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Steam Turbine Materials for Advanced Ultrasupercritical (AUSC) Coal Power Plants

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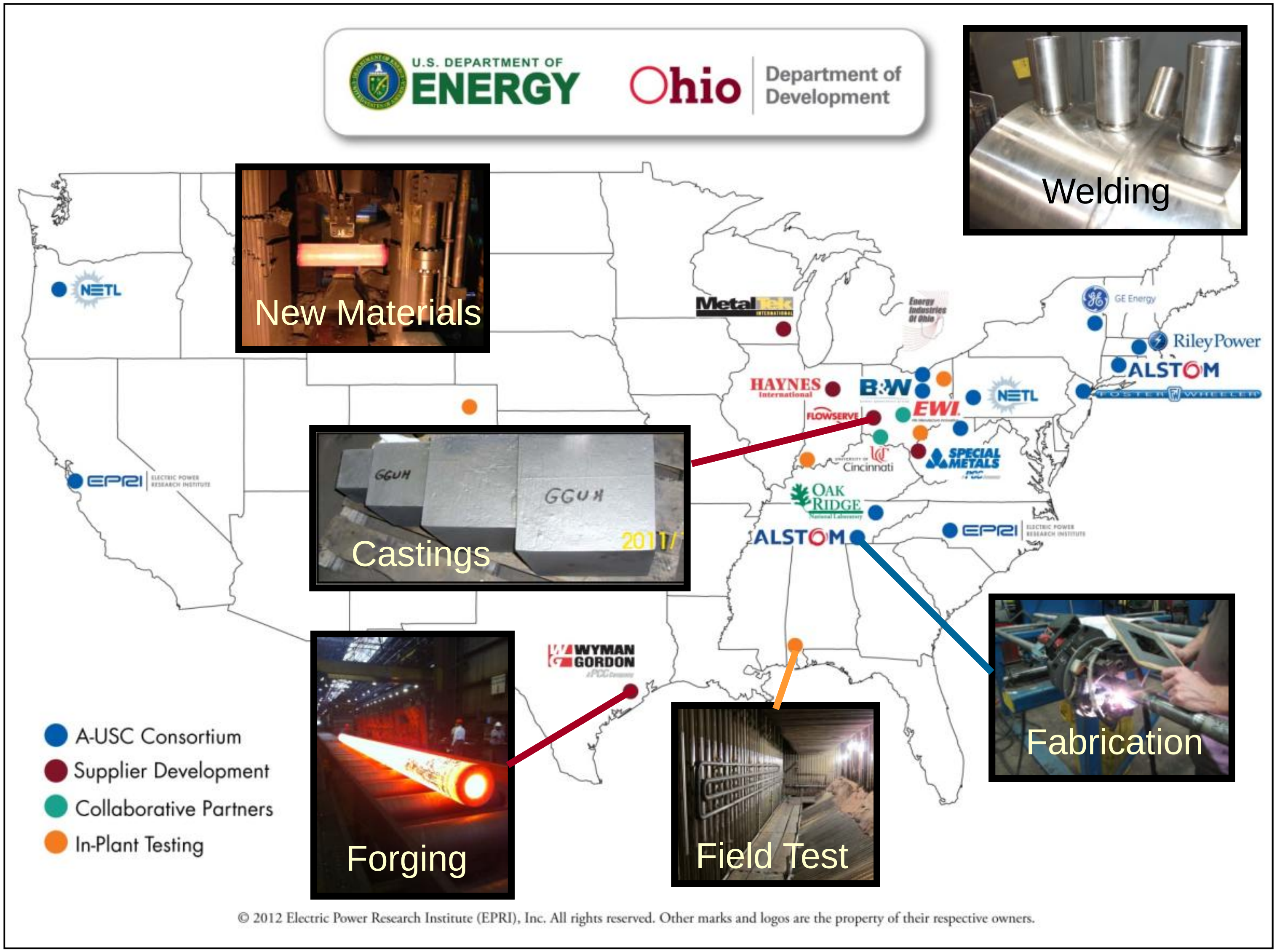
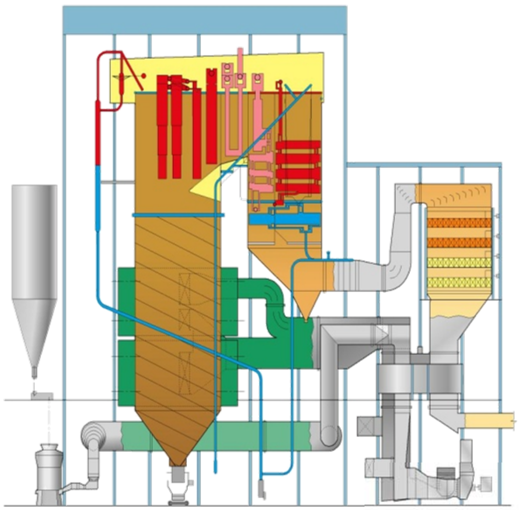
Federal – State – National Laboratory
Non Profit – For Profit
Cost Sharing Consortium



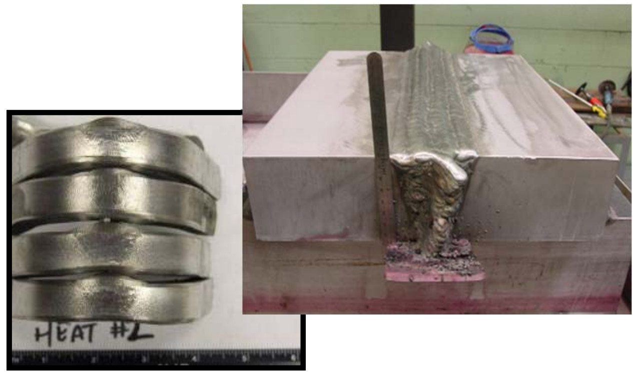
Accomplishments
A-USC Fact Book - EPRI 1022770

(download free at: www.epri.com)

General design studies show favorable economics



Welding Technology Developments



Fabrication Processes

Steam-Side Oxidation

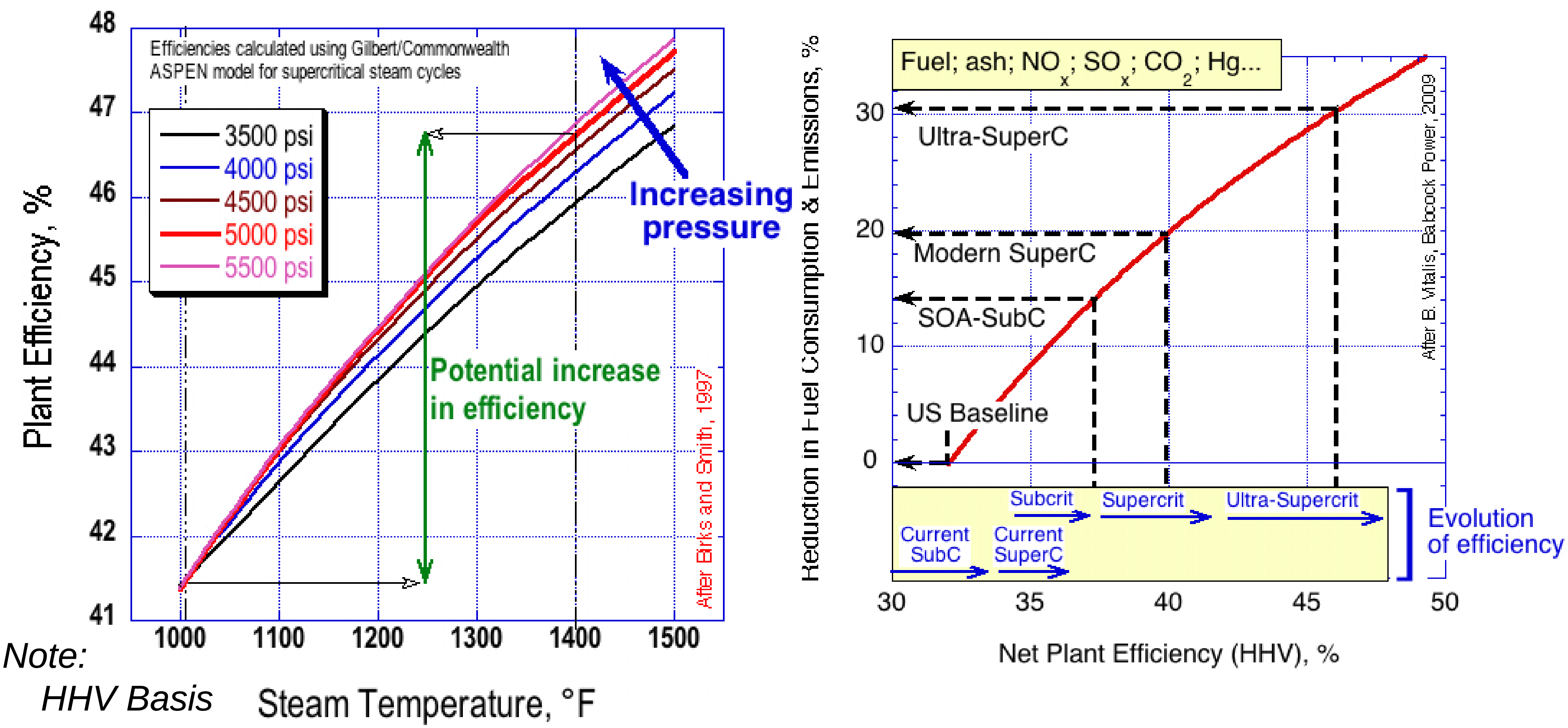
Fireside Corrosion (High-Sulfur Coal & In-Plant Testing)

