Advanced Ultra-Supercritical Steam Power Plants

Marion, John*[a] Drenik, Olivier [b], Frappart, Christophe[b], Kluger, Frank[c], Sell, Michael[d], Skea, Adrian[d] ,Rod Vanstone[e],Walker, Peter[d]

[a]*ALSTOM Power, Inc., 200 Great Pond Road, Windsor, CT 06096, USA*

[b]*ALSTOM Power Systems SA, 3 avenue des Trois Chênes, 90018 Belfort, France*

[c]*ALSTOM Boiler Deutschland GmbH, Augsburger Strasse 712, 70329 Stuttgart, Germany*

[d]*ALSTOM Power (Switzerland) Ltd., Brown Boveri Strasse 7, Baden CH5401, Switzerland*

[e]*ALSTOM Power Ltd, Newbold Road, Rugby, CV21 2NH, United Kingdom*

IEA Workshop on Advanced USC Coal-fired Power Plants
Vienna, Austria

John L. Marion

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POWER | ALSTOM

Agenda

Overview of A-USC

A-USC Development – Alstom's Historical Involvement

A-USC Boiler Design

A-USC Steam Turbine Design

A-USC Steam Power Plant Design

A-USC Economics

A-USC – Next Steps

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Benefits of A-USC

- A-USC refers to steam cycles with steam temps of 700-760ºC (1300-1400ºF)
- A-USC steam cycles increase net plant efficiency by approx 7% vs USC (600ºC or 1100ºF)
- A-USC reduces emissions (including CO2) and flue gas

Nomenclature	Conditions	Net Plant Efficiency (%, HHV)	Net Plant Heat Rate (HHV)
Subcritical	2400 psi 1050°F/1050°F	35	9751 Btu/kWh
Supercritical	>3600 psi 1050°F/1075°F	38	8981 Btu/kWh
Ultrasupercritical	>3600 psi 1100°F/1150°F	>42	8126 Btu/kWh
"Advanced" Ultrasupercritical	4000–5000 psi 1300–1400°F main steam	>45	7757 Btu/kWh

7% increase

Note: 45%+ net plant efficiency on HHV basis can be equivalent to 50%+ on LHV basis – a frequently-quoted target for A-USC technology

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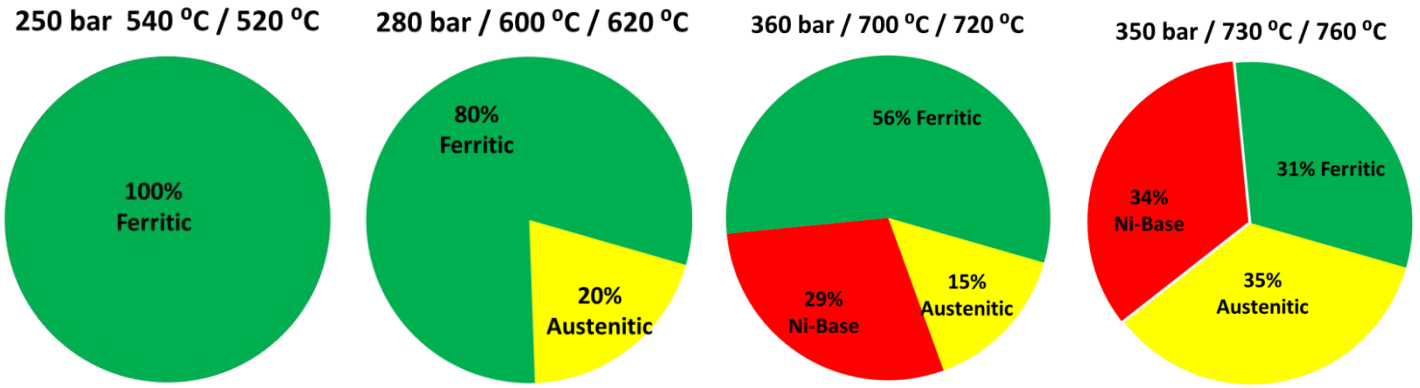
A-USC Development Required

- Achieving 700/760^{o}C steam temps requires;
  - New materials
  - New fabrication techniques
- New materials include;
  - Ni-based alloys for SH/RH tubing/piping and turbine forgings/castings
    - 617, 263, Sanicro 25, 740, 625
- New fabrication techniques include;
  - Waterwall tube panels from high-Cr ferritic alloy
    - T91/92
  - Dissimilar welds in turbine rotor



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A-USC Development Programs

- **Alstom is strongly involved in A-USC development:**
  - For 700-760^{o}C steam temperatures
    - In collaboration with various groups in Europe and USA
    - Material tests completed and also on-going
    - Component tests completed
    - Component tests (thick walled) under cyclic conditions on-going
    - Detailed 550 MW Tower boiler design
    - 550 MW steam turbine design
    - 1000 MW reference Two Pass boiler design
    - 1100 MW reference Tower boiler design
    - 1100 MW steam turbine design
    - 1100 MW steam plant concept design

