Technology Options for New Coal Units

Advanced Ultra-Supercritical (A-USC) Power Plants

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Workshop on Best Practices in Production of Electricity from Coal
United Nations Economic Commission for Europe
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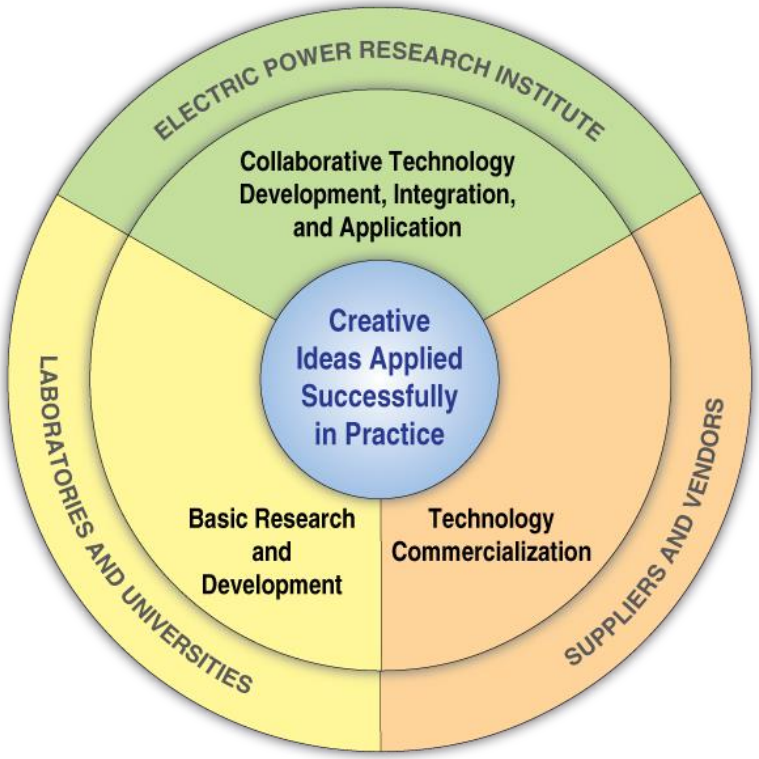
EPRI Overview



Mission

- Assure long-term availability of affordable, reliable, and environmentally responsible electricity through collaborative research, development and demonstration.

Key Facts

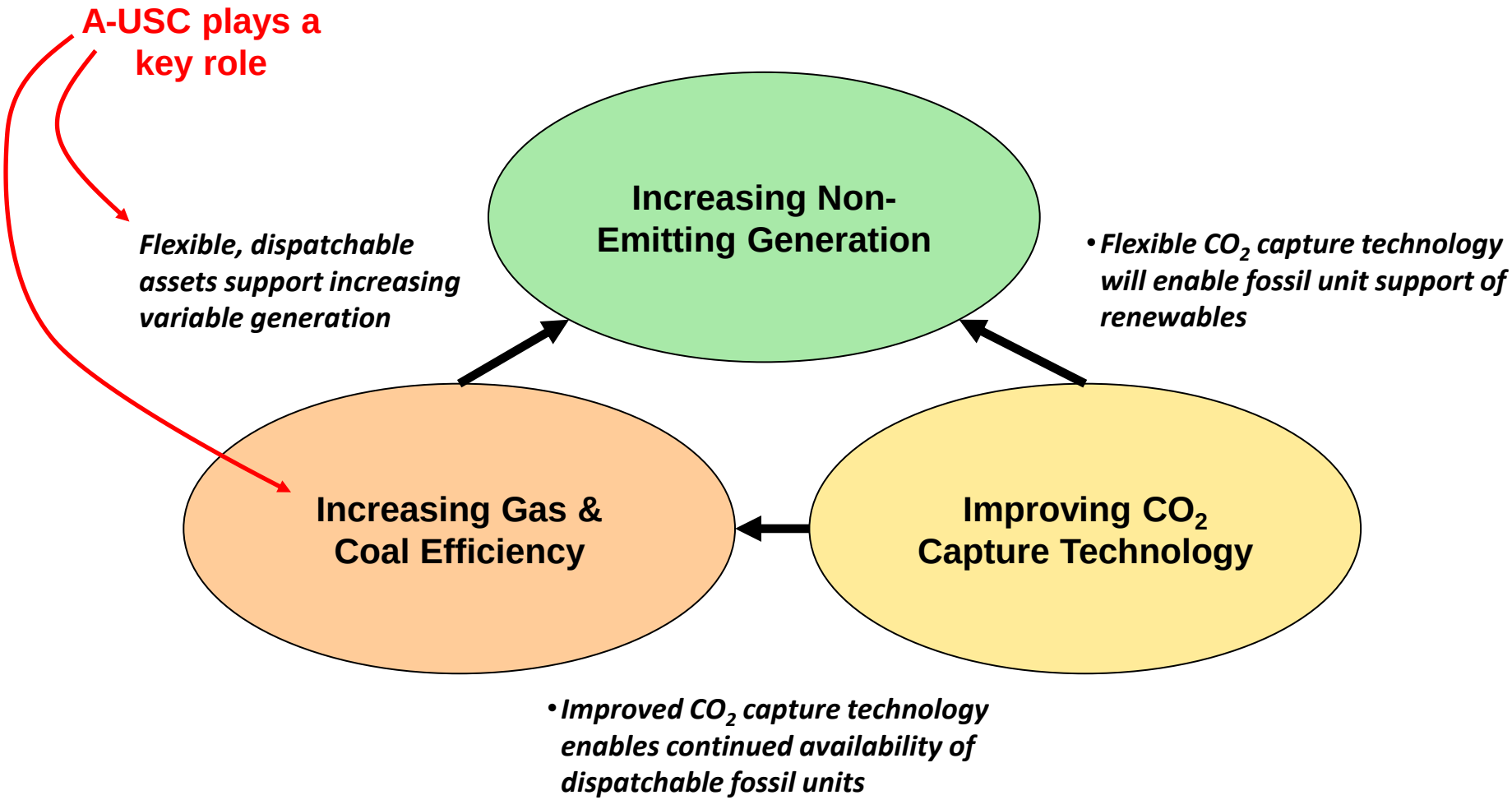
- 450+ participants in more than 30 countries
- EPRI members generate approximately 90% of the electricity in the United States
- Approximately $380M annual funding.
- International funding of nearly 25% of EPRI's research, development and demonstrations
- Non-profit, independent, collaborative R&D institution

