Collaborative support for supply chain development

A-USC Experience & a Perspective on Supply-Chain

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EPRI

Innovation Network for Fusion Energy Workshop
co-host: Electric Power Research Institute (EPRI)
Fusion Industry Association (FIA)
Virutal: 12-2-2020

Supply Chain for Power Generation (new power plants)

Material Manufacturers
- Alloy Producers
- Forging, casting, tubing, piping, etc. fabricators houses

OEMs
- Major Components (Boilers, Turbines, Generators, Environmental Controls,…)
- Balance of Plant (Valves, etc.)

EPCs
- Piping design, subsystem integration, construction
- Field Fabrication, start-up, early operation, warranty

Utility
- Plant specifications
- Oversight

Shape – *Fabrication via Established Production Routes*

↓

Components/Sub-Systems – *Shop Fabrication*

↓

Systems/Plant – *Field Fabrication*

↓

Operation

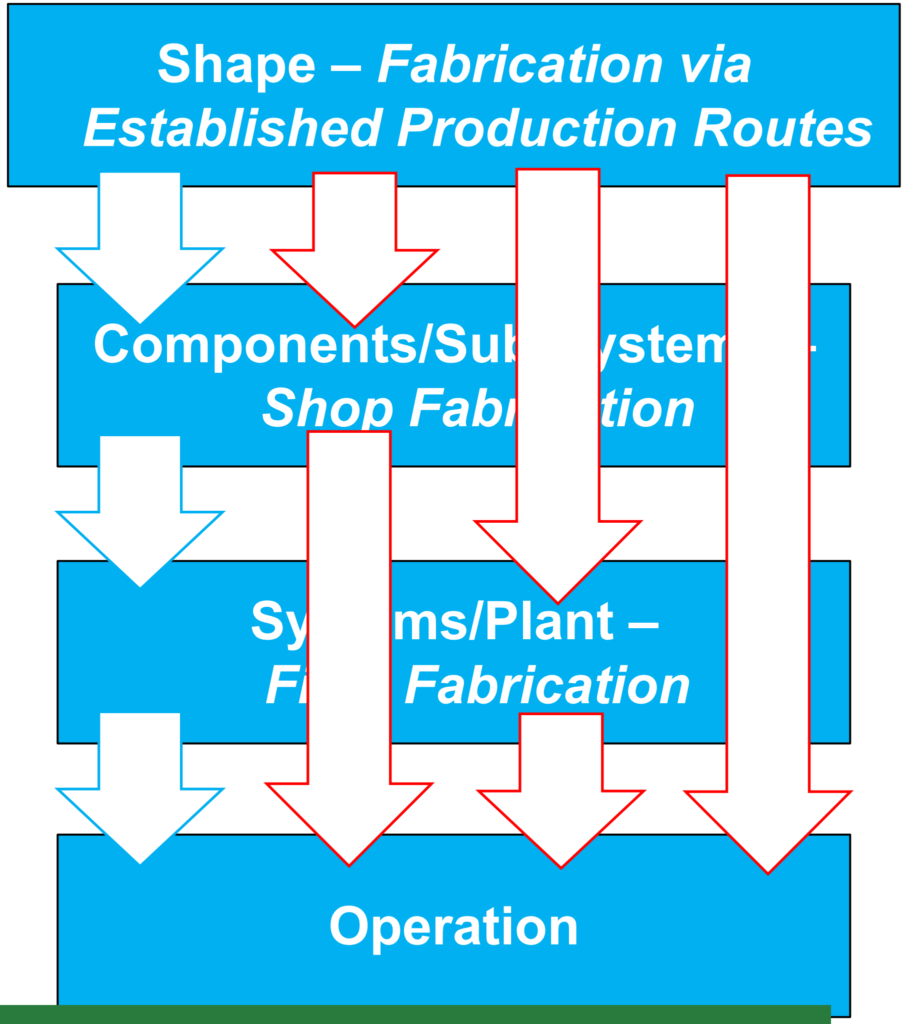
Supply Chain for Power Generation (replacement/modifications)

Material Manufacturers
- Alloy Producers
- Forging, casting, tubing, piping, etc. fabricators houses

OEMs
- Major Components (Boilers, Turbines, Generators, Environmental Controls,…)
- Balance of Plant (Valves, etc.)

EPCs or 3rd Parties
- Piping design, subsystem integration, construction
- Field Fabrication, start-up, early operation, warranty

Utility
- Plant specifications
- Oversight



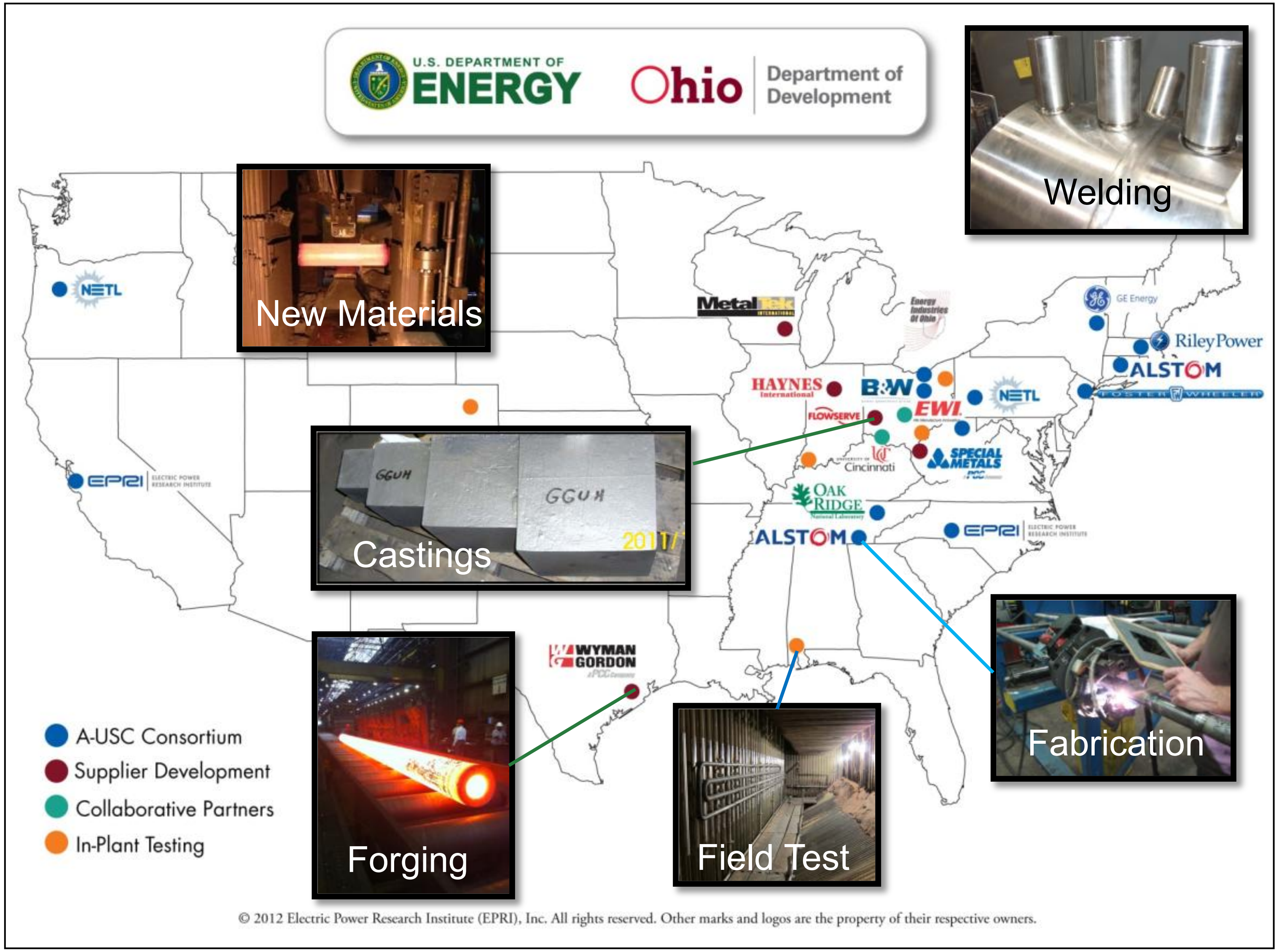
EPRI's main members are utilities, but in order to meet its mission, EPRI is involved in all aspects of the electricity supply chain to enable technology innovation