Turbine Component Scale-up

Outline

- A-USC Steam Turbine (This Talk)
  - General motivation for A-USC
  - Results from Phase I study
  - Current project approach and results (Phase II)
  - Next Steps
- A-USC Boiler (Next Talk)
  - Project Approach
  - Successes and Recent Activities
  - A-USC Economics and Future Applications

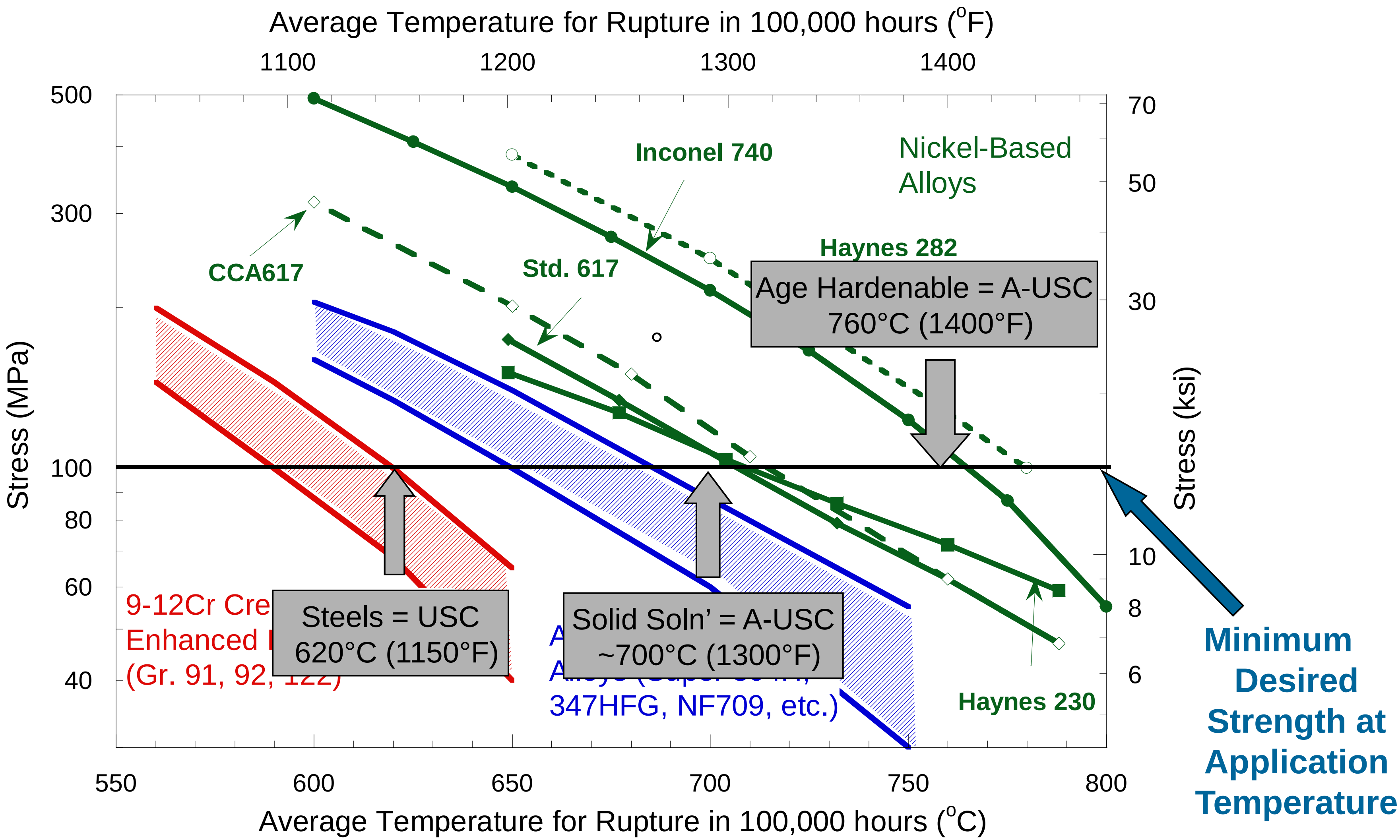
Increasing Steam Temperature and Pressure Increases Thermal Efficiency and Decreases Emissions



Note: HHV Basis

"Least Regret" Strategy for CO_2 Reduction

Materials Limit the Current Technology



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Primary Technical Goals of US A-USC Materials Programs

- Materials Technology Evaluation
  - Focus on **nickel-based alloys**
  - Development of fabrication and joining technology for new alloys
- Unique Conditions for US Program Considerations
  - Higher-temperatures than Other International Programs (760°C versus 700°C) means **additional alloys** are being evaluated
  - For Boiler:
    - Corrosion resistance for **US coals**
    - Data for **ASME code** acceptance of new materials
    - Phase II Boiler work includes **Oxycombustion**

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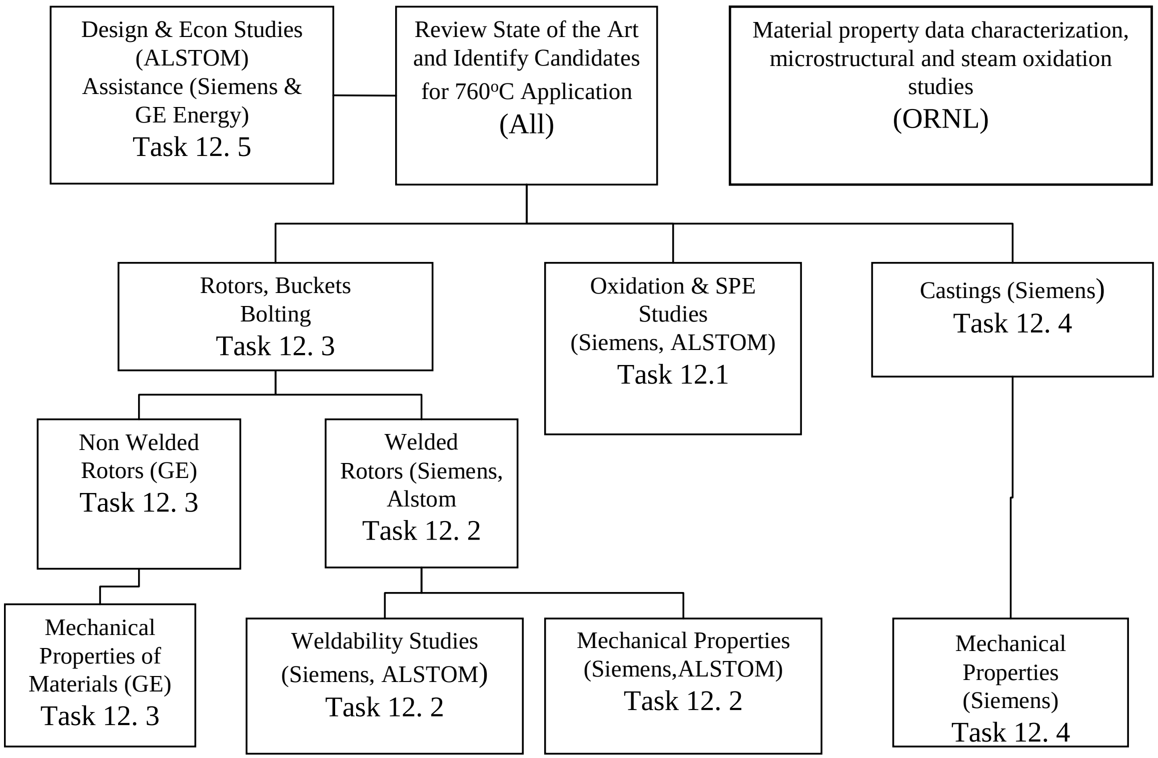
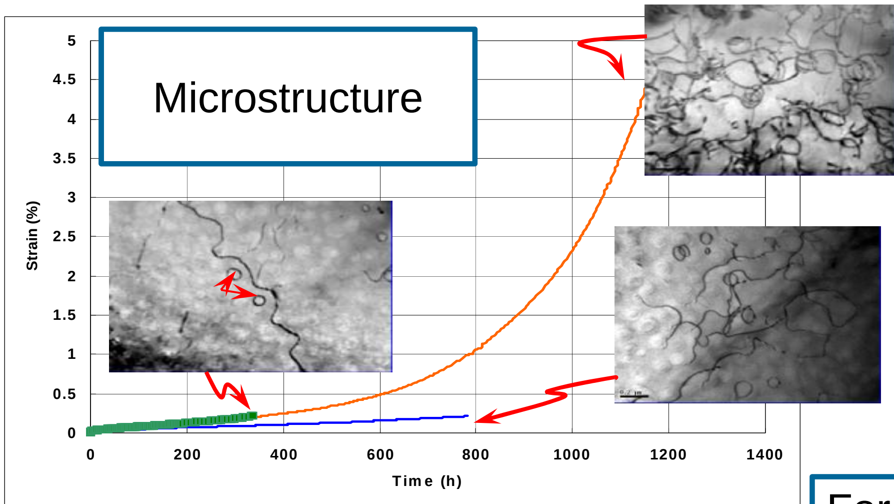
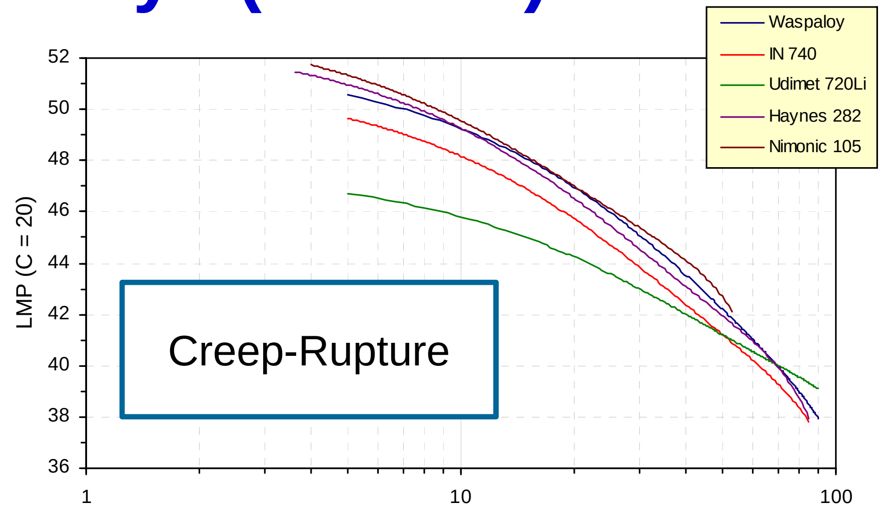
A-USC Steam Turbine Program: Phase I (complete: 2005-2009)