Technology Transfer Considerations

- Key approaches
  - Training from technology developers/researchers
  - Development of in-house experts
  - Proficiency evaluations
  - Development of reference tools: best practices guidelines, field guides, mobile phone/tablet applications

- Key challenges
  - Inconsistent levels of technical experience in receiving organization
  - Maintaining continuity in technical staff
  - New technology must be understood in context of related research/technology
  - Integration into engineering, operations and maintenance
  - Integration into training and procedures

EPRI Perspective – Key Future Role for Coal



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Key Benefits of Advanced Ultra-supercritical Materials

- Minimum desired strength not reached until much higher temperature (1400F/ 760° C)

- Increasing Steam Conditions Dramatically Improve Efficiency and Reduce CO_2 Emissions
  - Efficiency: ~45% HHV (from current levels ~35%)
  - Reduced CO_2 emissions intensity on the order of 28-32%

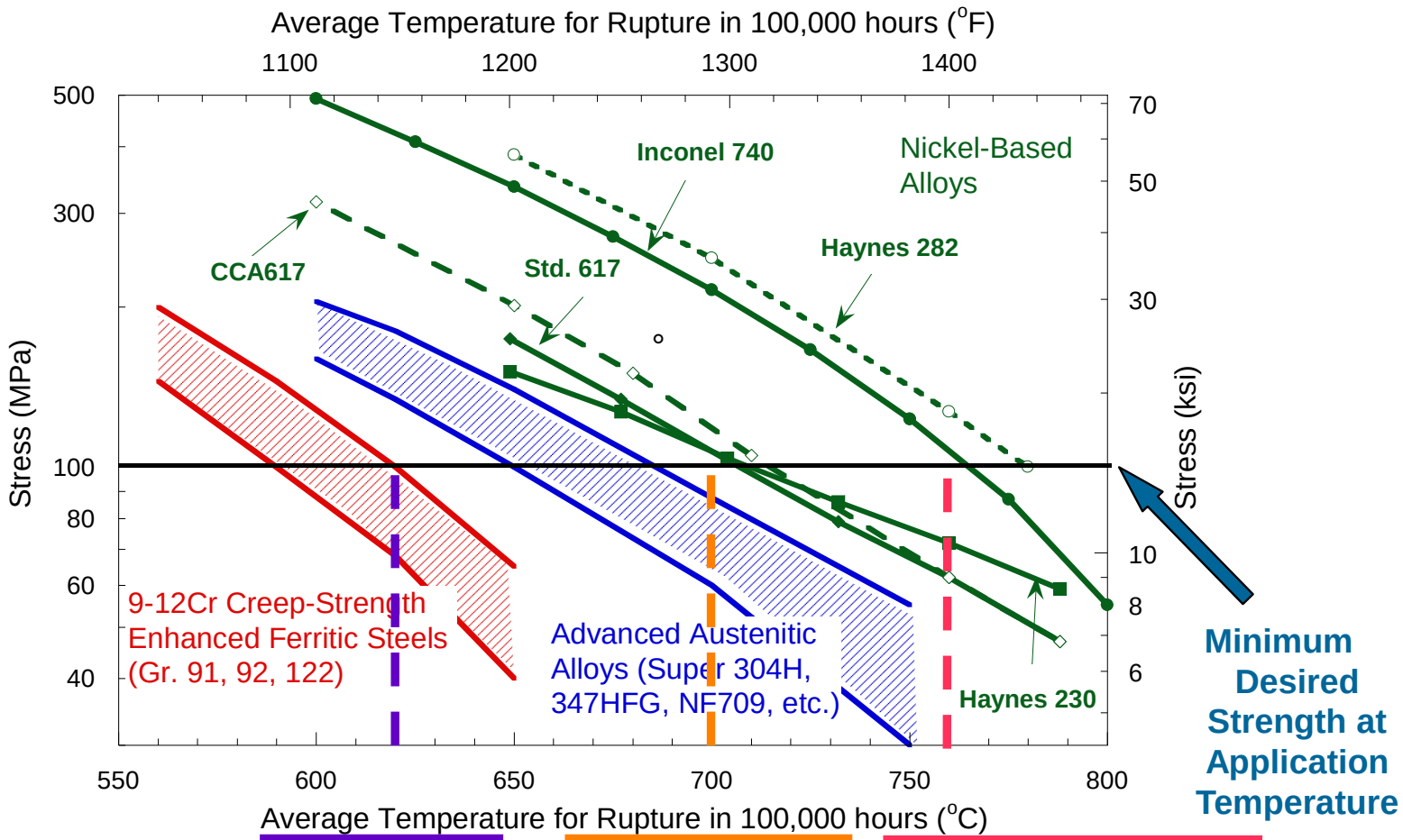
- Higher-strength alloys provide an avenue for cost savings (*comparison of 740H vs. alloy 617 for a main steam and hot-reheat piping system*)
    - Reduced piping material cost (less material) by a factor of ~2
    - Reduced welding cost (less welding material, less welds due to longer extrusions)