U.S. Department of Energy (US DOE) / Ohio Coal Development Office (OCDO) A-USC Steam Boiler and Turbine Consortia – EPRI Served as Technical Project Lead

Federal – State – National Laboratory

Non Profit – For Profit

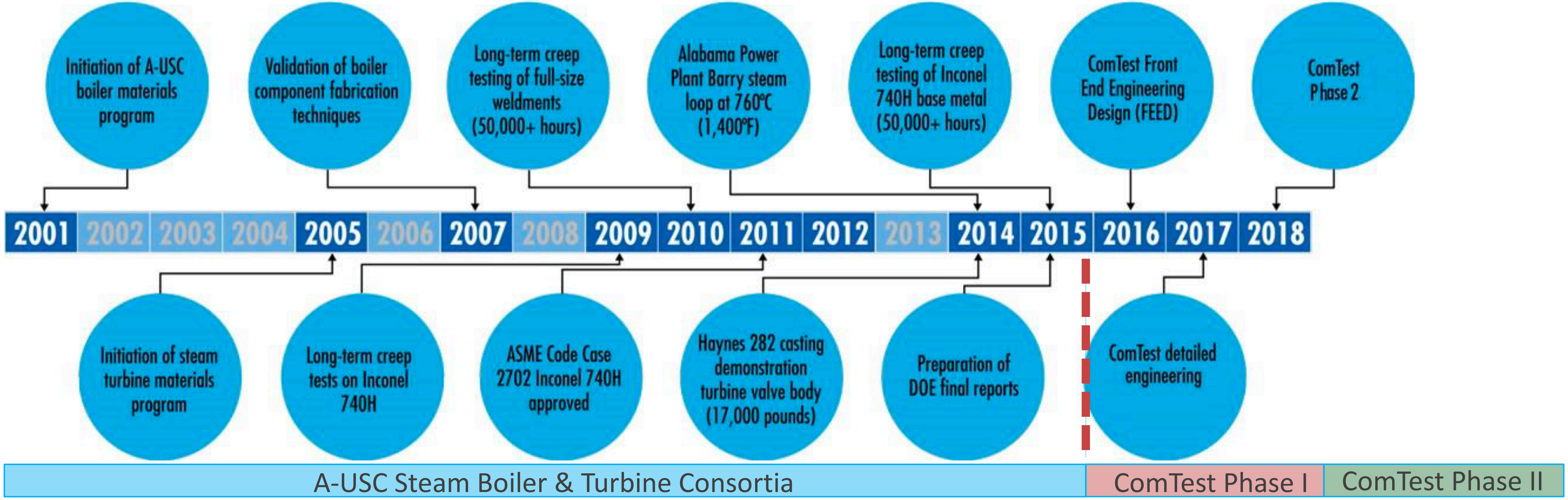
Cost Sharing Consortium



<u>Project Goal:</u>
Develop the materials technology to build and operate an A-USC Boiler & Turbine with steam conditions up to **760°C and 35MPa**

