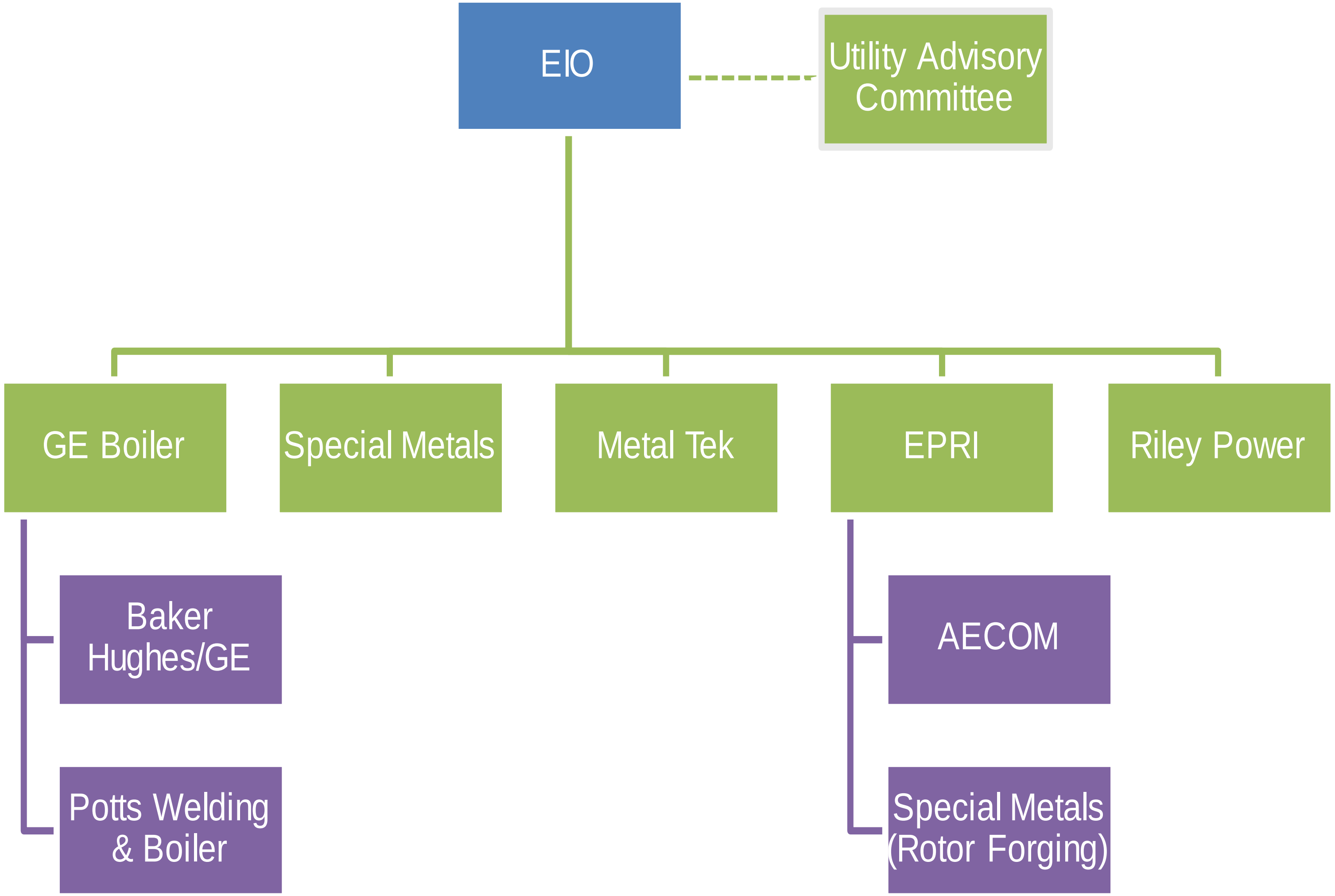
Additional benefit:

- 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 – Project Organization Chart



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).