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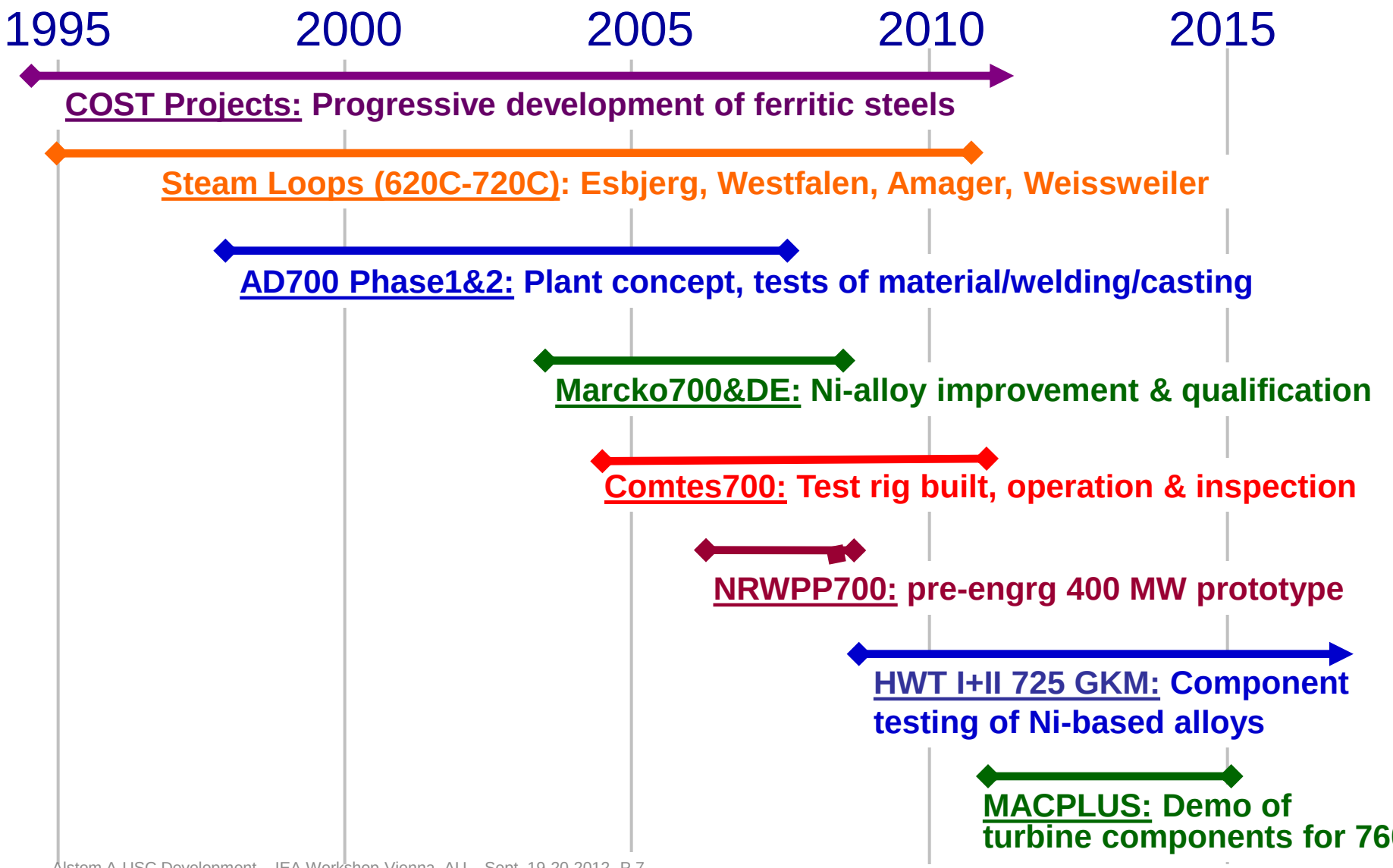
A-USC Development Programs Europe (700C)



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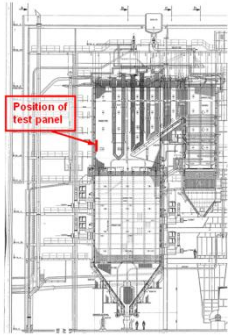
A-USC Development Programs Europe (700C)

ALSTOM

AD 700-2 Amager Test Rig



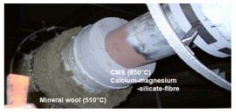
Water Wall Panels Manufacturing

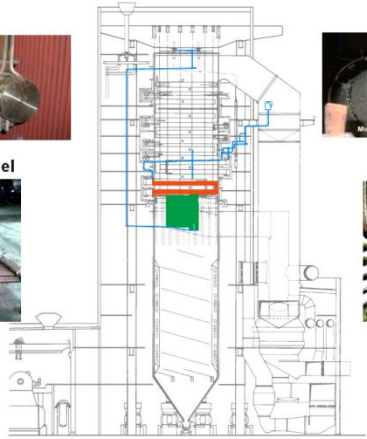
Water Wall Panels:
T 92, 8-tubes
OD 38 x 6.3 mm
SAW-Welding,Wire ∅ 2 mm

COMTES 700 Components Test Facility

HP Header

Piping





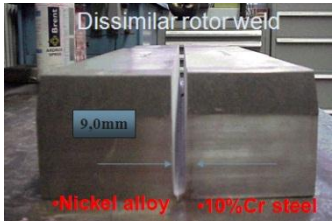
Test Evaporator Panel

Test Superheater

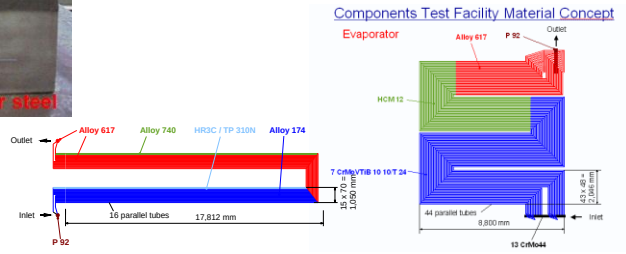
Esbjerg Test Rig 720°C Test Loop

In 617 Welding for Large Wall Thicknesses

In the framework of the Marcko DE2 Program, welding tests of pipes were successfully performed in ALSTOM Power Boiler in Stuttgart.



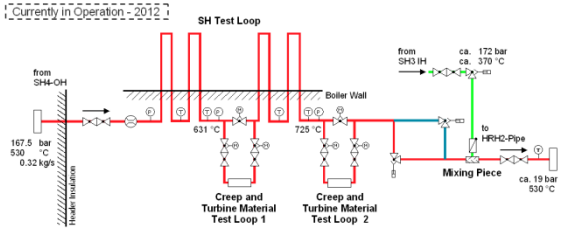
Components Test Facility Material Concept



MARCKO 700 Header from Alloy 617 mod.