Key Features of A-USC Materials

- Materials Technology Evaluation
  - Focus on Nickel-based alloys
  - Numerous successes: fabrication technology now proven, ASME Code Acceptance Granted for Alloy 740H

- Key Aspects of A-USC Materials
  - High strength at high temperature capability (760° C)
  - For Boilers:
    - Corrosion resistance with different coals
    - Recent Success: 2+ year boiler exposure at 760° C)
  - For Turbines:
    - Recent Success: Haynes 282 Triple Melt ingot for rotor forging
    - Recent Success: Haynes 282 full-size casting: ~17,500lbs

A-USC Increases Limit on Minimum Desired Strength



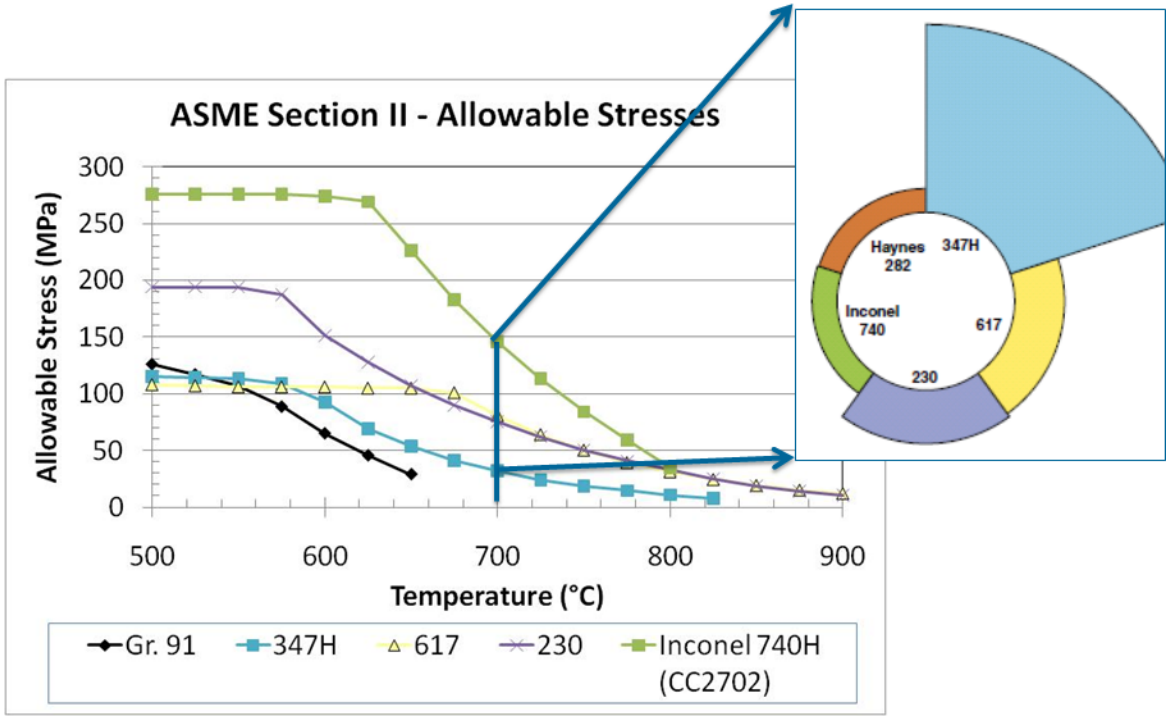
Steels = USC 620°C (1150°F)

Solid Sol'n = A-USC ~700°C (1300°F)

Age Hardenable = A-USC 760°C (1400°F)

Higher-strength alloys provide cost savings

- A-USC plant design study looked at using 740H compared to alloy 617 for a main steam and hot-reheat piping system:
  - Reduced piping material cost (less material) by a factor of ~2
  - Reduced welding cost (less welds)
  - Provided a buffer for nickel-based alloy price fluctuations