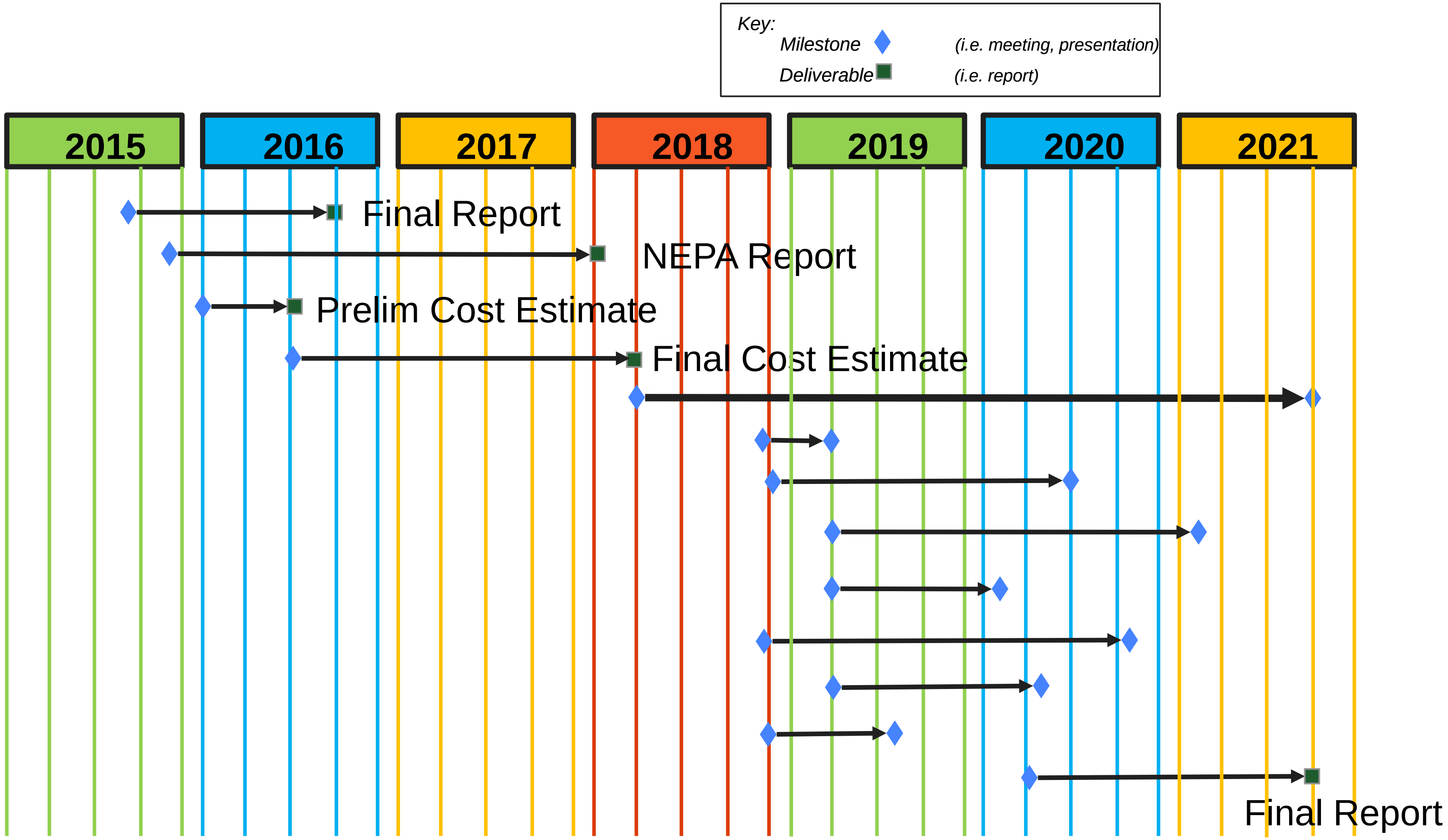
Task 10 – Fabricate forged nickel-based components for an AUSC steam turbine (Haynes 282) and for an AUSC main and reheat steam piping system Inconel 740).