Header: OD 460 x 80 mm
Nozzles: OD 38 x 6.3 mm
Header-Nozzle-Welds:
Inside-GTAW
Outside-SAW

725 HTW GKM Steam Flow Diagram



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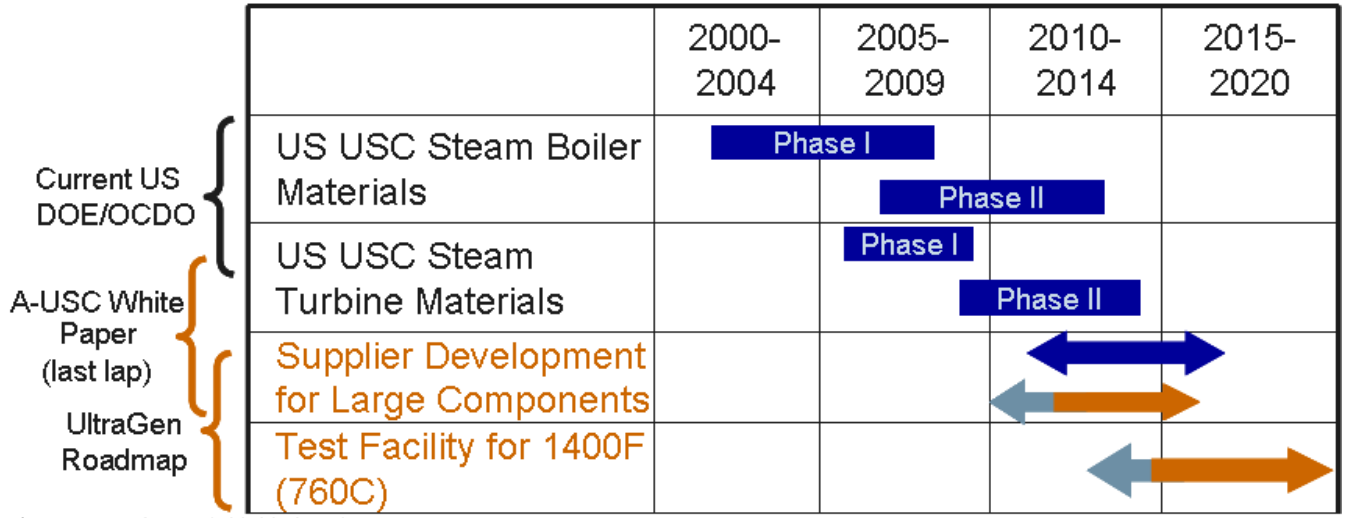
A-USC Development Programs USA (760C)

- DOE, the State of Ohio Office of Coal Development and Industry have teamed to develop next generation technology which will provide efficiency and environmental gains

- A uniquely qualified industry team - Energy Industry of Ohio, *all* the major US boiler manufacturers, US steam turbine manufacturers, Oak Ridge National lab, Ohio organizations, and EPRI

- An aggressive goal – 760C (1400F) steam temperature



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760ºC vs 700ºC

- Continuous evolution of steam conditions (historical trend) exploits materials to their maximum capacity.
  - Nickel alloys can permit steam temperatures to reach 760ºC.
- Cost of (precipitation strengthened) nickel-based alloys for 760ºC applications is predicted to be similar to their weaker (solution strengthened) counterparts for 700ºC applications.
  - More nickel alloy for 760ºC, but not more expensive.
- Conventional steam generator designs (tower and two pass) and steam turbine design can be configured for 760ºC steam temperatures.
  - Familiar technology but extensive Ni alloy heat exchange surface

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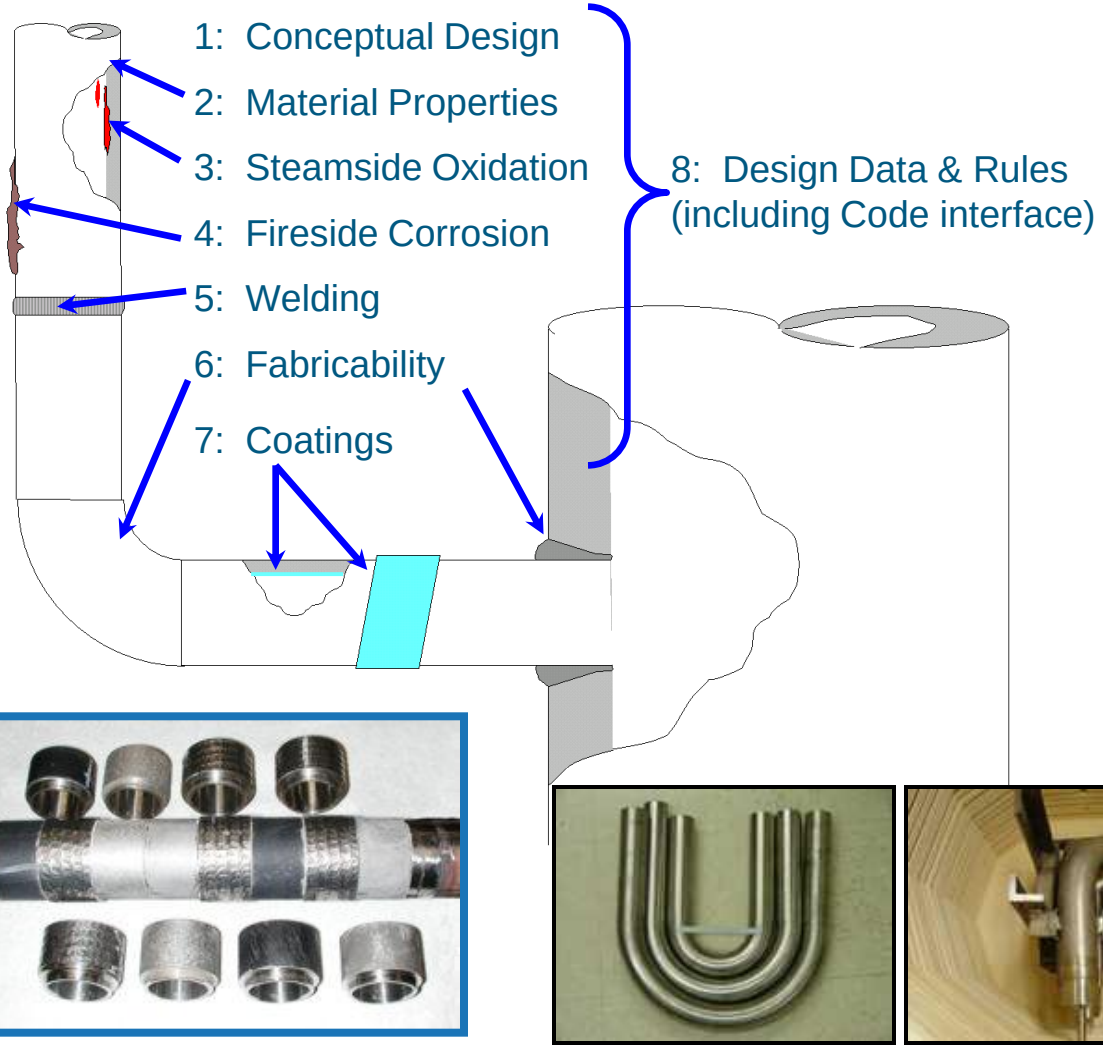
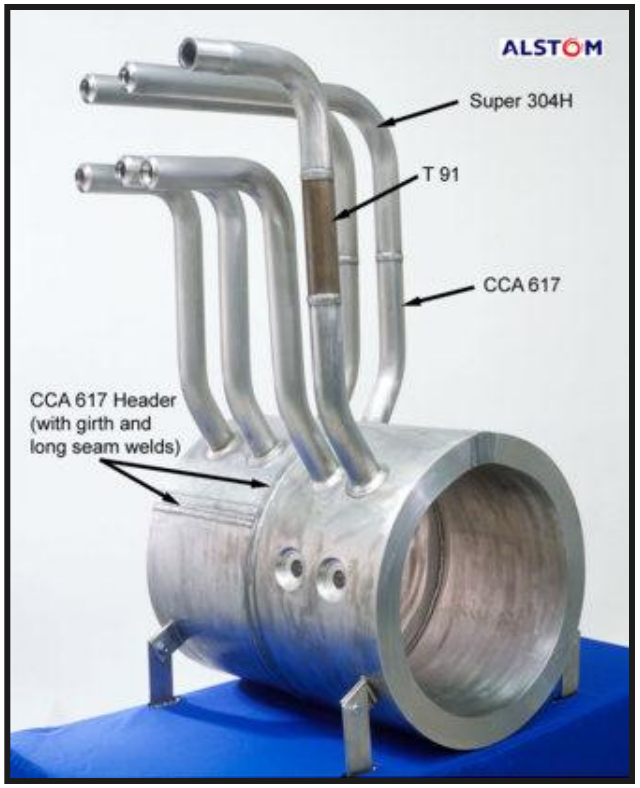
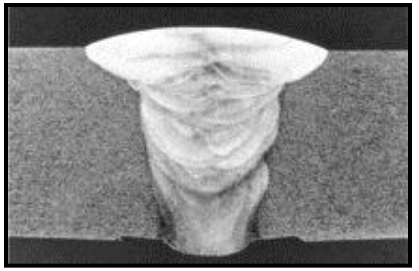
A-USC Development Programs
USA (760ºC)