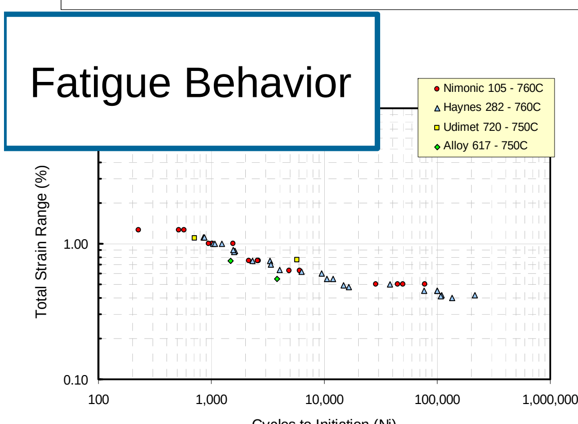


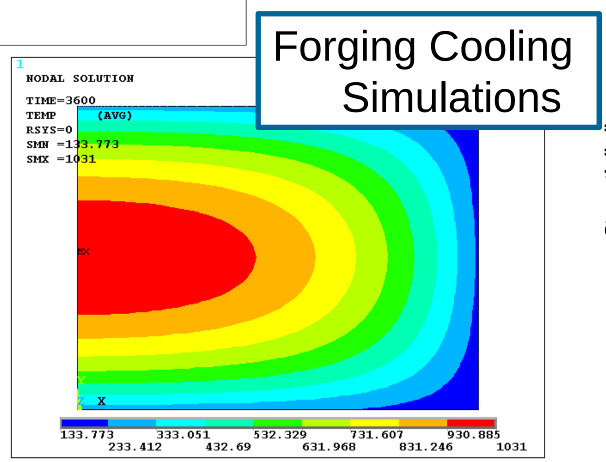
- Scoping Studies – Downselect Materials
- Key Issues
  - Welded rotors materials
  - Non-welded rotor materials
  - Air Casting
  - Erosion resistance
  - Oxidation resistance

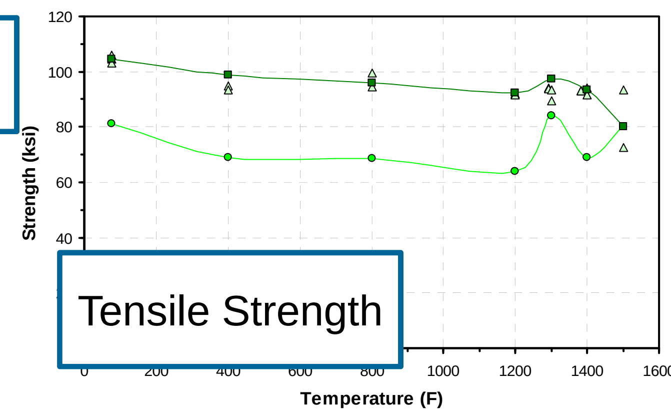
Initial Material Selection for A-USC Turbine: Behavior of HP/IP Rotor Alloys (Phase I)











Best Candidates: Nimonic 105, Haynes 282, Waspalloy

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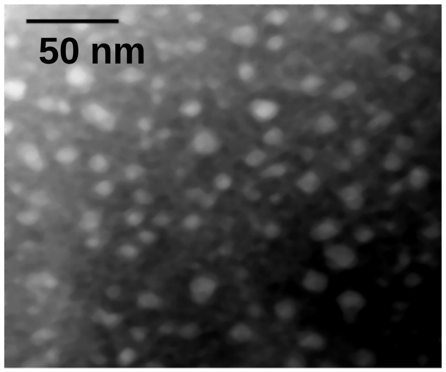
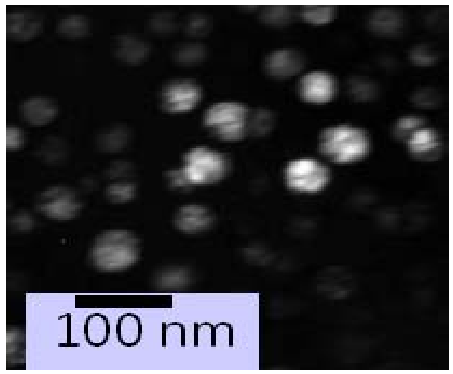
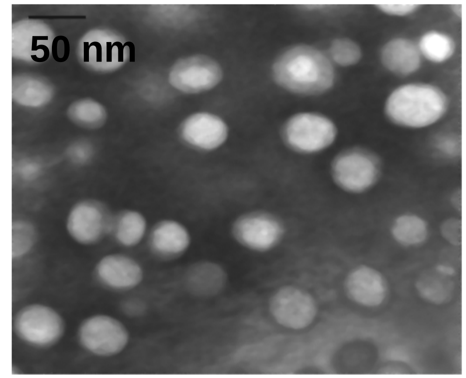
Successes: Large Forgings Research Requires an Understanding of Microstructure & Properties as a Function of Heat-Treatment



Solution Annealed



PA = SA + 8h @ 790°C



OV = PA + 250h @ 775°C

Studies on Haynes 282:

•Creep-rupture strength was relatively insensitive to heat-treatment

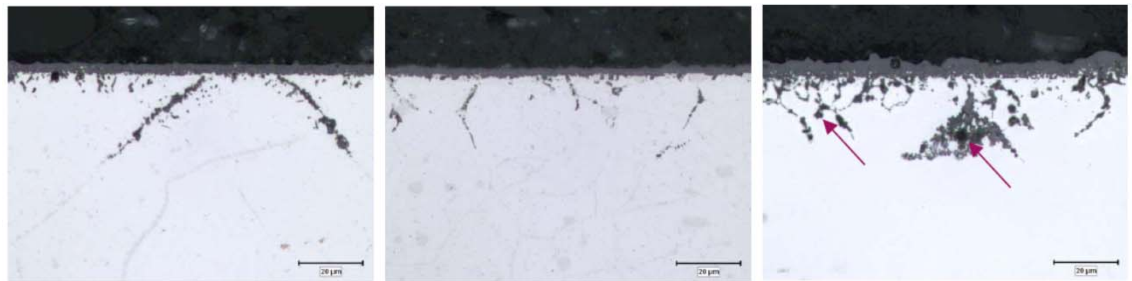
•Detailed microstructural studies on gamma prime precipitates after heat-treatment and creep were conducted

•Both mechanical property data and microstructure studies suggest the alloy has a large processing window making it attractive for steam turbine forgings

Source: R. Viswanathan, J. Shingledecker, J. Hawk, S. Goodstine. "Effect of Creep in Advanced Materials for Use in Ultrasupercritical Power Plants." *Proceedings: Creep & Fracture in High Temperature Components, 2nd ECCC Creep Conference, April 21-23, 2009, Zurich, Switzerland."* © 2009 DEStech Publications, Inc. 31-43