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

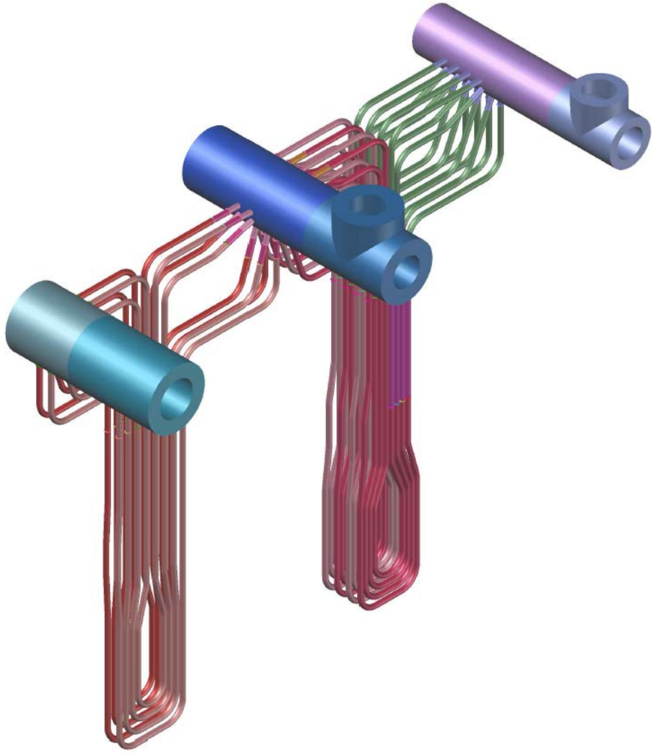
Item	Scope of Work
Boiler / Superheater	Build 800-MWe sized nickel-based alloy parts of superheater and steam piping system – steam headers, boiler tube assemblies, tube membrane panels and weld overlays, large diameter, thick-wall pipe and fittings (up to 25 inch OD x 4 inch thick wall). Field erection and repair simulation.
Nickel-based Alloy Valves	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
ASME Code Cases	Alternate pressure-relief method, flanged fittings, shielded metal-arc welding
Steam Turbine	Fabricate commercial-scale nozzle carrier casing (10 tons) and rotor disk forging (20 tons) – both from Haynes 282

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

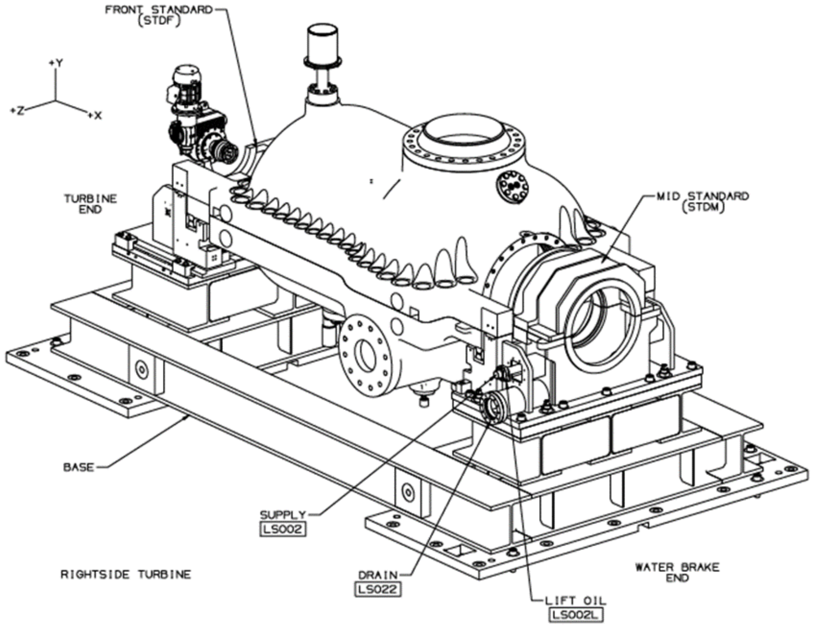
Applicable to multiple high-temperature advanced generation options

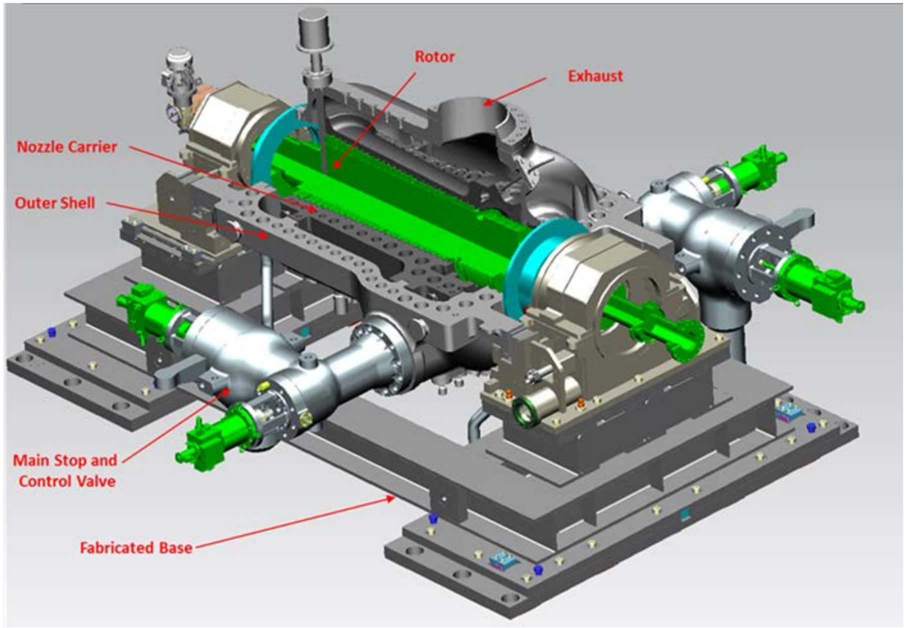
Boiler and Steam Piping Scope for Phase I