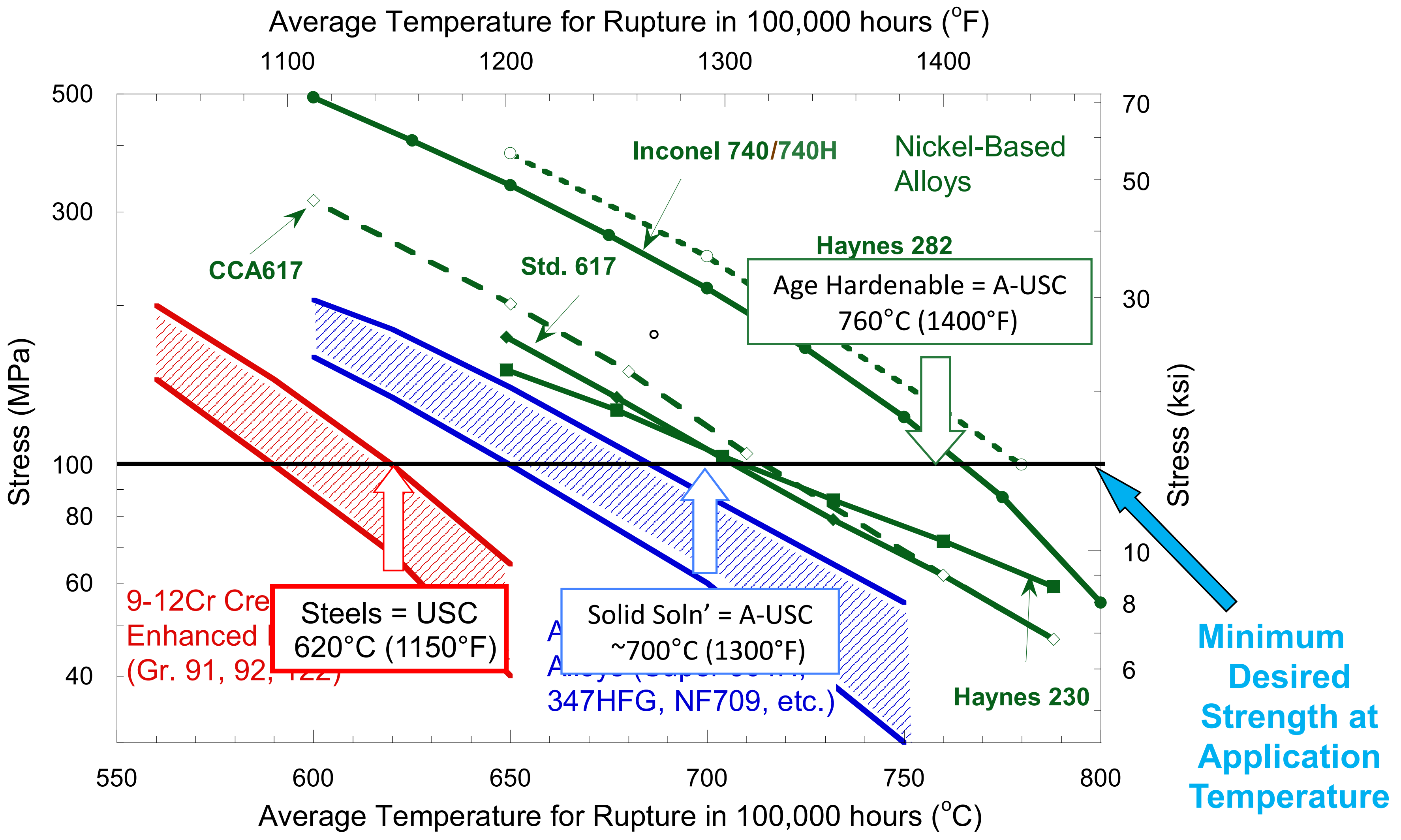
Key program attributes – 15 year effort +

- Precompetitive R&D to enable technology advancement
- Collaboration – all U.S. Boiler & Turbine Manufacturers + National Lab Support + EPRI/EIO Leadership
- Supply chain engagement



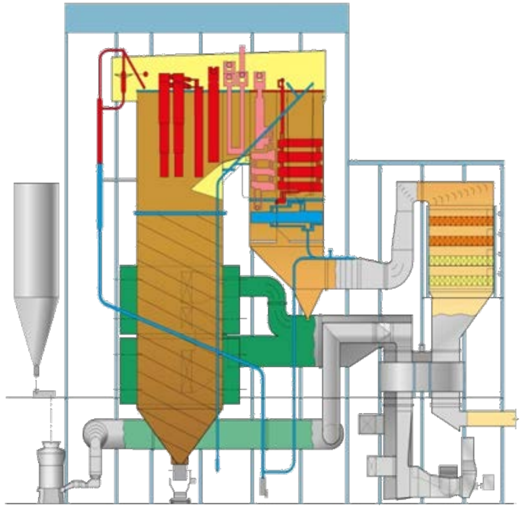
Materials Limit the Current Technology:

State-of-the-Art (USC) are defined by steel technology → New Alloys Required for A-USC



Example of Tasks Completed

General design studies show favorable economics

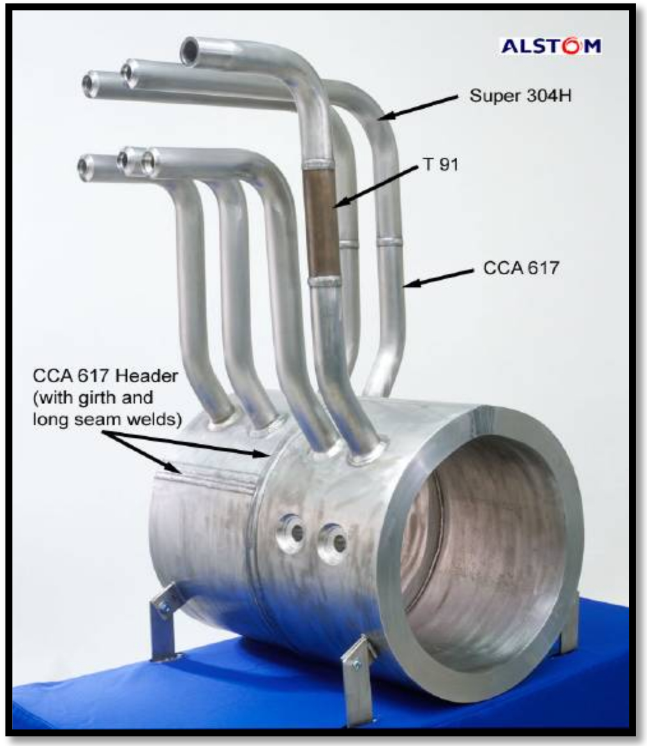


Steam-Side Oxidation

Welding Technology Developments

Fireside Corrosion (In-Plant Testing)

Fabrication Processes



Turbine Component Scale-up

- Materials for A-USC Turbines (DOE): (link, link)
- Boiler materials for A-USC (DOE) (final report)

Example Key Results: In-Plant Testing at 760°C (1400°F) Operating Steam Corrosion Test Loop

Southern Company – Plant Barry

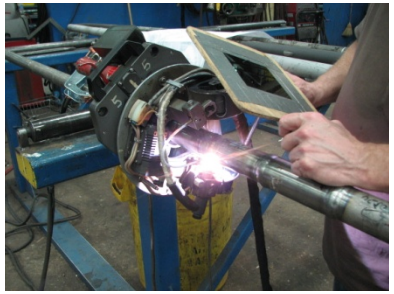
- Initial research:
  - Extensive laboratory testing &air-cooled probes in boiler
  - Steam-cooled loop (high S coal)
- 2nd Steam Loop
  - **World's first steam loop operating at 760°C (1400°F)**
  - **Removed from service after 33months with >16,000hrs in operation**
  - **Evaluations = little to no wastage**

Materials include:

740H, CCA617, HR6W, Super 304H, Coating, Overlays, and Others

Fabrication in Alstom Chattanooga TN shop

Prior to Welding



Being Welded

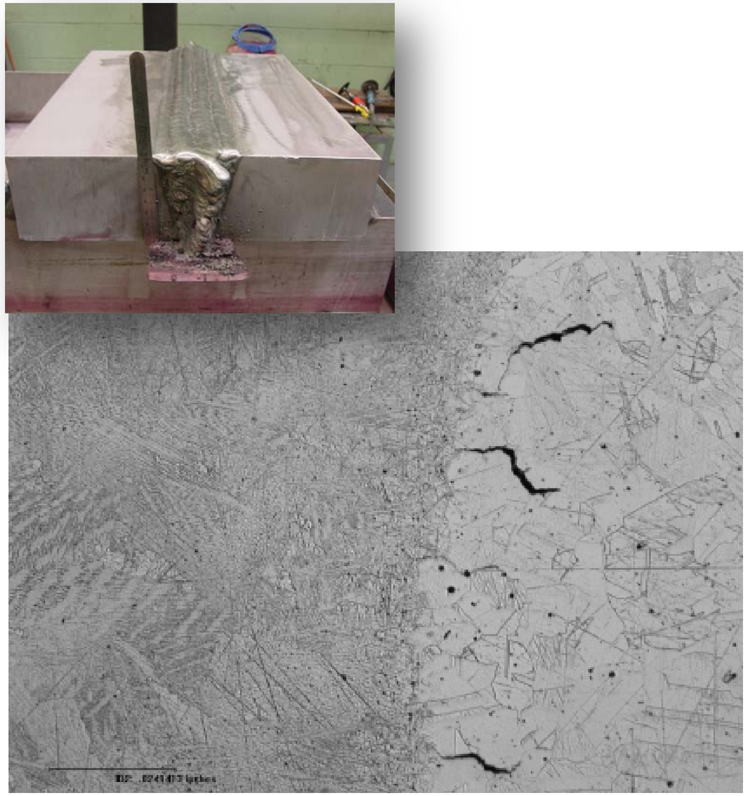
After Assembly

Example: Boiler Fabrication Successes - Performed at 4 different manufacturing centers

- No significant changes to fabrication techniques were required
- R&D was used to make changes to ASME Section I Table PG-19
- Full-size laboratory testing
- Initial tests on Inconel 740 led to additional phase 2 work on cold-work effects on creep which was needed for the code case

Welding Successes

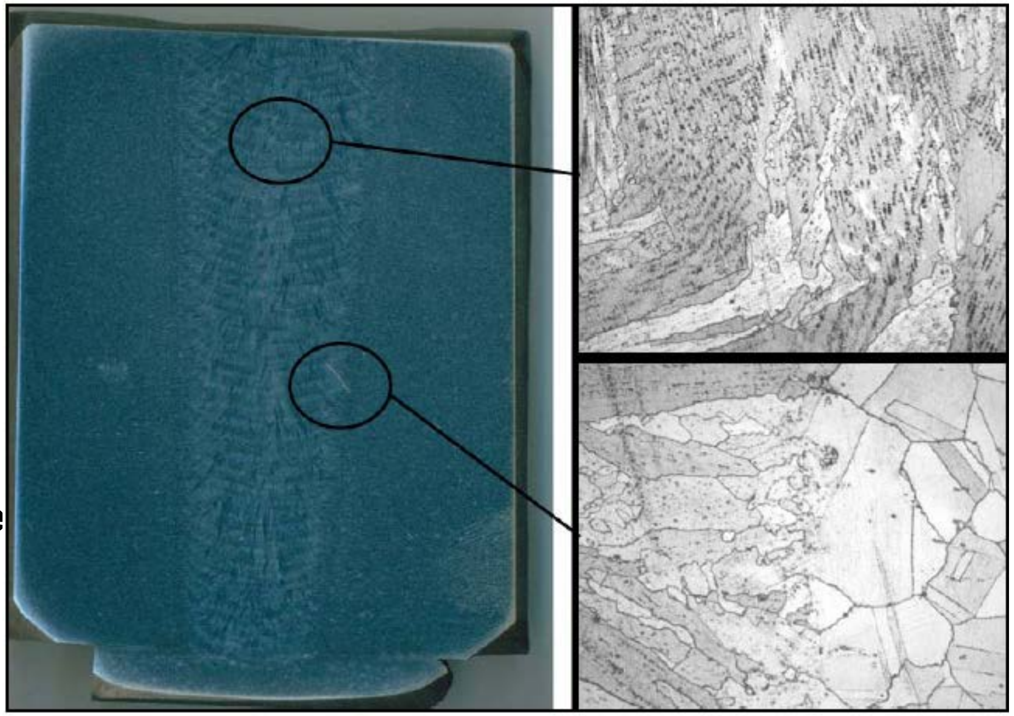
- 7 alloys, multiple processes, thin & thick section
- Over 20 combinations qualified
- Some processes eliminated
- New learning: modified weld metal chemistries, different fluxes, process selection, etc.



Original Inconel 740 weld trials
(Liquation cracking in heat affected zone

Consortium Research

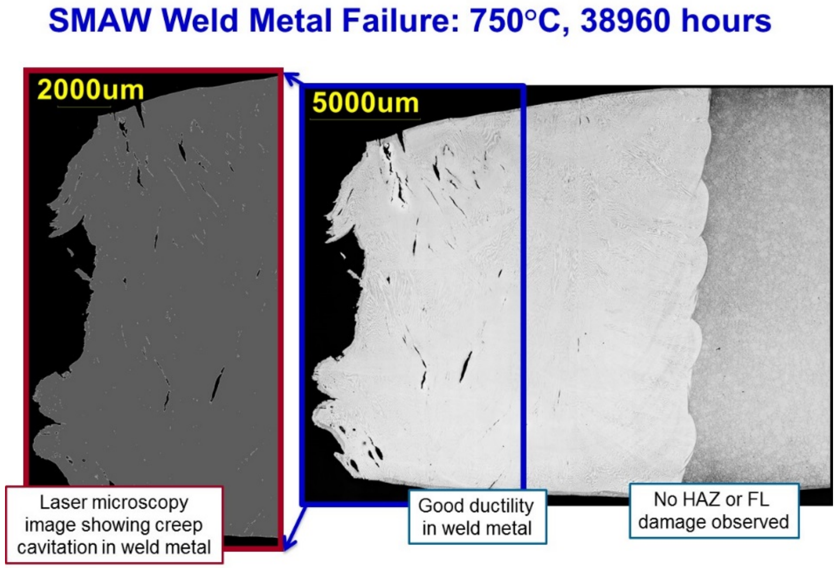
Today: Repeatable 3” (75mm) thick Inconel 740 welds without cracking