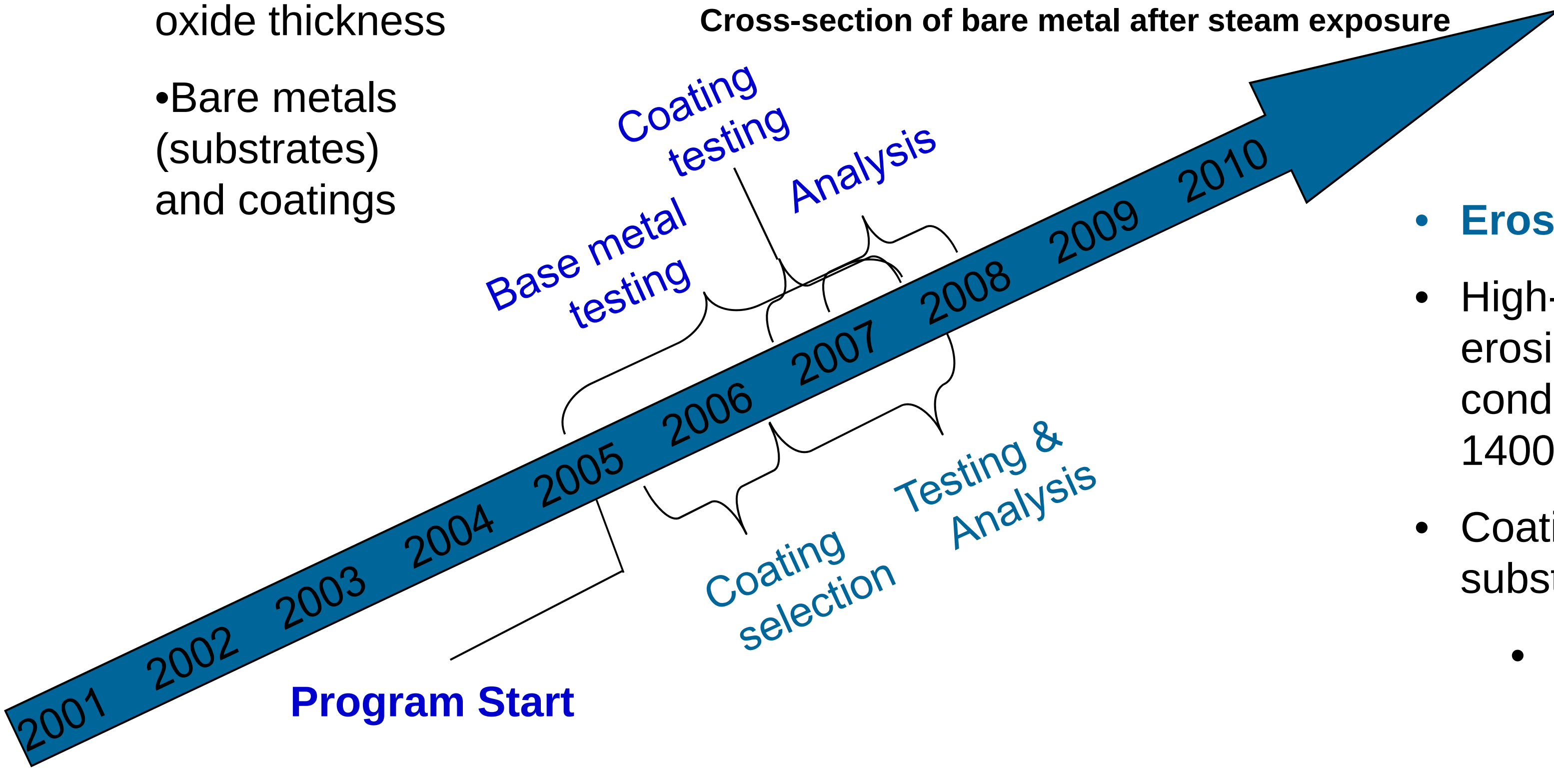
Erosion and Oxidation of Blade Materials and Coatings

- **Oxidation studies**
  - •Oxidation rates/kinetics
  - •Scale morphology
  - •Internal penetration vs. oxide thickness
  - •Bare metals (substrates) and coatings



CCA 617 | Haynes 230 | Haynes 282

Cross-section of bare metal after steam exposure



- **Erosion Testing**
- High-temperature erosion tests were conducted at 1400°F (760°C)
- Coating and substrates
  - 12 Coatings evaluated

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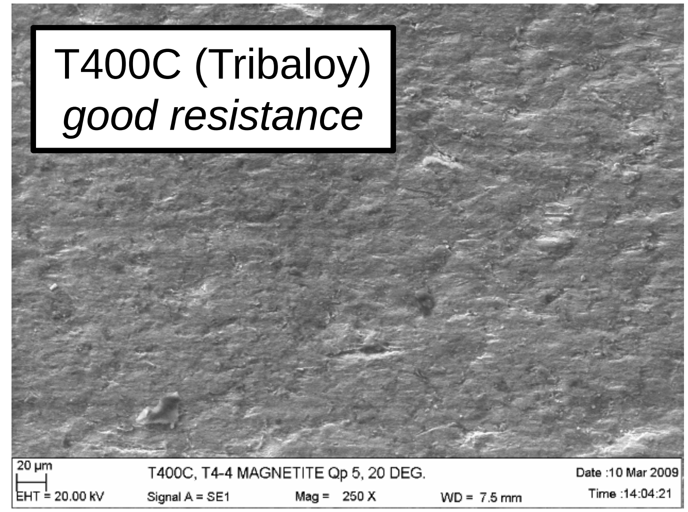
Coating Conclusions

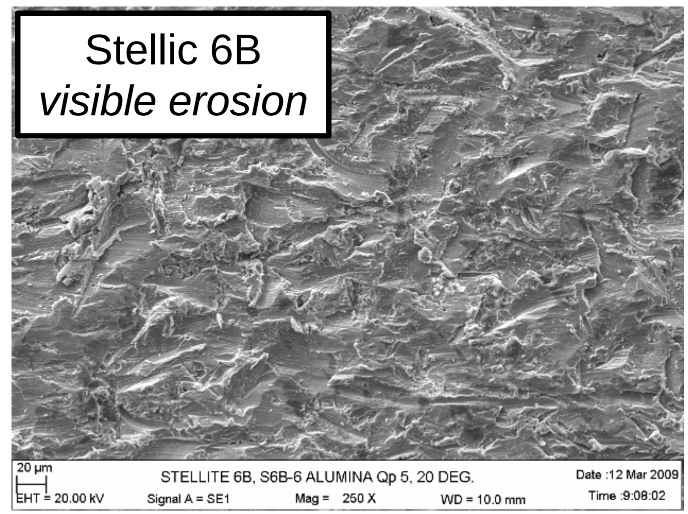
760°C Erosion Test Results for Coatings

Coating	Composition	Erosion Rate (info)
#1 Moly-Boride-Cobalt Chromium	Co-30 CrMo alloy–45 MoB–Balance (B total -8.2)	0 cc/gram erodent (0.008 g deposition noted)
#2 Zircoat	Dense segmented 8YSZ	1.70E-04 cc/gram erodent
#3 T400C (Tribaloy)	Cr-8.5, Mo-26, Si-2.6, Co Balance	2.35E-04 cc/gram erodent
#4 Conformaclad	WC based	2.65E-04 cc/gram erodent

- Oxidation rates (both internal penetration and mass gain) of candidate bare metal substrates were acceptable based on laboratory studies
  - Oxidation testing *showed unacceptable rates for some coatings* including top performing erosion resistant coatings

T400C (Tribaloy) was only coating to perform well in oxidation and erosion at 760°C





Surface morphology of coatings after 760°C erosion tests with magnetite

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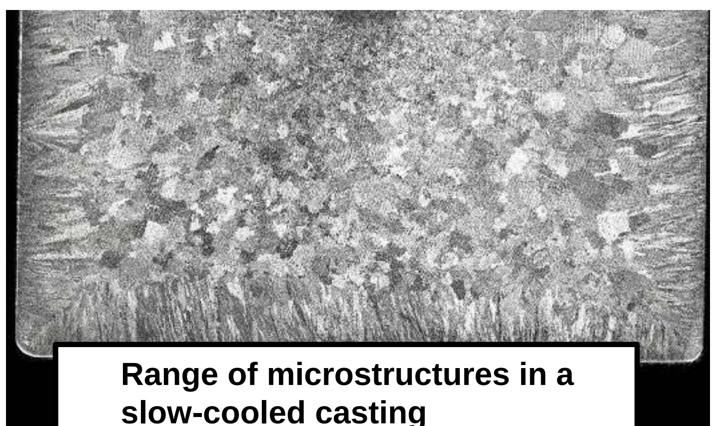
Phase I casting work helped guide the program

- A casting sub-team of OEM and National Laboratories (ORNL & NETL) was formed to address potential issues with nickel-based casing/shells
  - Seven trial alloys were cast
  - An innovative homogenization heat-treatment cycle was developed
  - Mechanical property testing identified the best performing alloys
  - Some alloys were eliminated due to lower strength or ductility compared to the wrought alloy counterpart
- Haynes 282, 263, and N105 were judged the best alloys for casting and castability trials were performed