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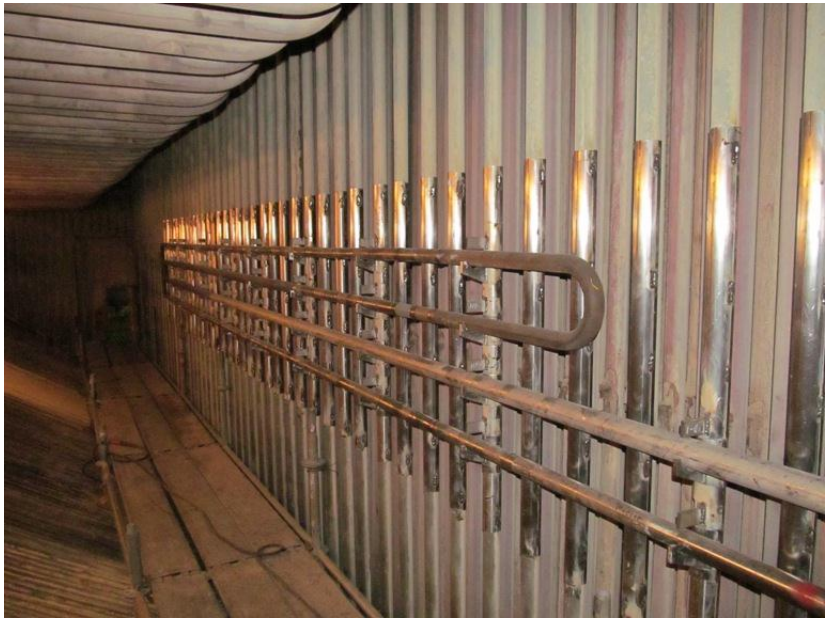
A-USC – USA (760°C)
Barry Steam Loop

Candidate materials for A-USC steam conditions have been installed in an operating coal fired boiler. Field exposure testing at A-USC steam temperature (1400°F) will validate laboratory corrosion and oxidation testing



Loop in operation and planned through mid 2013

Materials included are:

Super304H, HR3C, HR6W, Haynes 230, Haynes 230 with an Amstar thermal spray, Inconel 617, Inconel 617 with EN33 laser cladding, Inconel 617 with EN622 laser cladding, Haynes 282, and Inconel 740