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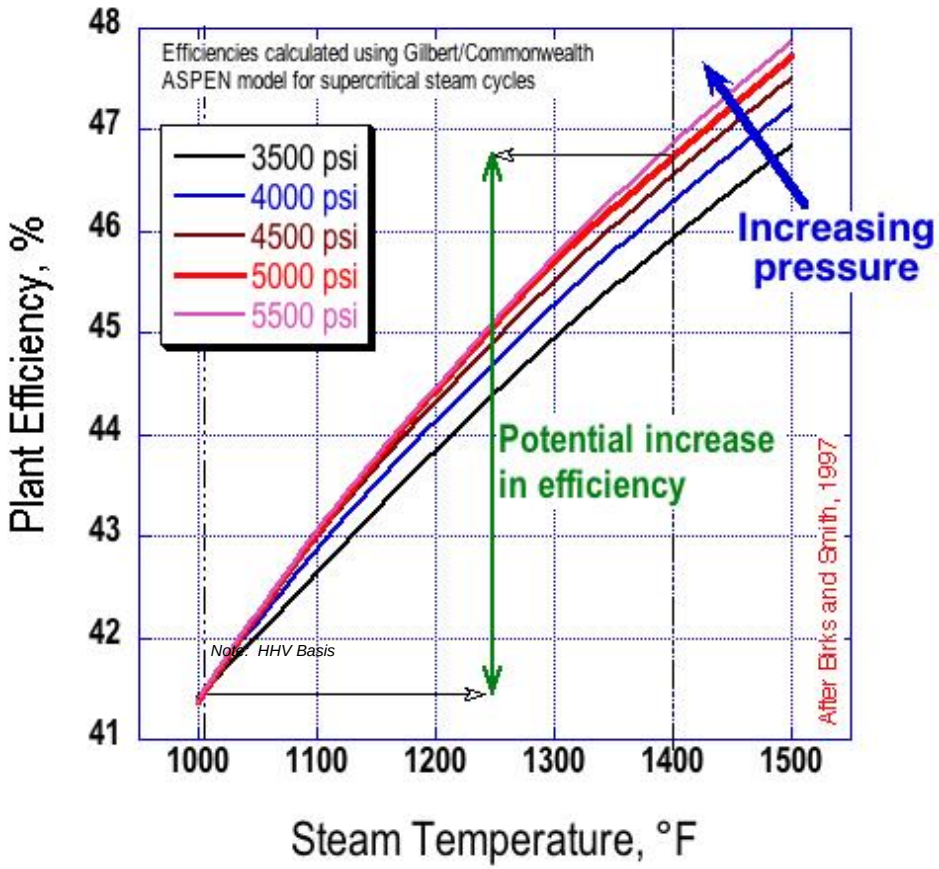
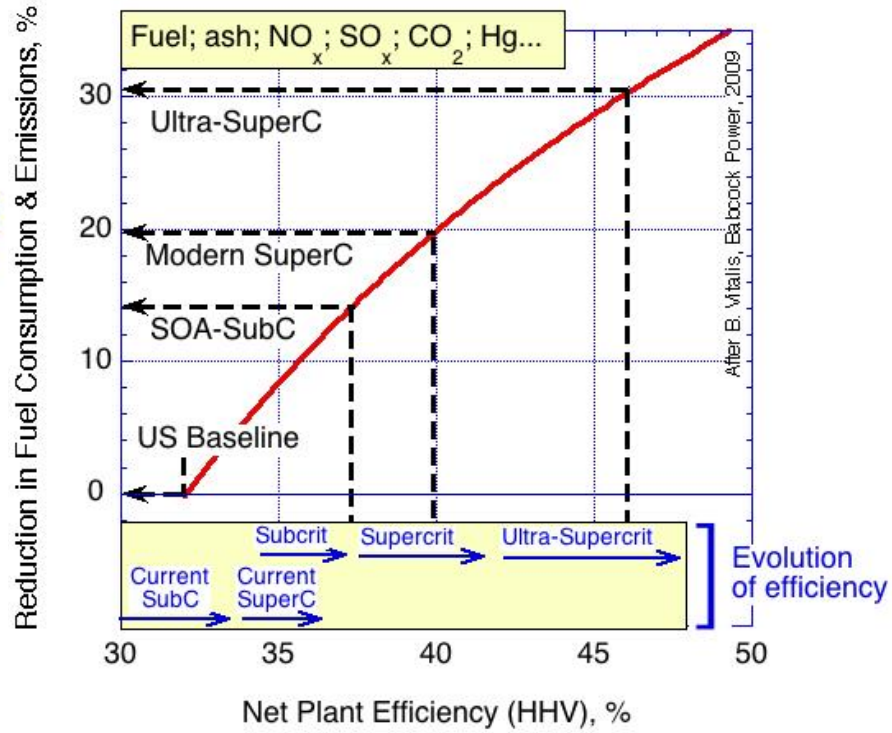
Increasing Steam Temperature and Pressure Significantly Improves Heat Rate





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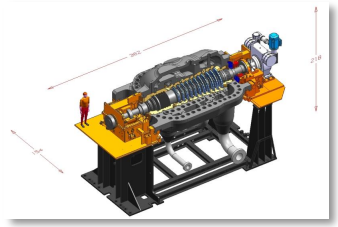
A-USC Materials/Components Enable Transformational Technologies