Range of microstructures in a slow-cooled casting

Alloy 263 casting – fluidity trial

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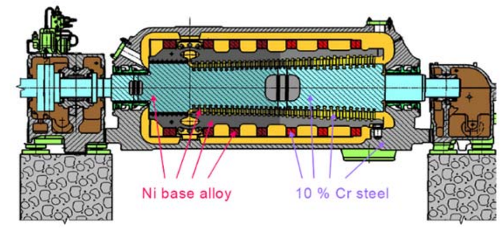
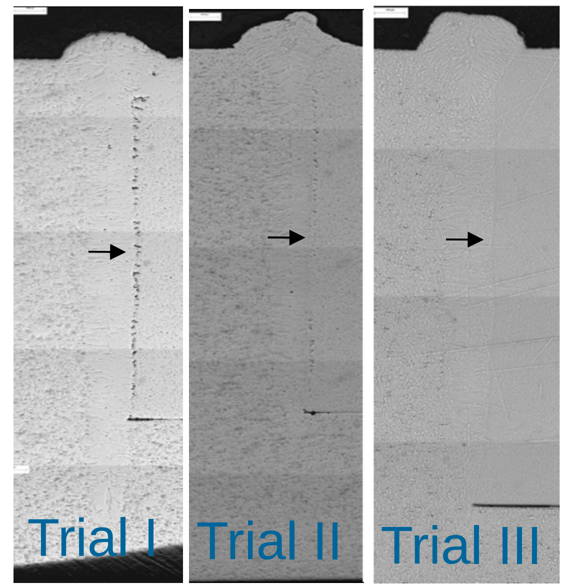
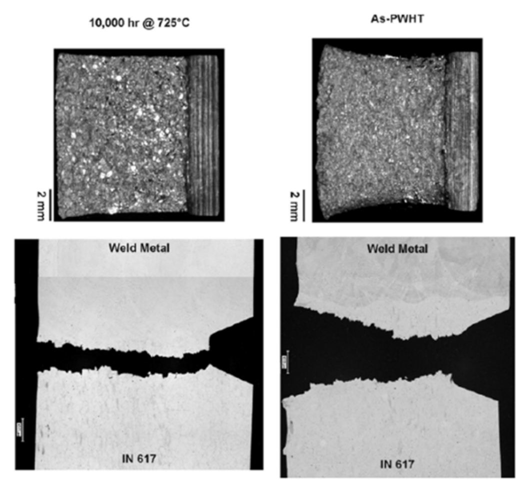
Phase I Welded Rotor Trials



- Successfully produced a thick-section 263-617-Ferritic Steel joint concept using traditional welding techniques.
  - Joint toughness was acceptable after aging (simulated service exposure)
- A second welded rotor configuration was evaluated for Haynes 282 to Udimet 720Li.
  - Welding development was successful and heat-treatment studies showed no evidence of strain age cracking after welding
  - Non destructive evaluation capability of joint was verified





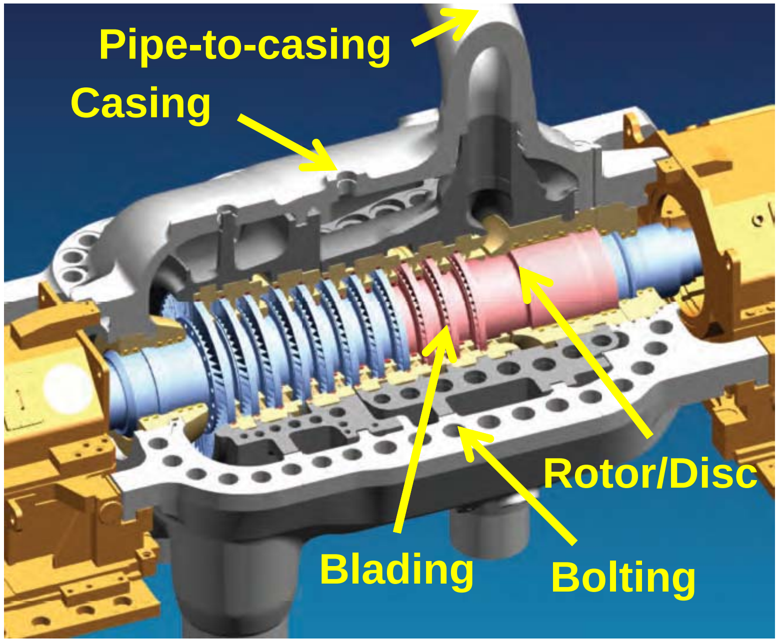
DOE/OCDO A-USC Steam Turbine Consortium Phase II

- Selected Materials from Phase I
- Rotor/Disc Testing (full-size forgings, environmental interaction)
- Blade Alloy Testing (and erosion resistant coatings)
- Cast Casing Scale-Up Alloy Testing
- Casing Welding and Repair

U.S. DEPARTMENT OF ENERGY | Ohio Coal Development Office

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

1400°F (760°C) Steam Turbine Conceptual Design (HP) – *Bolted Construction*



GE Energy

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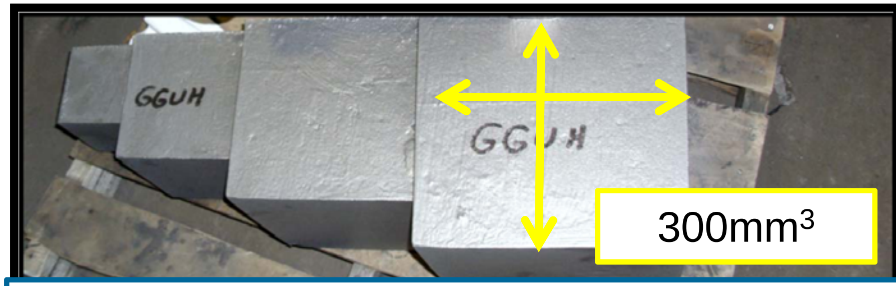
Casting scale-up and turbine casing welding is progressing

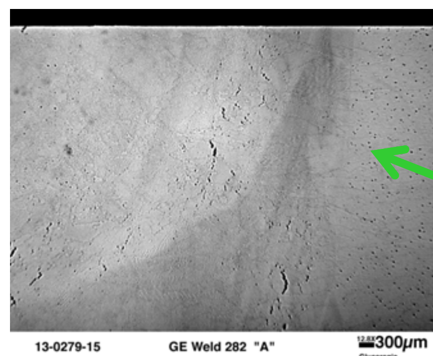


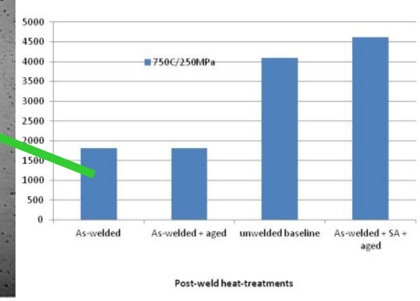
Haynes 282 and **Alloy 263** Step Castings
135-450kg sizes (300 to 1,000 lbs)

Haynes 282 centrifugal casting: 635kg (1,400lbs)

Long-term creep of weldments & microstructural assessment

Simulated casting weld defect repair



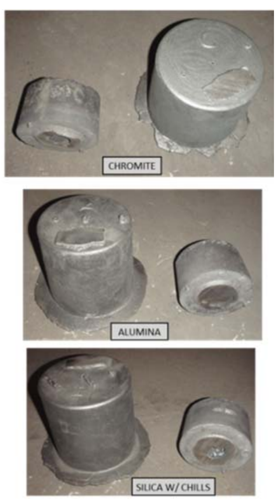


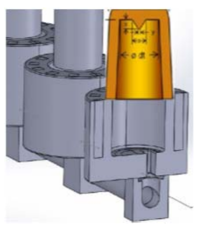
740H Pipe to 282 Casting Weld

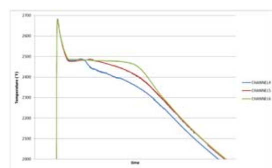
Properties: tensile, creep, aging/toughness, fatigue, weldments

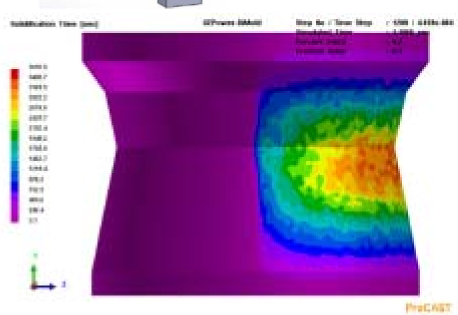
Casting Modeling and Next Steps

- Casting simulation are being utilized for nickel-based alloys
- Cooling rate and secondary dendrite arm spacing predictions are being validated for different cooling rates









Volume: 19,804 cub. Inches
Approx. Weight~ 5,942 Lbs.