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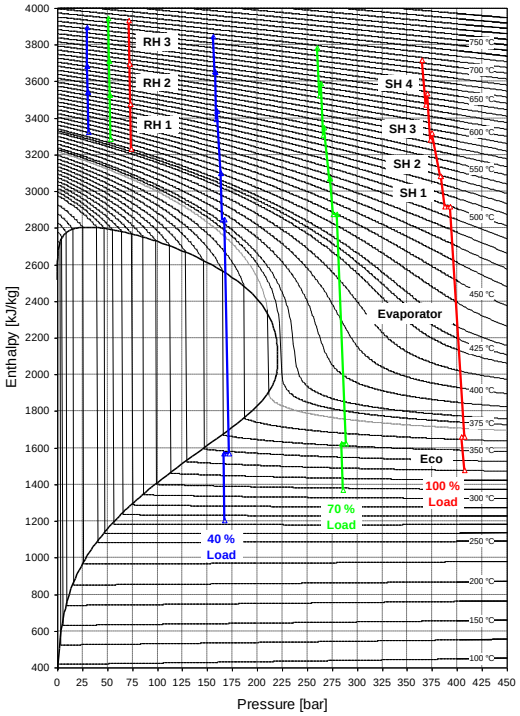
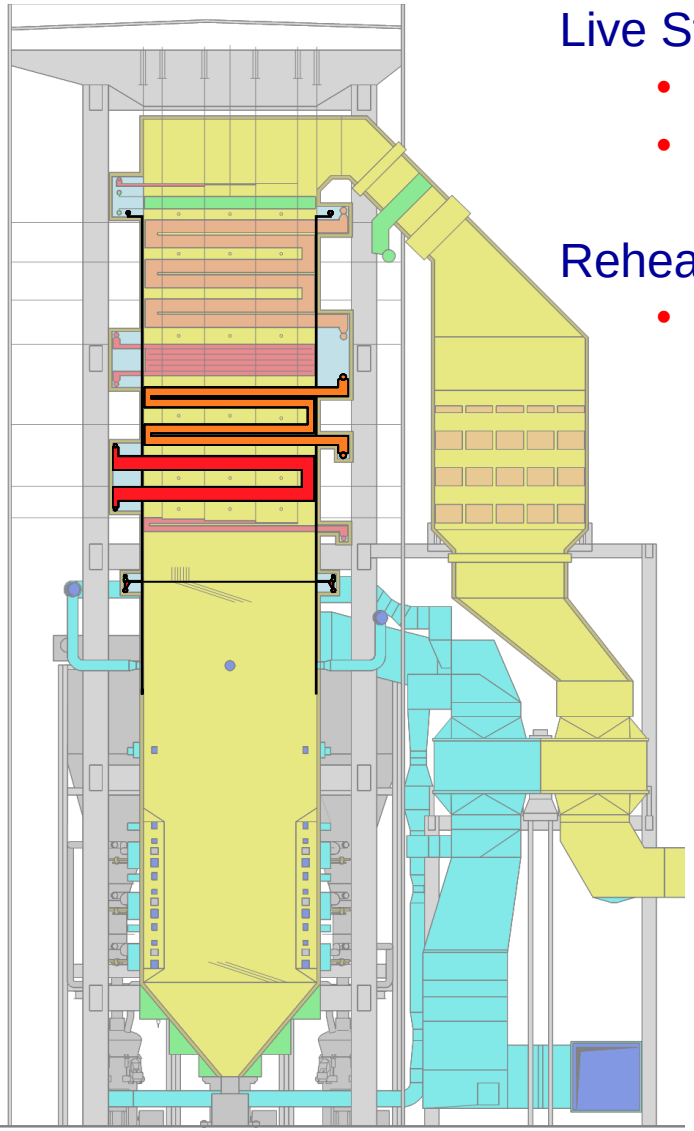
AD700 Boiler Design

Critical Components

- Boiler enclosing walls
- Heating surface final stages
- Header and piping materials
- Valves and fittings





Live Steam
- 350 bar
- 700 °C

Reheat Steam
- 720 °C

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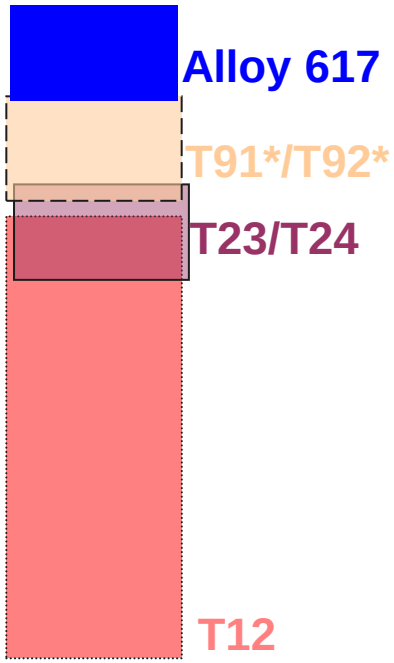
AD700 Boiler Design –
Materials Considerations

ALSTOM

T max

Membrane Walls

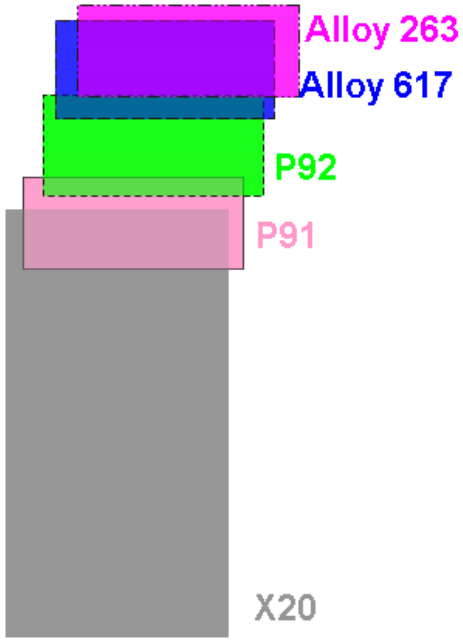


Considering:
- Creep strength
- Oxidation in steam
- *post-weld heat treatment

RH & SH Tubes

Considering:
- Creep strength
- Oxidation in steam
- High-temperature corrosion in flue gas

HP Headers & Piping



Considering:
- Creep strength
- Oxidation in steam
- Fatigue
- Consideration of load change rate (wall thickness & physical properties)