A-USC Materials R&D Consortium (Boiler and Turbine)

sCO2 R&D

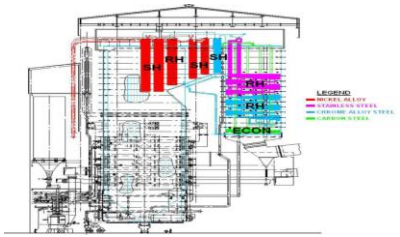
A-USC Component Test

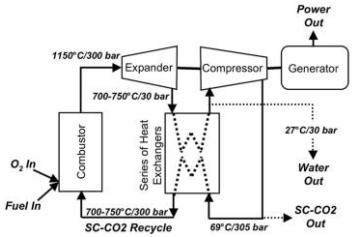
sCO2 PILOT

A-USC DEMO Plant

A-USC DEMO Topping/ Retrofit/ Repowering

sCO2 DEMO





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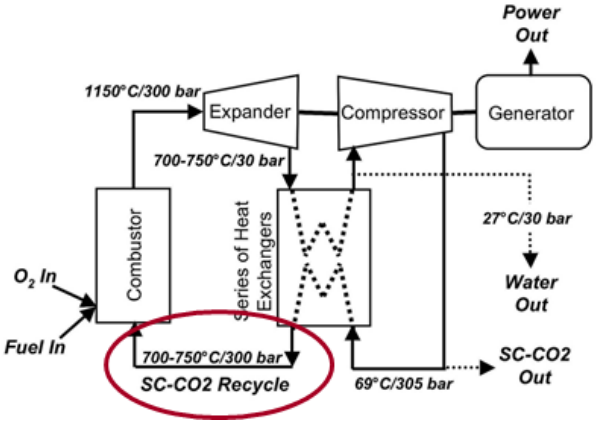
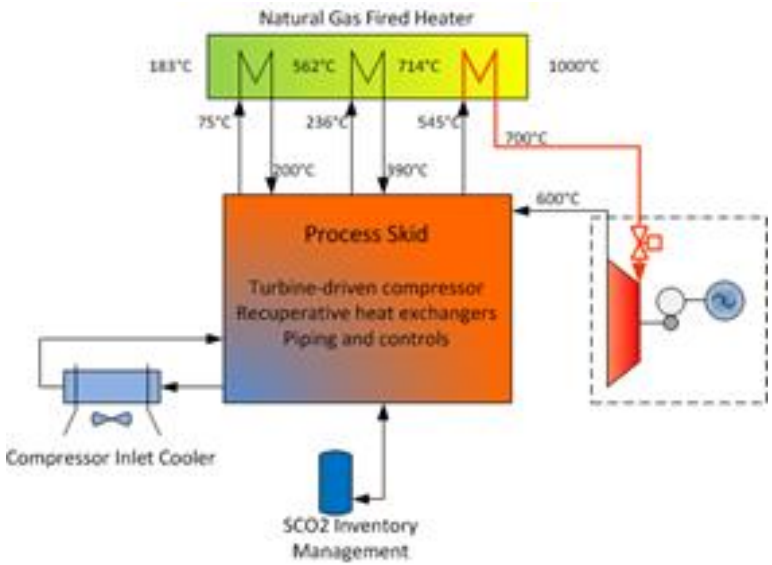
Alternative Supercritical CO_2 Power Cycles Need Advanced Materials Technology

- **NET Power Cycle 25MW Demo**
  - Gas-fired 100% carbon capture modified sCO_2 Brayton Cycle will use Inconel 740H for high-temp. CO_2 piping
  - Scale-up to 250MW will require large- diameter nickel-based alloy piping



- **DOE Sun-Shot sCO_2 Brayton Cycle**
  - 1 MW closed-cycle test facility being developed
  - Piping, valves, castings, forgings, welding are applicable



A-USC Expands Coal Unit Capabilities

- Heat rate
  - Higher temperature and pressure conditions => lower heat rate and higher efficiency
- Reduced plant emissions intensities
  - A-USC plants would reduce CO_2 capture needs.
  - Levelized cost of electricity thus would also be better.
- U.S. Department of Energy proceeding with A-USC component testing.

Supercritical Retrofit to an Existing Subcritical Plant

- UK's DTI Project 407 based on Ferrybridge Unit

- Current subcritical unit cycle efficiency 36.7% (LHV)
  - Replacement of boiler, within existing boilerhouse
  - Pipework and turbine modifications
  - Add FGD and SCR to new plant standards
  - Reuse bulk of ancillary equipment
  - Maximize use of existing infrastructure
  - Designed to be CO_2 capture ready

- A-USC retrofit, SCR & FGD, cycle efficiency 44.7% (LHV)
  - 22% increase in overall efficiency
  - Significant improvement despite SCR / FGD penalty
  - CO_2 reductions, at a load factor of 70%, are 483,500 te/yr (18%)

Summary

- Higher-strength A-USC alloys have an economic advantage.
- A-USC technology could offer significant heat-rate advantages and emissions intensity reductions compared to current coal generation.
- Research has made excellent progress on the materials technology for A-USC boilers & turbines
  - Fireside corrosion & oxidation (include in-plant data)
  - Welding and fabrication for boilers
  - Long-term data leading to ASME code rules/code cases
  - Rotor scale-up and testing
  - Casing technology scale-up
- Component testing (underway in the U.S.) and A-USC plant demonstration are next steps.
- Retrofit options are also being researched.