Understanding performance of weldments is critical to design and life management of future A-USC plants

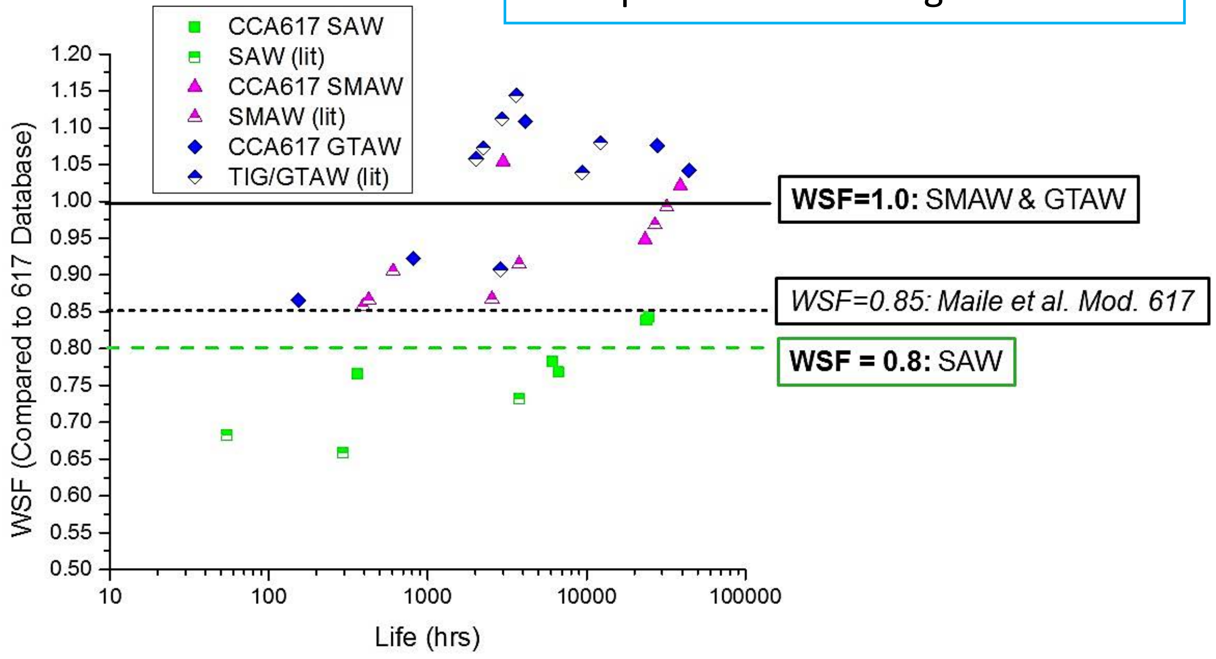
EPRI & ORNL Collaboration on data, metallurgy, etc.

- Long-term creep testing of full-size weldments
- Development of Weld Strength Reduction Factors



Metallurgical failure analysis of 38mm (1.5”) thick CCA617 Weldment Creep Samples

Comparison of long-term creep test on CCA617 with various welding processes showing WSRFs



Code Case 2702 (Inconel®740H) now Approved for Use in Section I and B31.1

Case developed collaboratively

- Maximum Use Temperature: 800°C (1472°F)
- Rules for:
  - Chemistry
  - Heat-treatment
  - Welding
  - Post-weld heat-treatment
  - Cold-forming
  - Weld strength reduction factors

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

CASE
2702

Approval Date: September 26, 2011

Code Cases will remain available for use until annulled by the applicable Standards Committee.

Case 2702
Seamless Ni-25Cr-20Co Material
Section I

Inquiry: May precipitation-hardenable Ni-25Cr-20Co alloy (UNS N07740) wrought sheet, plate, rod, seamless pipe and tube, fittings and forgings material conforming to the chemical requirements shown in Table 1, the mechanical properties listed in Table 2, and otherwise conforming to the applicable requirements in the specifications listed in Table 3 and in this Case be used in welded construction under Section I rules?

Reply: It is the opinion of the Committee that precipitation-hardenable Ni-25Cr-20Co alloy (UNS N07740) wrought sheet, plate, rod, seamless pipe and tube, fittings and forgings as described in the Inquiry may be used in welded construction complying with the rules of Section I, provided the following rules are met:

(a) Material shall be supplied in the solution heat treated

(d) Postweld heat treatment for this material is mandatory. The postweld heat treatment shall be performed at 1,400°F to 1,500°F (760°C to 815°C) for a minimum of 4 hr for thickness up to 2 in. (50 mm), plus an additional 1 hr per additional 1 in. (25 mm) of thickness. If a longitudinal weld seam is required in the construction of a component, a weld strength reduction factor of 0.70 shall apply in accordance with rules in PG-26 for applications at temperatures above 1,112°F (600°C).

(e) After cold forming to strains in excess of 5%; after any swages, upsets, or flares; or after any hot forming of this material, the component shall be heat treated in accordance with the requirements specified in (a). No local solution annealing may be performed. The entire affected component or part that includes the cold-strained area and transition to unstrained material must be included in both heat treatments. The calculations of cold strains shall be made as described in Section I, PG-19.

(f) The maximum use temperature is 1,472°F (800°C).

(g) S_u and S_y values are listed in Tables 5 and 5M and

Larger forging window for Inconel 740H compared to CCA617 = longer pipes or larger possible diameters

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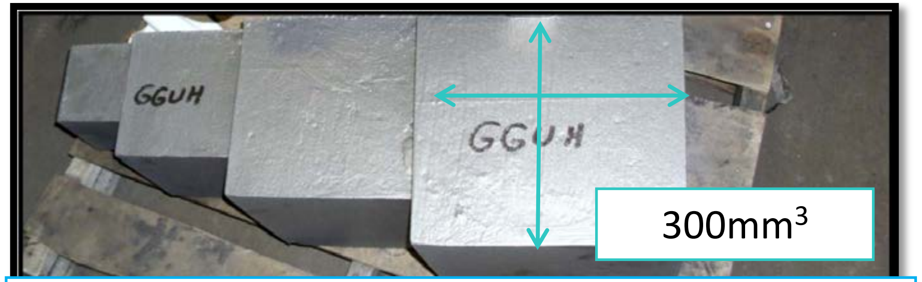
Casting scale-up and turbine casing welding has progressed with supply chain development