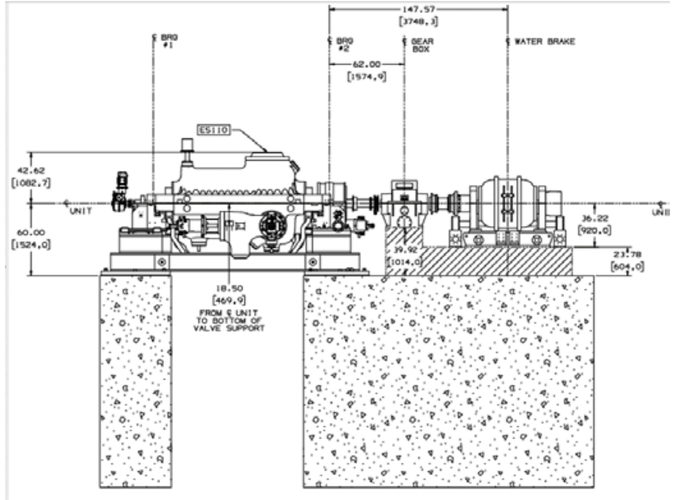


- Fabricate A-USC boiler and superheater components and sub-assemblies, membrane panels, SH/RH tubes, headers, pipes
- Bend thick wall large diameter Inconel 740 pipe
- Fabricate forged Inconel 740 wye fitting
- Field erection and repair simulation
  - Waterwall panel butt welds and longitudinal seam 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