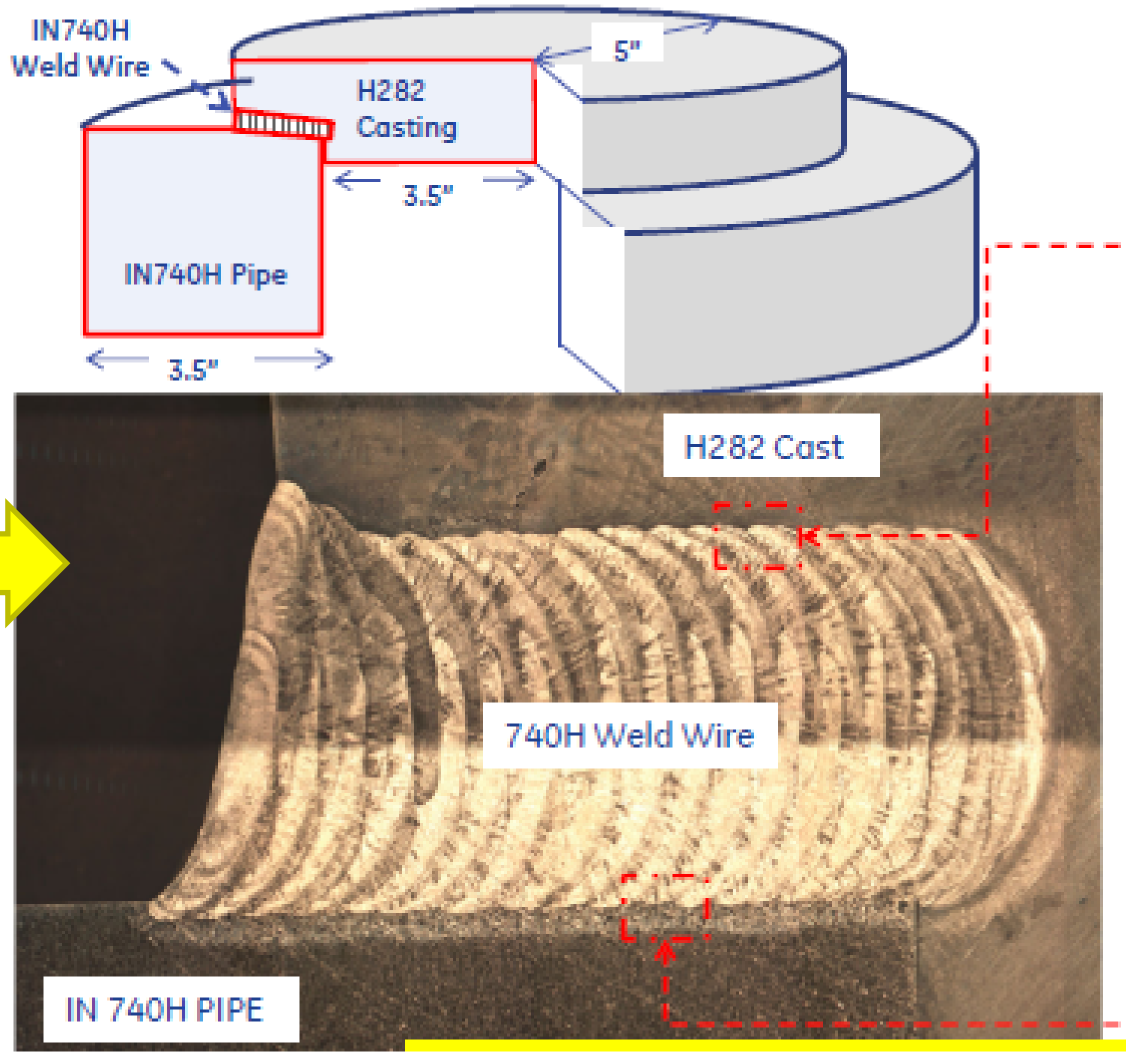
~2700kg (6,000lb) ½ Valve body

(simulate full-size valve)

Casting planned for mid 2014

Casing to Pipe Weld

- Boiler to turbine connection
- Leverage A-USC boiler knowledge from Inconel 740H welding
- Successful weld completed

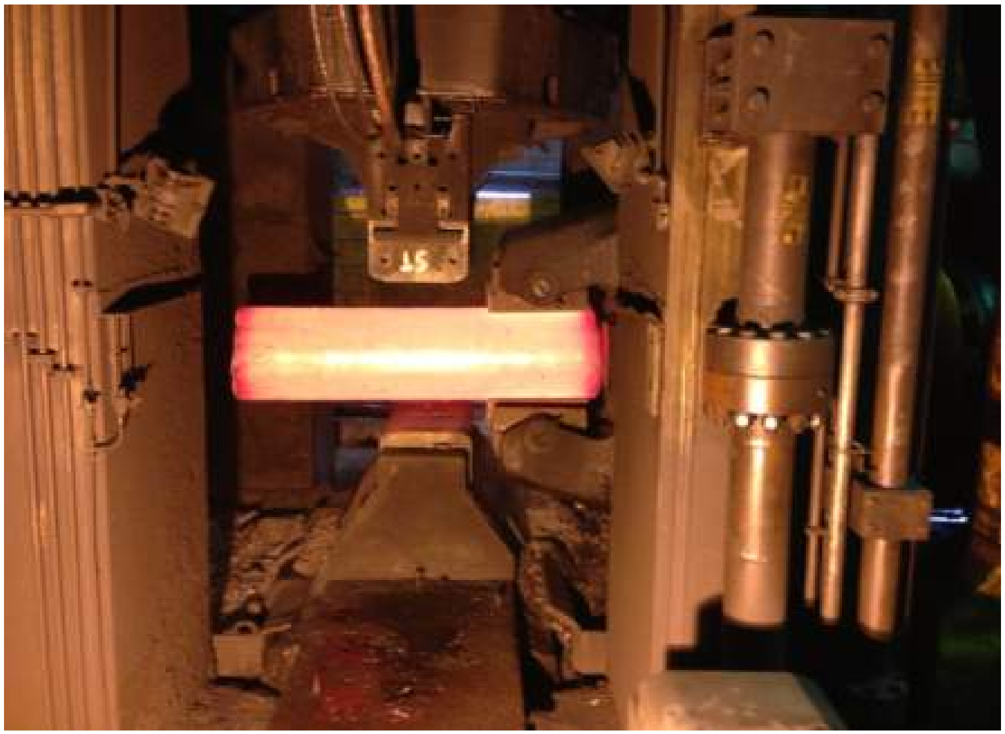


A-USC Turbine Highlight
Haynes 282 Rotor Scale-Up

Two ingots now produced:

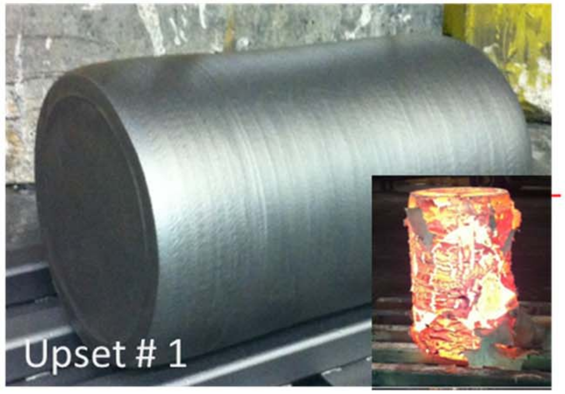
1. Chemical homogeneity / grain size / defects evaluation

2. Disc forging



World's First Haynes 282 Triple Melt Ingot

Haynes 282 (Triple Melt) has been successfully forged into a disc for detailed evaluations



Diameter (Top) = 44”
Diameter (Bulge) = 49.5”
Thickness = 9.5”

Disc meets criteria for largest
A-USC forging needed
(IP turbine)

Characterization Plan: Tensile, Creep, LCF, HCF, FCGR and Toughness + fatigue in steam (ORNL)

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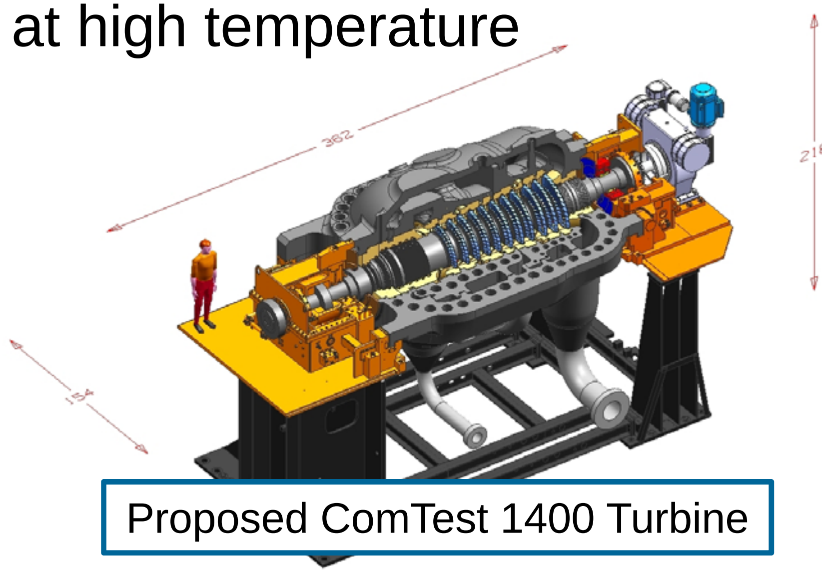
Next Steps: ComTest 1400

- Evaluation of advanced materials and components under coal fired, A-USC conditions.
- Minimize risk for a utility desiring to build an A-USC Plant.
  - Demonstrate turbine operation
  - Demonstrate reliability and safety
  - Understand manufacturing and cost
- Evaluation of the constraints in the supply chain
- Validation of fabrication techniques, and the ability to construct, install and repair ComTest with on-site labor.