Supply Chain Engagement: 3 Foundries Qualified

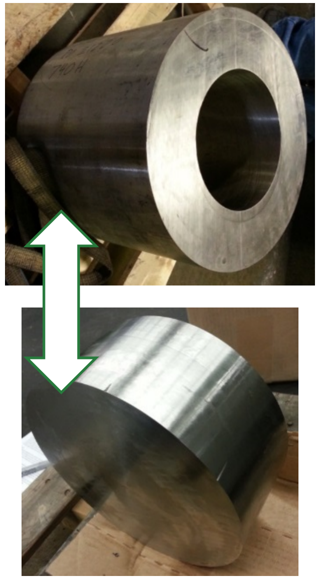


300mm³

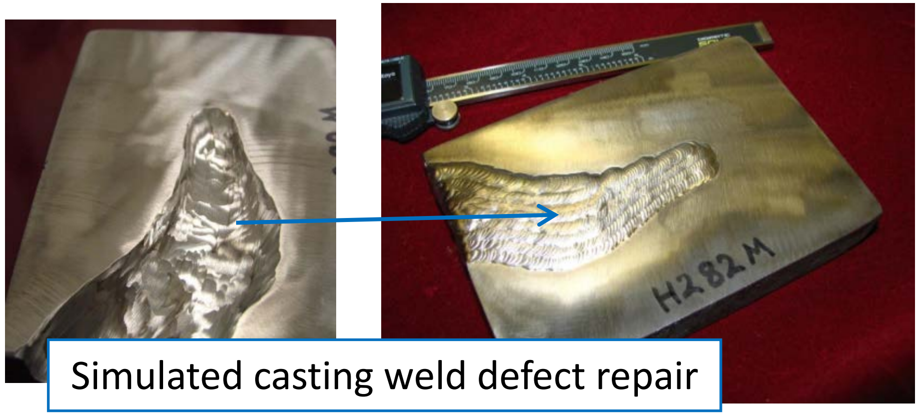
Haynes 282 and **Alloy 263** Step Castings 135-450kg sizes (300 to 1,000 lbs)

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

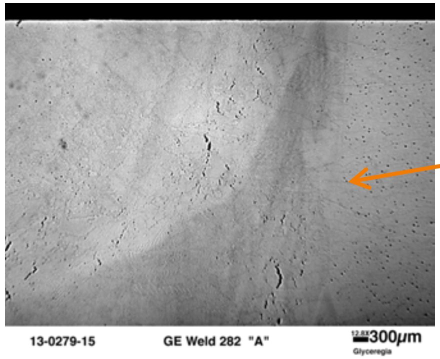
Long-term creep of weldments & microstructural assessment

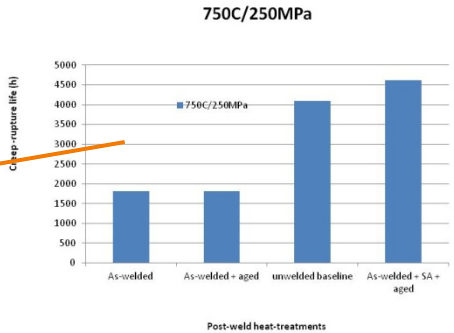


740H Pipe to 282 Casting Weld



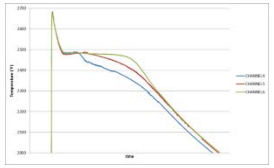
Simulated casting weld defect repair

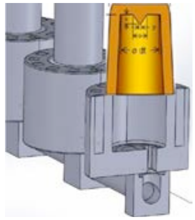


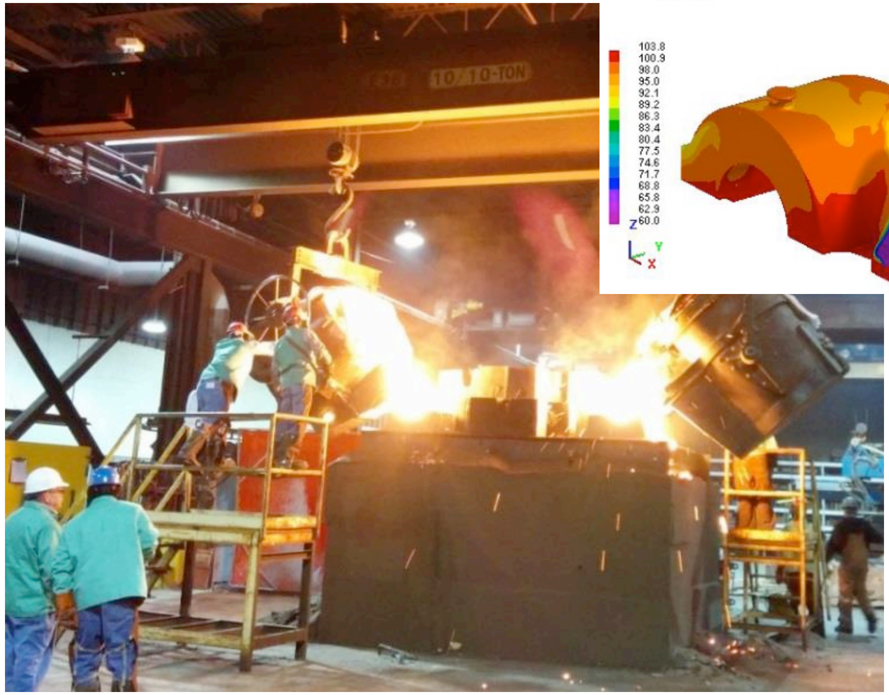


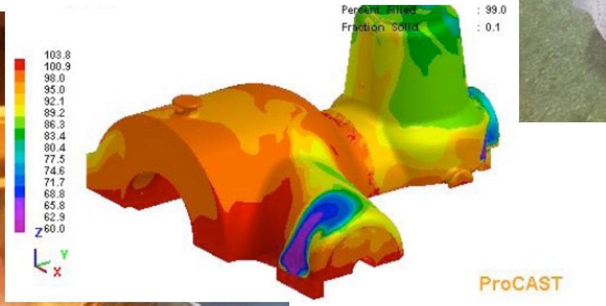
Modeling and Large-Scale Casting Development: Worlds Largest 282 Casting

- Casting simulation developed
- Cooling rate and secondary dendrite arm spacing predictions validated
- Modeling used to design valve body casting









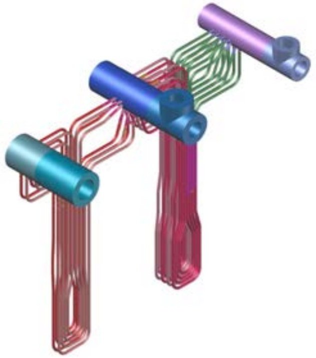
Volume: 19,804 cub. Inches
Approx. Weight~ 5,942 Lbs.