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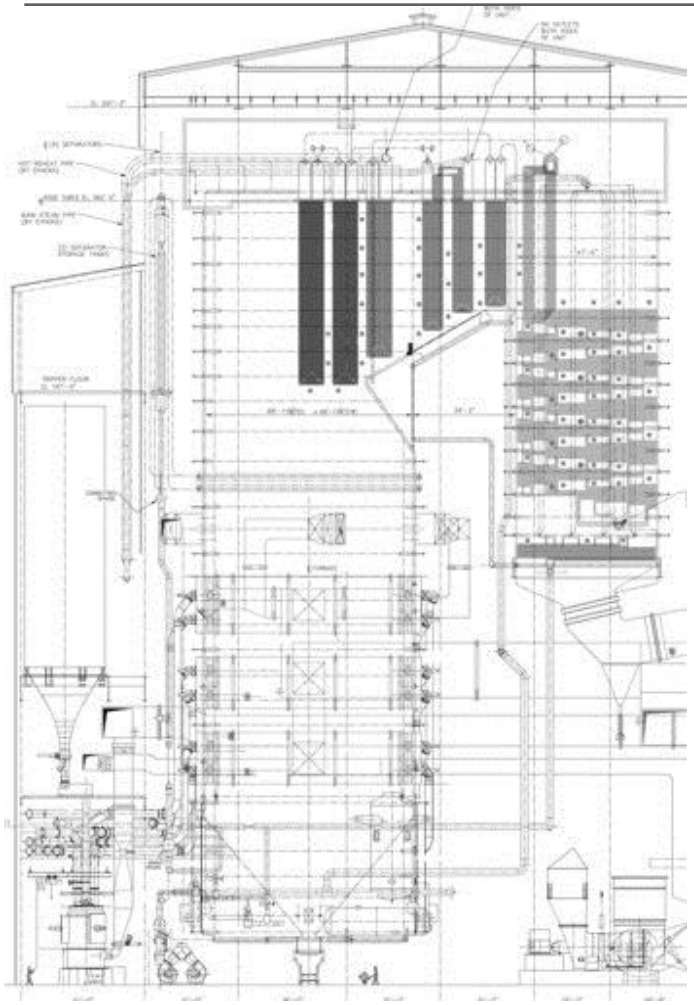
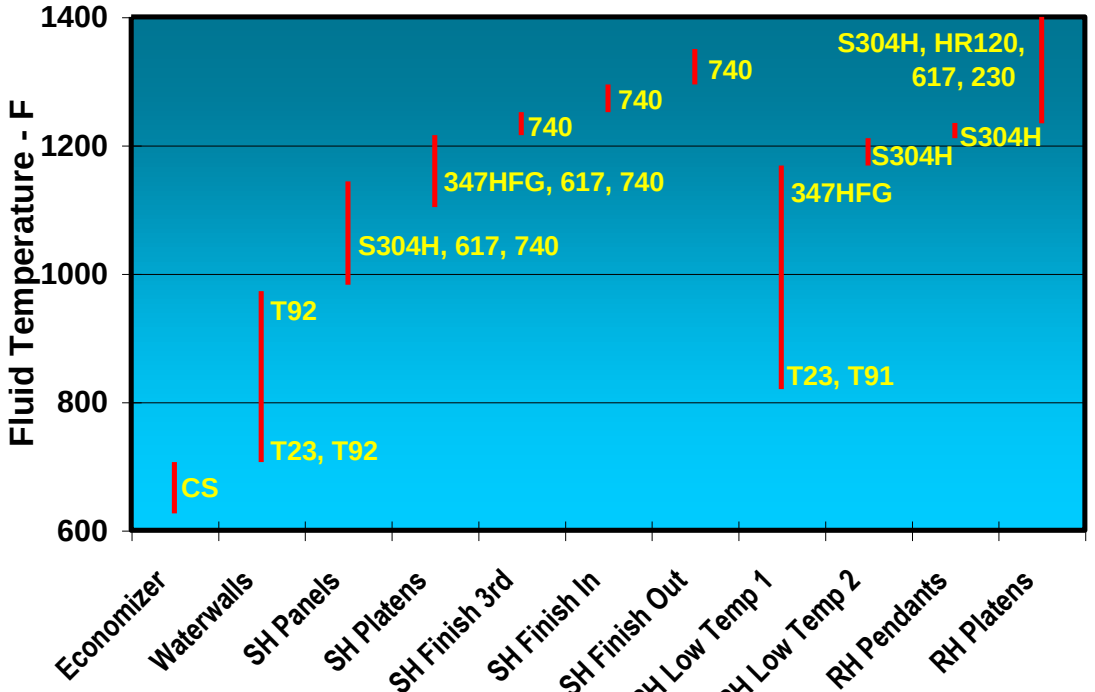
Conceptual Design – 1000MW
A-USC two pass boiler



730C/760C/350bar
1350F/1400F/5500 psi



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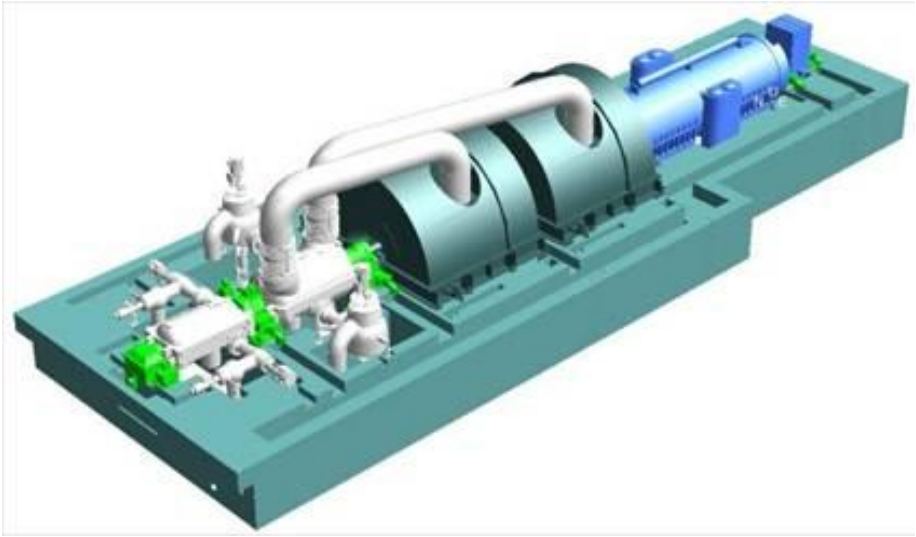
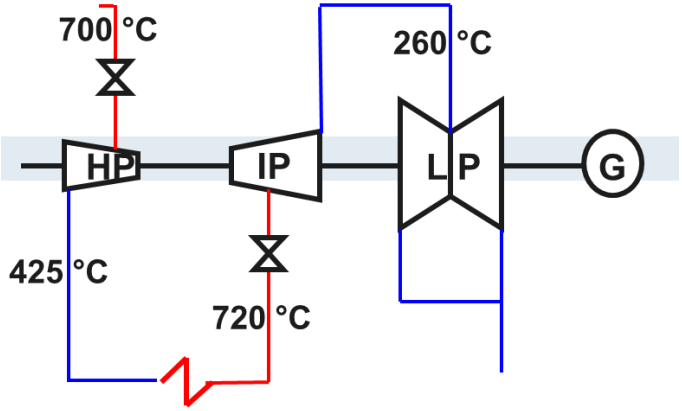
Alstom Concept for 700 °C +