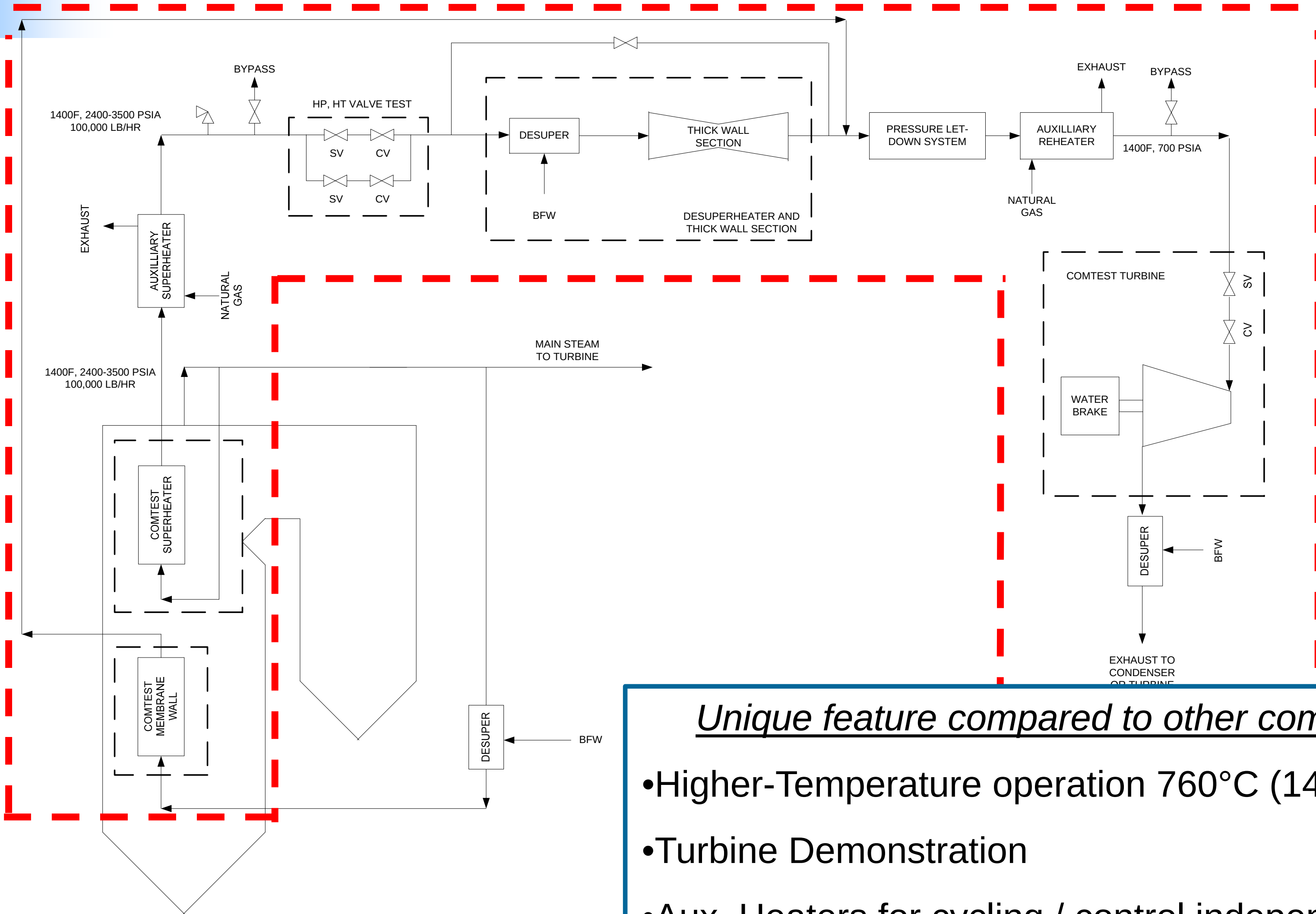
Specific Goals

- Boiler: Design, install, start-up, operate and **cycle** high temperature nickel components (740H & others)
    - Large diameter piping
    - Header and tubes (gas fired heater)
    - Superheater materials exposure (at pressure)
- Turbine: Design, install, start-up, operate and cycle **full size** Steam Valves & COMTEST steam turbine for 760°C (1400°F).
    - – Periodic testing of steam valves at high temperature
    - – Materials & coatings
    - – Turbine architecture
    - – Oxidation, deposits, SPE
    - – NDE/NDT
- Fabrication methods & supply chain for super-alloys



Proposed ComTest 1400 Turbine

ComTest 1400 Schematic



<u>Unique feature compared to other component tests:</u>

- Higher-Temperature operation 760°C (1400°F)
- Turbine Demonstration
- Aux. Heaters for cycling / control independent from boiler
- Innovative membrane wall concept

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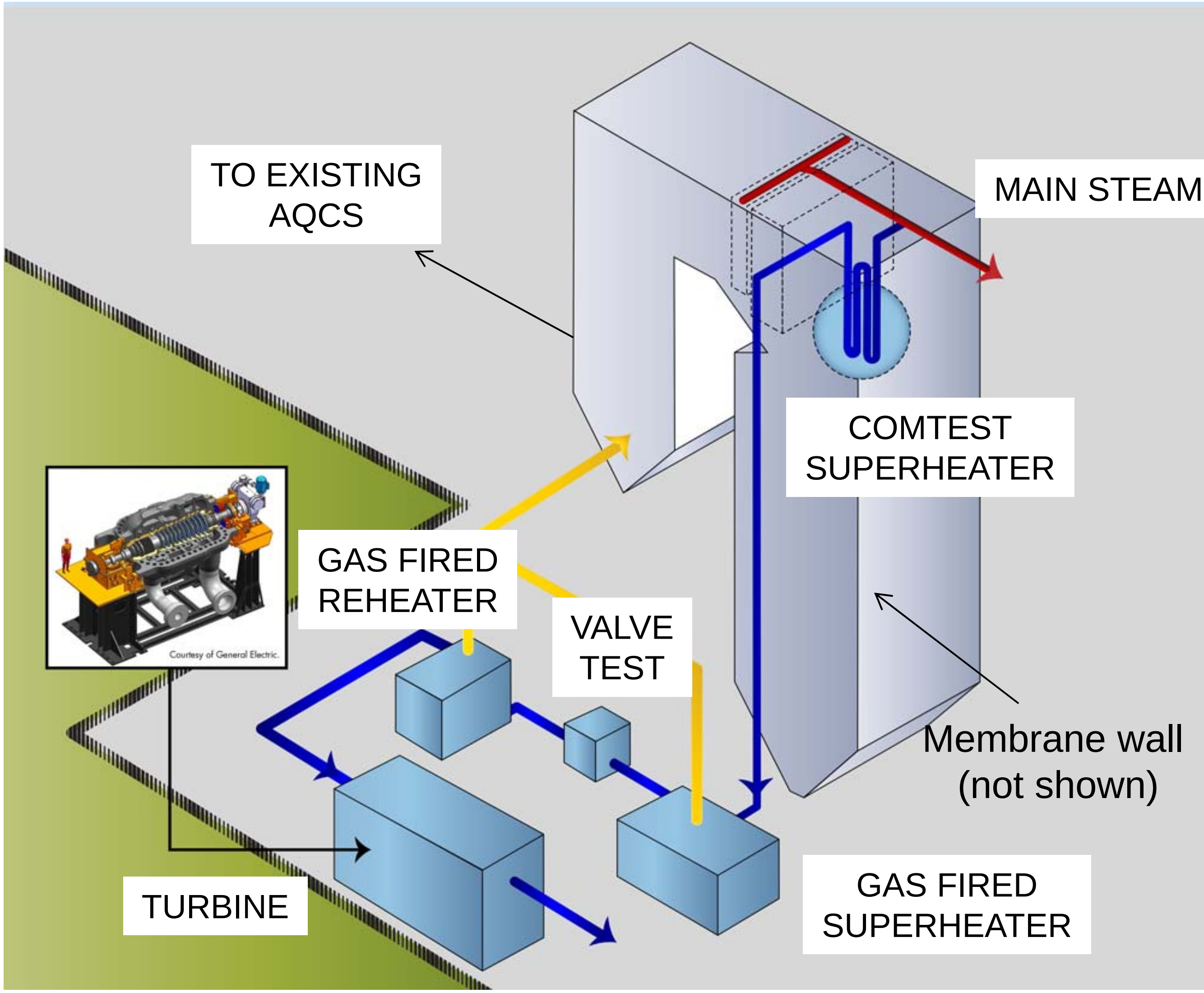
ComTest 1400