Together…Shaping the Future of Electricity

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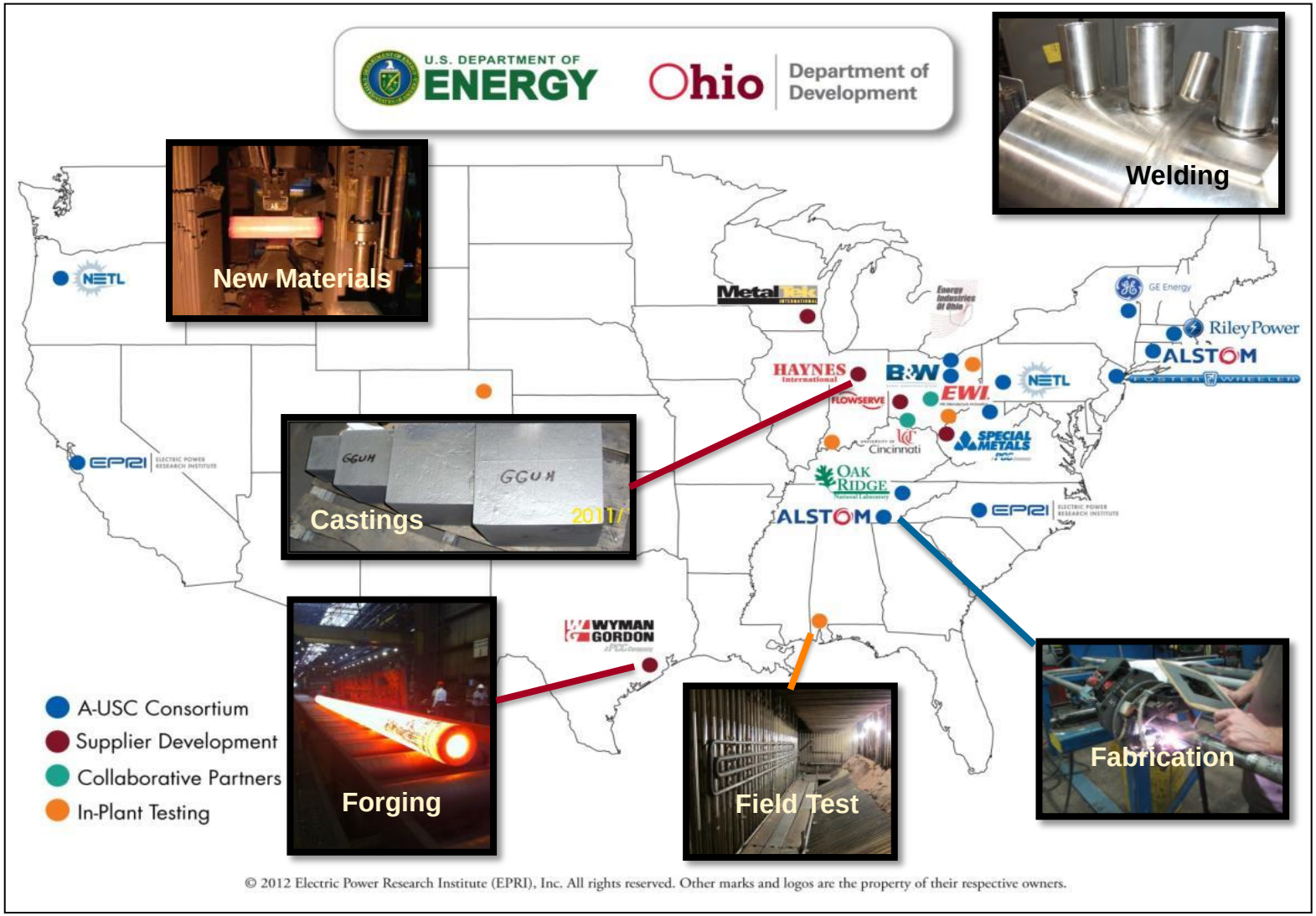
A-USC Materials: Broad-Based Consortium

Federal – State – National Laboratory - Non Profit – For Profit



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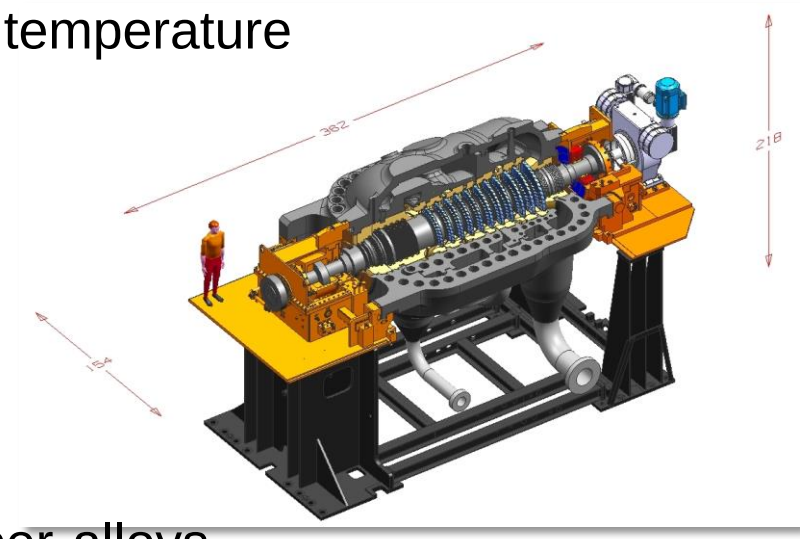
A-USC ComTest Objectives

- 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 for advanced materials, including all necessary components, instruments, valves and fittings
- Validation of fabrication techniques, and the ability to construct, install and repair ComTest with on-site labor (i.e. avoid necessity of using specialized vendor staff.)