1000 MW arrangement



Example of single reheat arrangement



ALSTOM standard design tools:
Thermodynamic calculations
Steam path design
Rotordynamics

Adaptation by material selection:
Blade materials:
- nickel base alloy
- austenitic steel
- 12% Cr steel

Rotors and casing sections:
- Nickel base alloy & ferritic steel

No change in standard procedures and design rules for a safe introduction of advanced technologies

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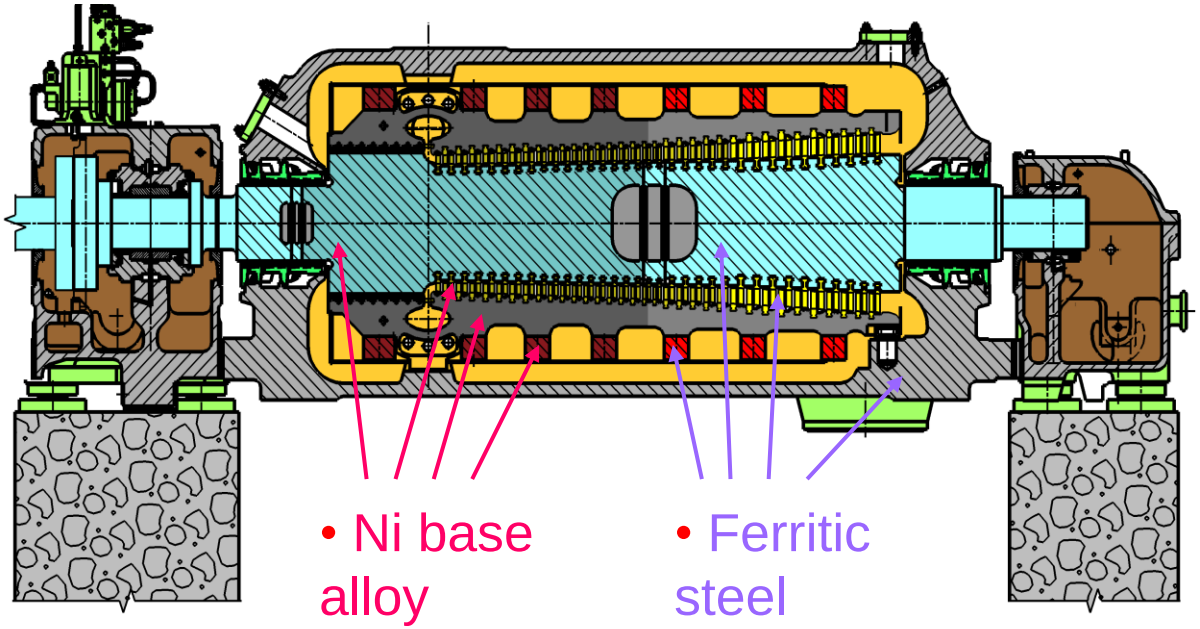
Turbine Design

- Shrink ring design used by Alstom since 1960
- Excellent design for very high pressures and temperatures
  - Very low casing distortion for sustainable efficiencies
  - Relatively thin structure allows good transient behavior



ALSTOM's 700°C turbines stay with proven design adaptation is done by material selection

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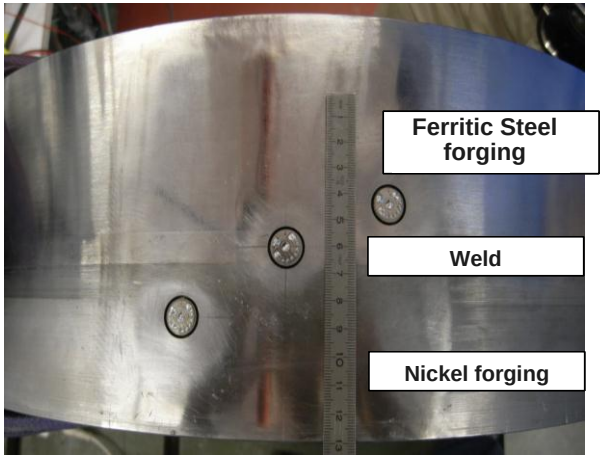
Welded Rotor Design

- Alstom has over 70 years experience in in rotor weld technology - Several thousand welded rotors in operation
- Not a single case of a ruptured welded rotor
- Excellent material testing conditions, good access for ultrasonic testing
- Successful test welds carried out at Alstom:
  - Full scale test block weld between alloy 617 and ferritic steel
  - Full scale test block weld between alloy 625 and ferritic steel



ALSTOM has longest experience in welded rotor technology

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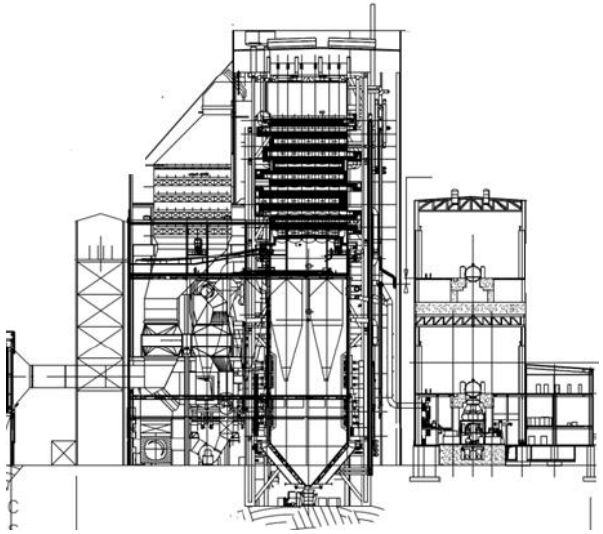
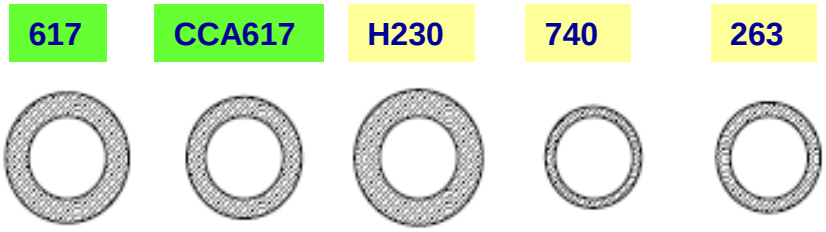
Boiler to Turbine Pipe arrangement