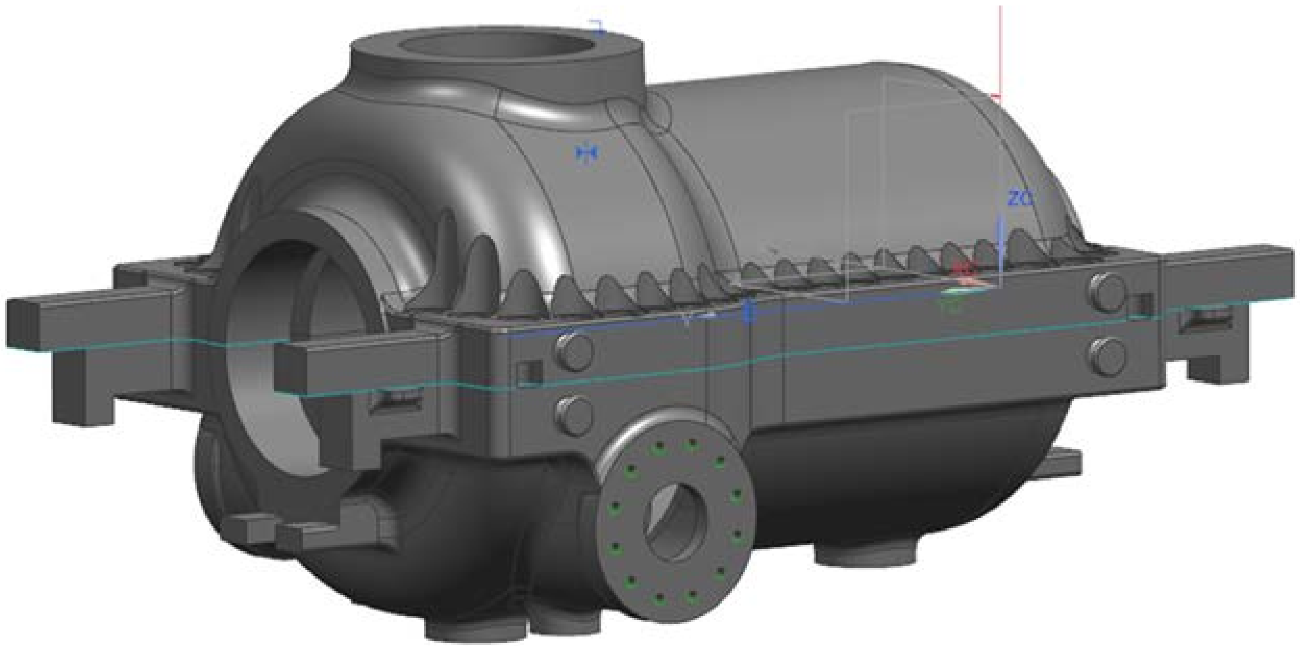


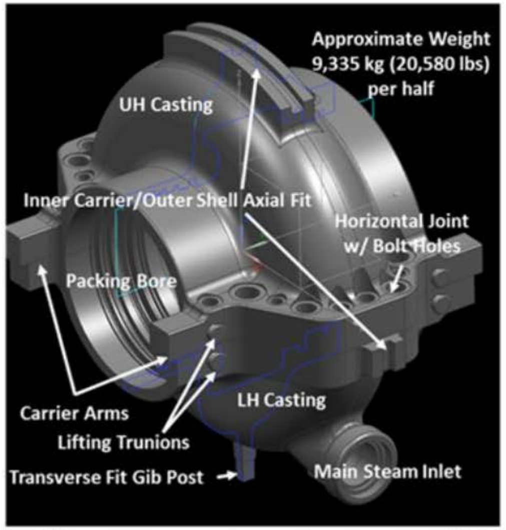


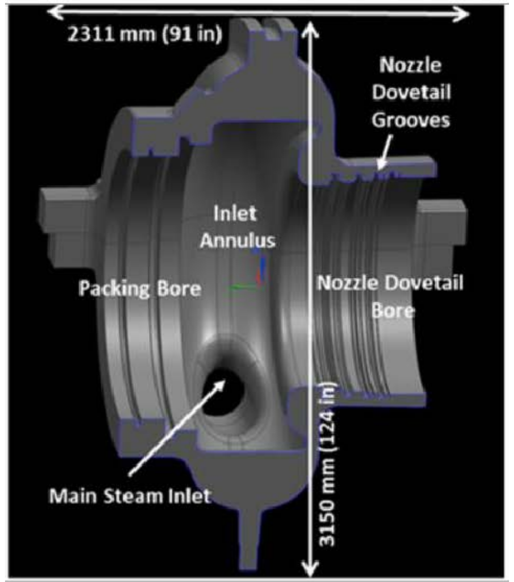


STEAM TURBINE ELEVATION VIEW

A-USC Steam Turbine Nozzle Carrier Casting (10 tons Haynes 282)
Note: Trial casting is half of lower section



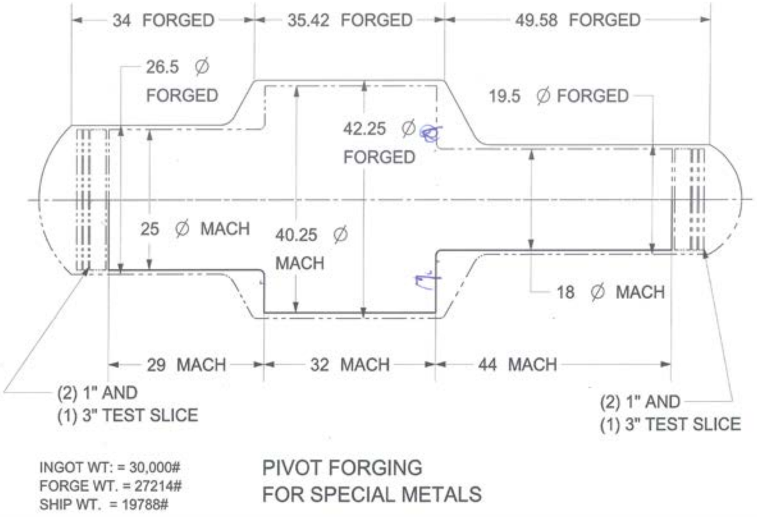




Steam Turbine Rotor Forging in Phase II

- 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 submited 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

ComTest Phase II – Expected Key Outcomes

Task Areas	Key Outcomes
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

ComTest Support Acknowledgement

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Together…Shaping the Future of Electricity