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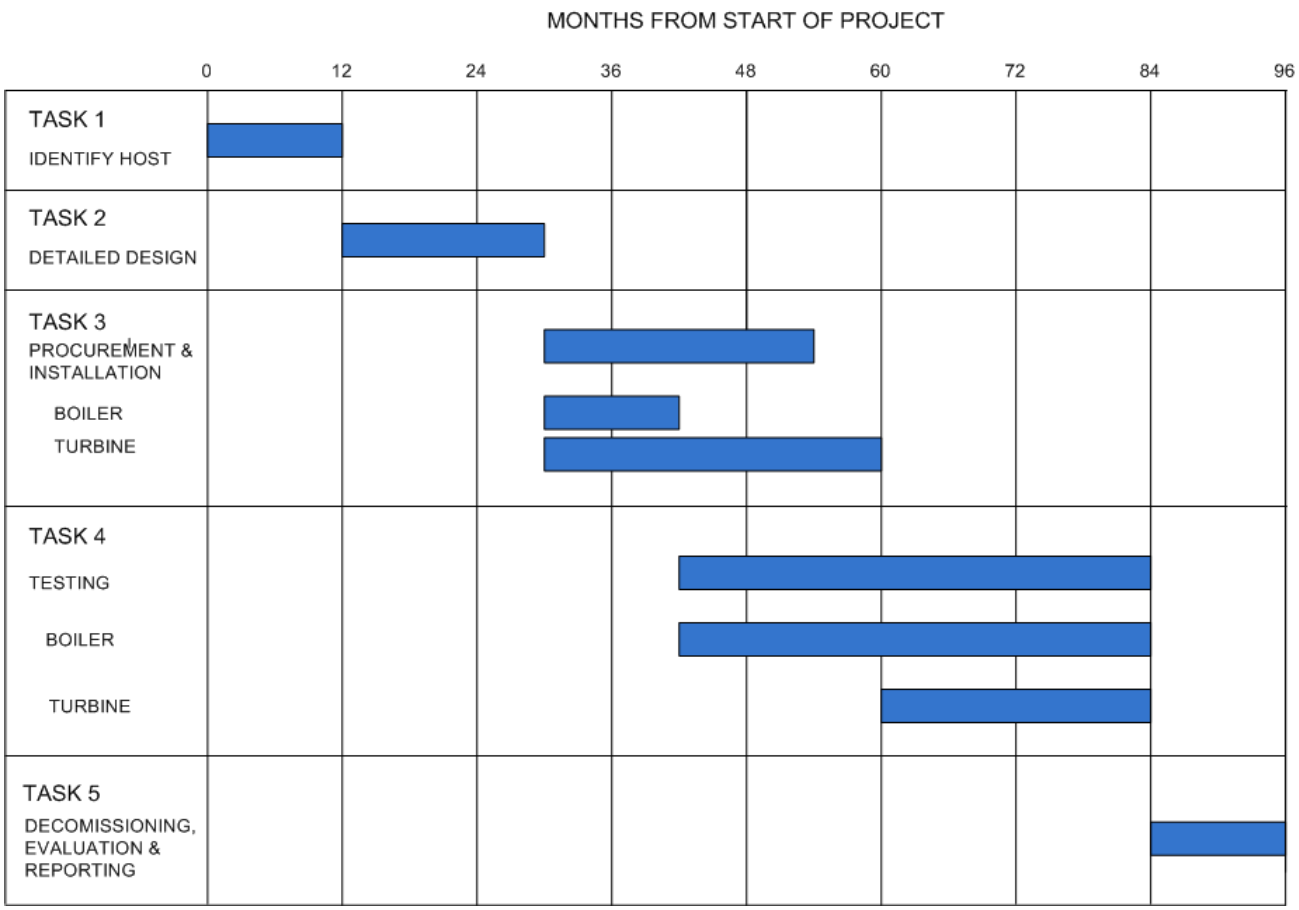
ComTest 1400 - Schedule



Task 1 is underway and has proven to be challenging

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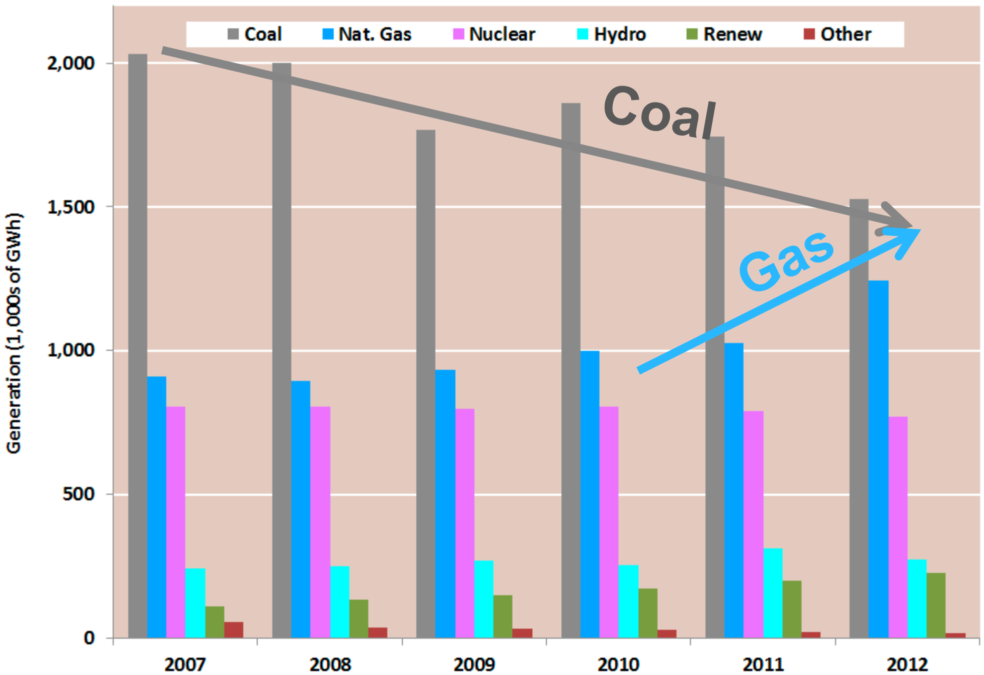
Major shift from Coal to Gas in the United States impacted opportunities for testing/demonstration

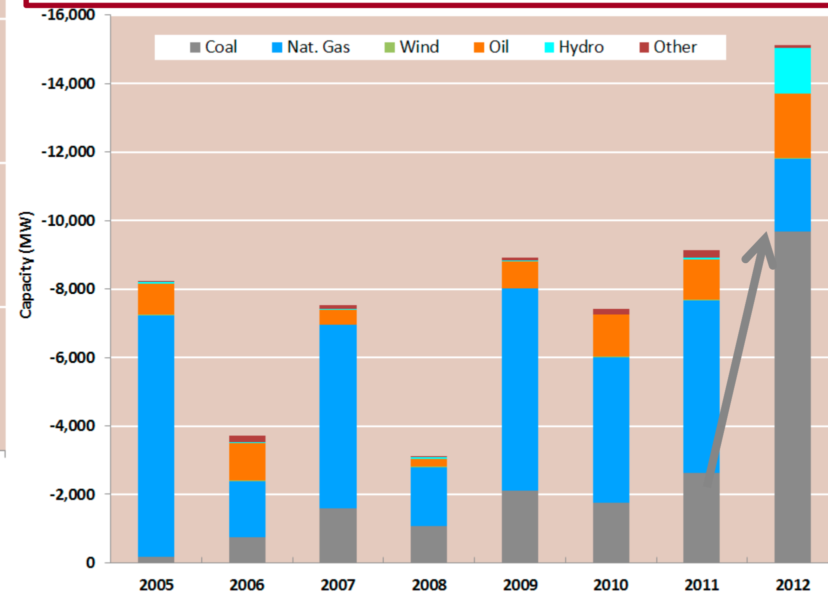
Electricity Production in United States

Shift from coal to gas



Plant Retirements in U.S.

Accelerating Retirements for Coal



Source: FEDERAL ENERGY REGULATORY COMMISSION

www.ferc.gov/oversight

Coal

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ComTest approach for first A-USC turbine

- Host identified: municipal steam source (coal-fired)
- Advantages:
  - Coal + Natural Gas onsite for gas-fired heater to maintain desired temperature/cycling
  - Favorable options for layout including existing building for turbine
  - Staff for operation
- Disadvantages
  - Pressure will be lower than desired (turbine test was planned to be at lower pressure)
  - No membrane wall or heavy wall cyclic header test

Exploring options to split into 2 projects but achieve same objectives

Summary

- A-USC = Least Regret Strategy
- Materials are key enabling technology
- U.S. Program continues to make excellent progress on the materials technology for A-USC Turbines
  - Rotor scale-up and testing
  - Casing scale-up
- Planning work for a 760°C (1400°F) test facility is ongoing
  – New possibilities including a host site for a portion of the test program have been identified

Together…Shaping the Future of Electricity