- Live and Reheat steam piping for A-USC plant requires application of Nickel Alloys
- Piping is a significant cost increase in a A-USC plant
- Solutions to reduce piping volume (through thickness decrease) and piping routing (improved plant arrangement) are key drivers to manage A-USC plant costs

- Example of improved plant arrangement (elevated HP turbine)



- Options for Ni alloy pipe



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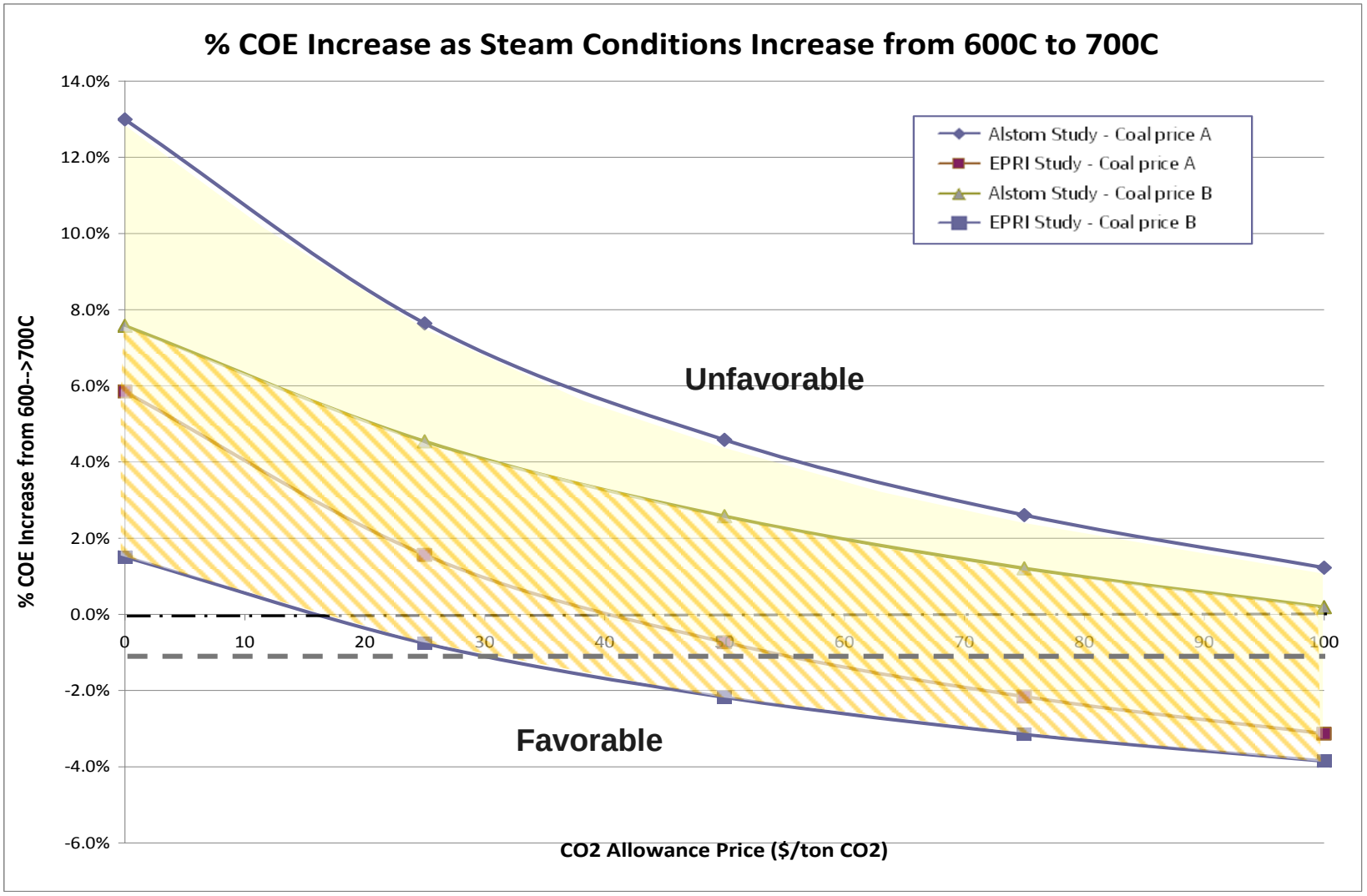
A-USC Economics

- Results from several studies, Alstom and other:



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A-USC Economics

- Economic studies of A-USC (700/760^{o}C) indicate:
  - Cost of Ni-based alloys very high, variable
    - Significantly increases capital cost of boiler, turbine, and high pressure piping
    - Supply chain not mature – potential for future cost reduction
  - w/o CO2 cost
    - Cost of electricity is slightly higher than for USC
      - 1.5-13% higher based on several studies
  - W/ CO2 cost
    - Cost of electricity may be lower than for USC
    - Comparison depends mainly on:
      - CO2 cost
      - Capital cost (amount/cost of Ni-based alloy materials)
  - w/ CCS
    - Cost of electricity is lower than for USC
      - 6% lower based on external studies
      - Including both PCC and Oxy

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Agenda

Overview of A-USC

A-USC Development – Alstom's Historical Involvement

A-USC Boiler Design

A-USC Steam Turbine Design

A-USC Steam Power Plant Design

A-USC Economics

A-USC – Next Steps

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A-USC Development
Key Next Steps

- Major development work is done and the general feasibility has been demonstrated

- Design work is complete based on proven architecture and experience

- A demonstration project is needed, to prove:
  - First-Of-A-Kind [FOAK] A-USC reference
  - Performance and operational characteristics
  - Supply chain for advanced nickel alloy components
  - Cost and economics

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