~2700kg (6,000lb)
½ Valve body

(simulate full-size valve)

Casting successful
Nov. 2014 (17,500lb pour)

What now? – ComTest Phase II (2019-2021)

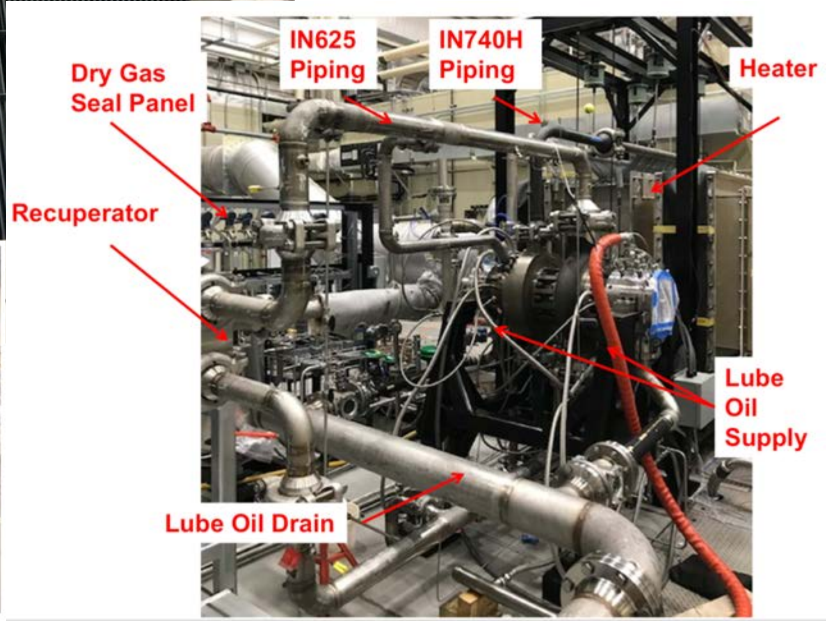


- ‘Final Hurdle’ in supply chain readiness and demonstration
  - Full Size Components + Testing
  - New/alternative fabricators/suppliers → industry transition
- ***Boiler SH/RH/Header Assembly***
- ***Turbine Casing***: Nozzle Carrier (4X compared to valve body)
- ***Turbine rotor forging*** (largest possible ingot size)
- ***Codes***: pressure relief valve

A-USC Materials Enables New sCO2 Power Cycles

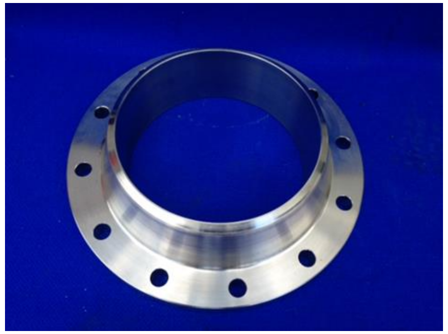
Sunshot (SwRI) 1MWe 700C+ sCO2 Test Loop

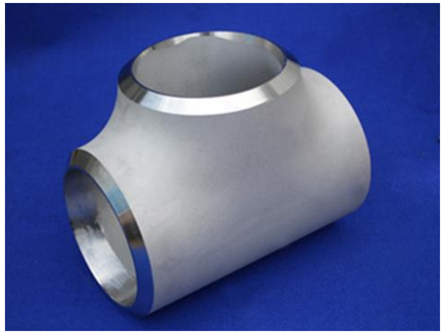
	Recuperator Outlet/ Heater Inlet	Heater Outlet/ Turbine Inlet
Temperature	470°C	715°C
Pressure	251.9 bar	250.9 bar
Mass flow rate of CO_2	8.410 kg/s	8.410 kg/s



Moore et al., sco2symposium.com

Alloy 740H Piping & Components for sCO2 Application





deBarbadillo et al., sco2symposium.com

A-USC Alloys (Alloy 740H) being used in heaters, piping, and components for sCO2 Demos

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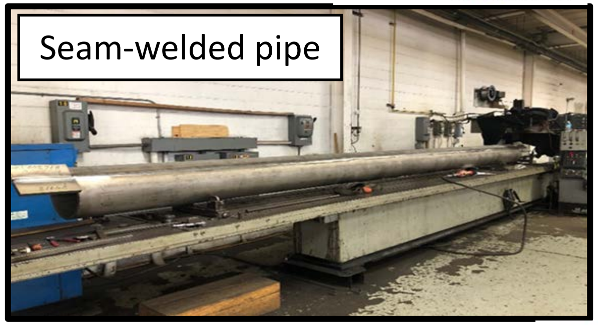
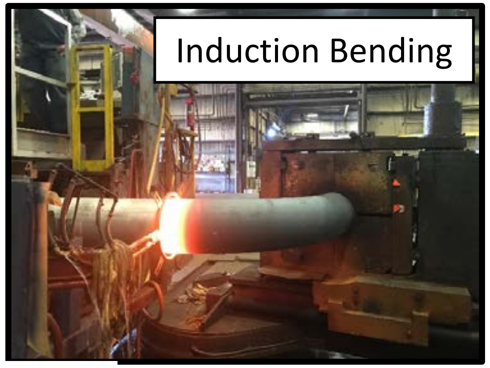
Lowering Costs: Collaborative Work on Concentrating Solar Power (CSP) – Gen3 Developments