Specific Goals (Defined by Power Companies)

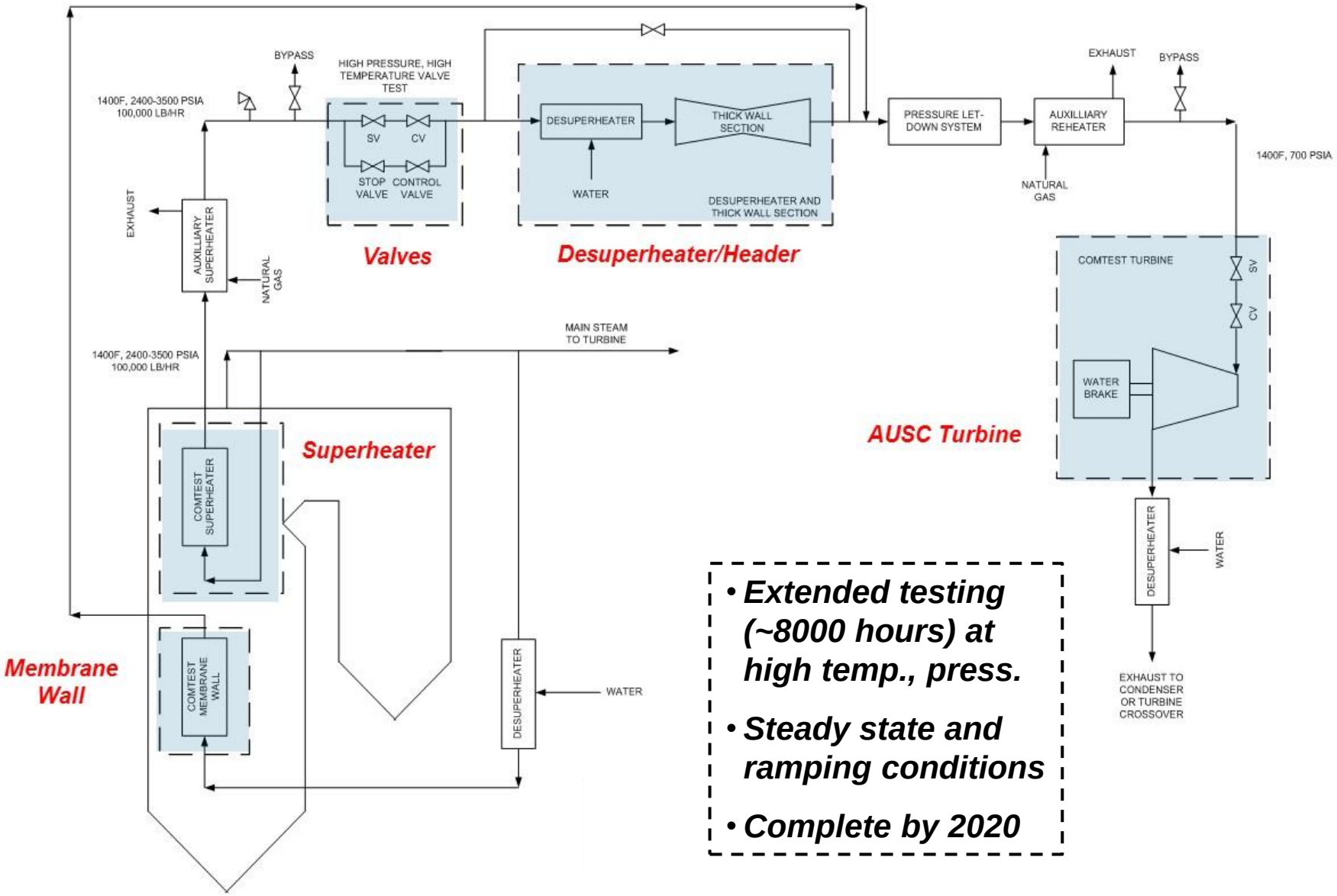
- Boiler: Design, install, start-up, operate and **cycle** high temperature nickel components (740H & others)
  - Large diameter piping
  - Header and tubes (gas fired heater)
  - Superheater materials exposure (at pressure)

- Turbine: Design, install, start-up, operate and cycle **full size** steam valves & steam turbine for 760°C (1400°F).
  - Periodic testing of steam valves at high temperature
  - Materials & coatings
  - Turbine architecture
  - Oxidation, deposits, solid particle erosion (SPE)
  - Non-destructive examination/testing (NDE/NDT)



- Fabrication methods & supply chain for super-alloys

A-USC Component Test (ComTest) Approach



- ***Extended testing (~8000 hours) at high temp., press.***
- ***Steady state and ramping conditions***
- ***Complete by 2020***

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Key A-USC Component Testing Issues

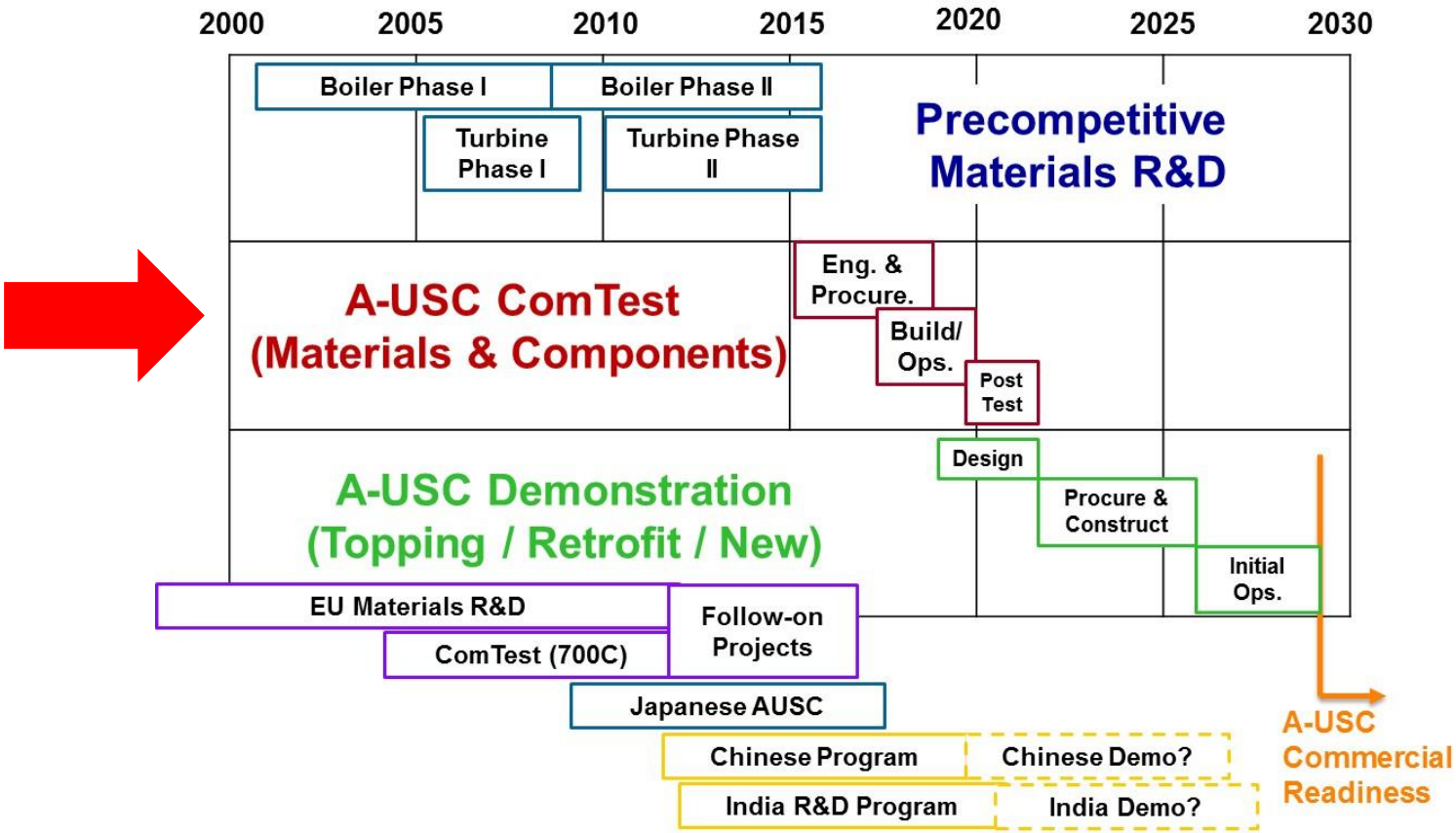
- Testing A-USC turbine at low vs. high pressure
  - Design of an A-USC turbine operable at full high pressure conditions associated with A-USC still presents a technical challenge and requires additional research.
  - Insights gained from testing at high temperatures and lower pressures will definitely be valuable and will inform this research.
  - EPRI is investigating development of a separate project to retrofit an A-USC turbine to an existing power plant to test at reheat process conditions.

- Testing under dynamic conditions
  - Needs for flexible operations are anticipated to be increasingly more frequent for a growing proportion of the existing coal and gas fleet.
  - Varying combinations of temperature and pressure, and testing under dynamically changing conditions will be very valuable for understanding the performance of A-USC components under cycling conditions.
  - Thinner-walled A-USC piping is likely to successfully sustain greater thermal gradients, a critical capability.

Notable Results for Inconel 740H

- Shows lower wastage after 2 years exposure in a coal-fired boiler at A-USC temperatures
- Testing at 760° C (1400° F) in an operating steam corrosion test loop shows minimal wastage
- No significant changes to fabrication techniques appear to be required
- Successful pipe extrusion
- Successful welding demonstrations, e.g. 76 mm (3”) circumferential pipe weld
- 2011 approved ASME Boiler & Pressure Vessel code case for maximum temperature use of 800° C (1472° F)

Timeline for U.S. A-USC Development



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