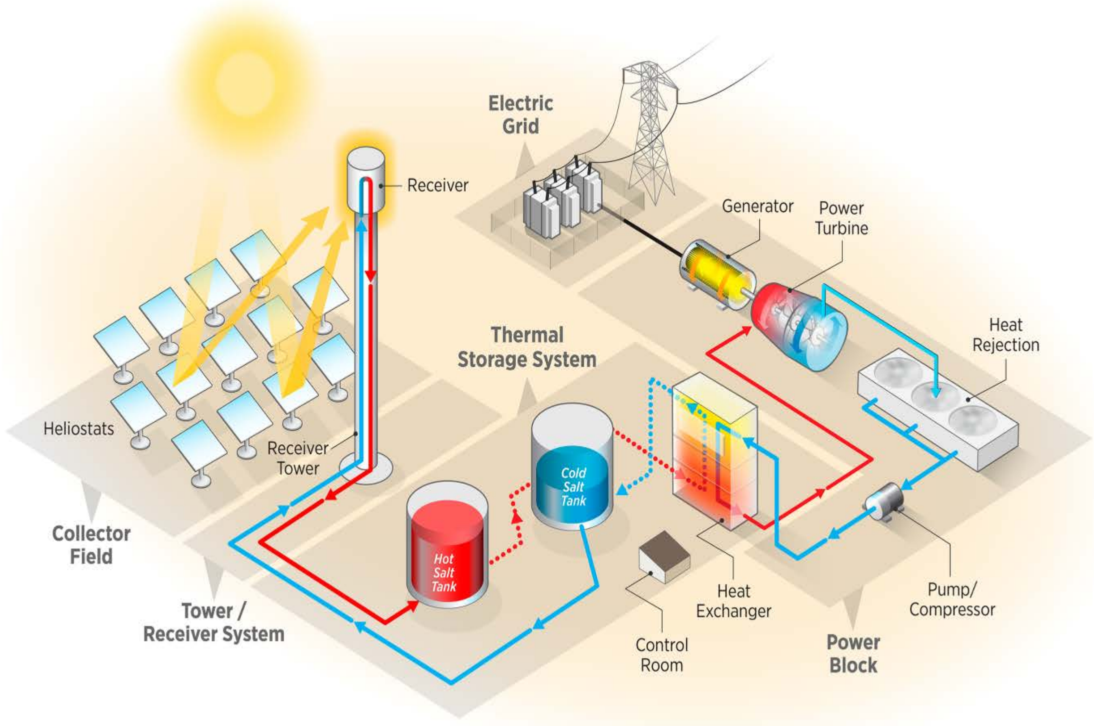
Manufacturing & Supply Chain

SPECIAL METALS
A PCC Company





Shaw Swepco GTC Greenville Tube Company RathGibson A PCC Company

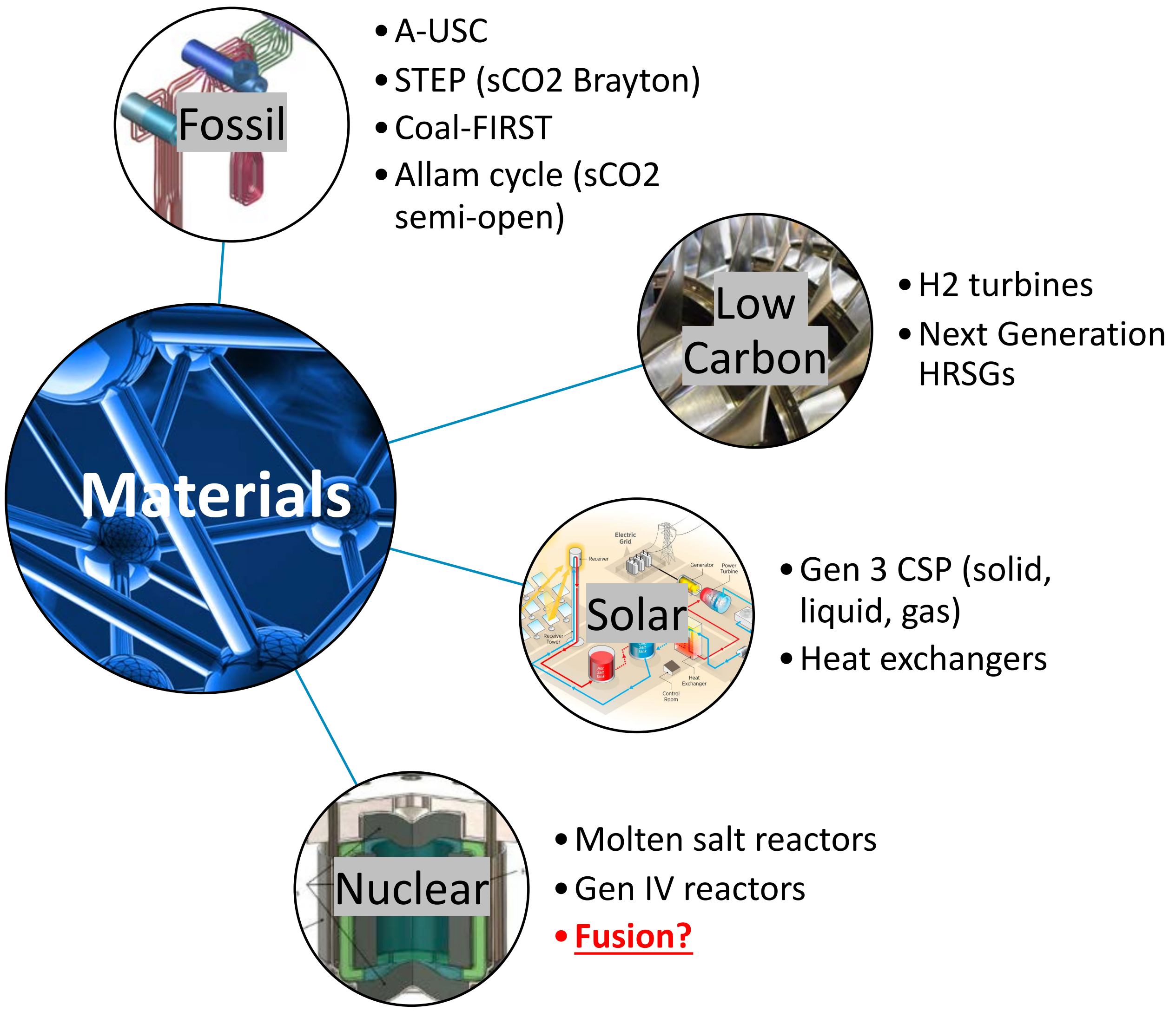


High-Temperature Testing & Analysis

- Relevant testing product forms (welded structures)
- New testing capabilities (multiaxial)

Convergence of technologies with complimentary needs

- Common conditions across multiple advanced power generation technologies:
  - Supercritical steam or CO2 power cycles
  - Molten salt heat-transfer and thermal energy storage
  - Temperatures >700^{o}C
  - Introduction of innovative technologies (e.g. high efficiency heat exchangers, advanced manufacturing)
- Materials & Manfacturing are the enabling technology for all these new technologies



Summary

- Developing a supply chain for a new industry and technology will take collaboration and innovation
- Collaboration:
  - Projects which engage the entire supply chain which may include competitors (e.g. A-USC)
  - Leverage work across multiple technologies (e.g. synergies between solar-fossil-nuclear)
- Innovation:
  - New materials
  - New manufacturing

Investor and end-user acceptance and cost will only be achieved through pro-active and sustained supply chain engagement

Together…Shaping the Future of Electricity