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U.S. Program on Advanced Ultrasupercritical Power Plant Materials – The Economy of Using Advanced Alloys

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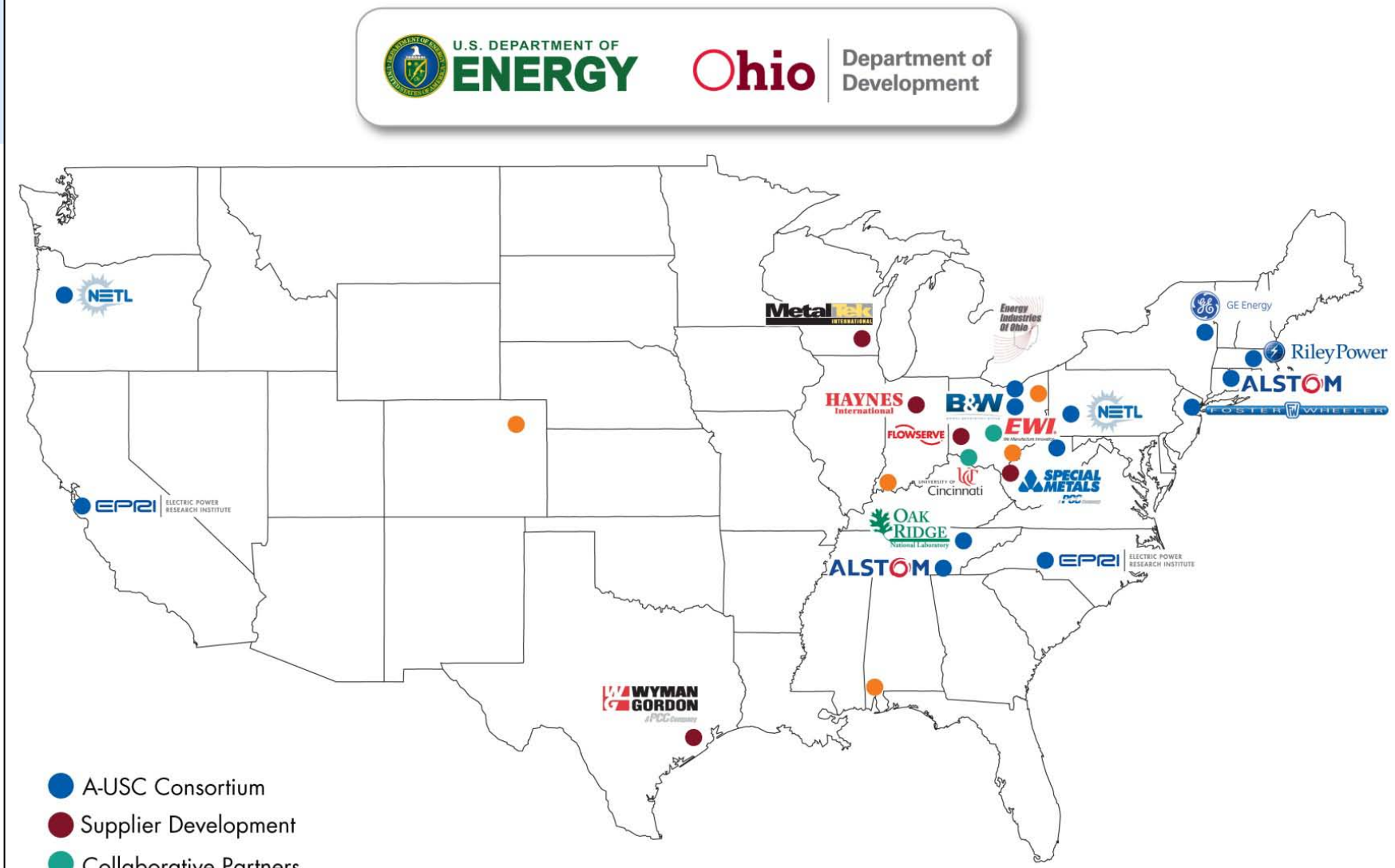
IEA Clean Coal Centre Workshop: Advanced ultrasupercritcial coal-fired power plants
19-20 September 2012, Vienna, Austria



Acknowledgements

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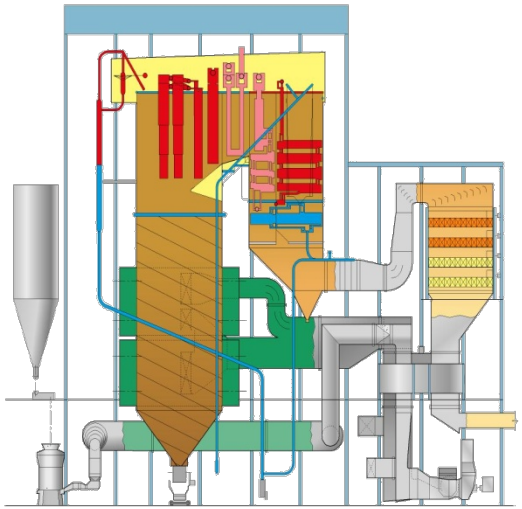
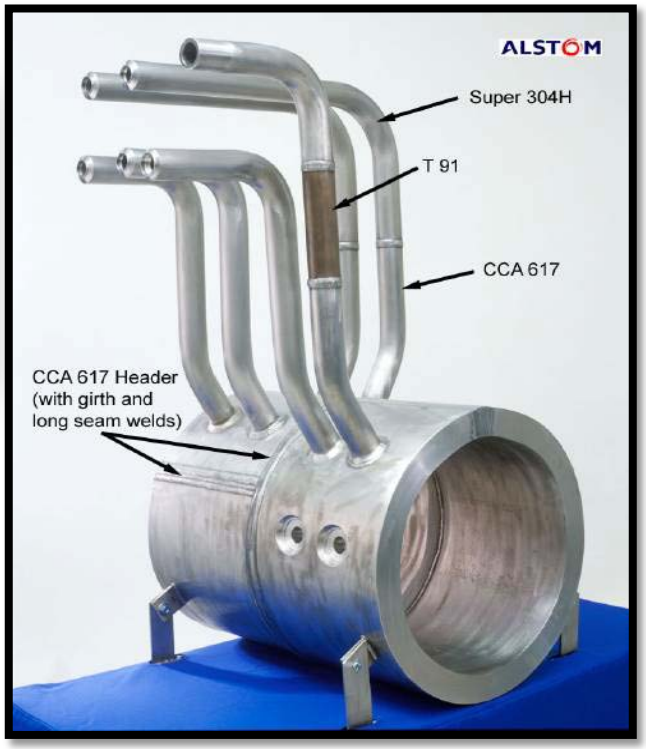
Accomplishments

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

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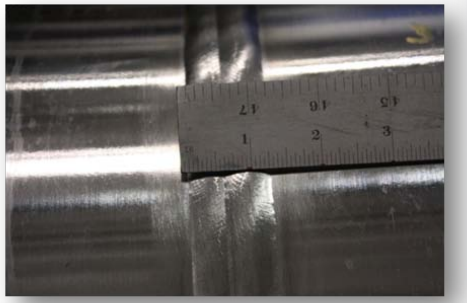
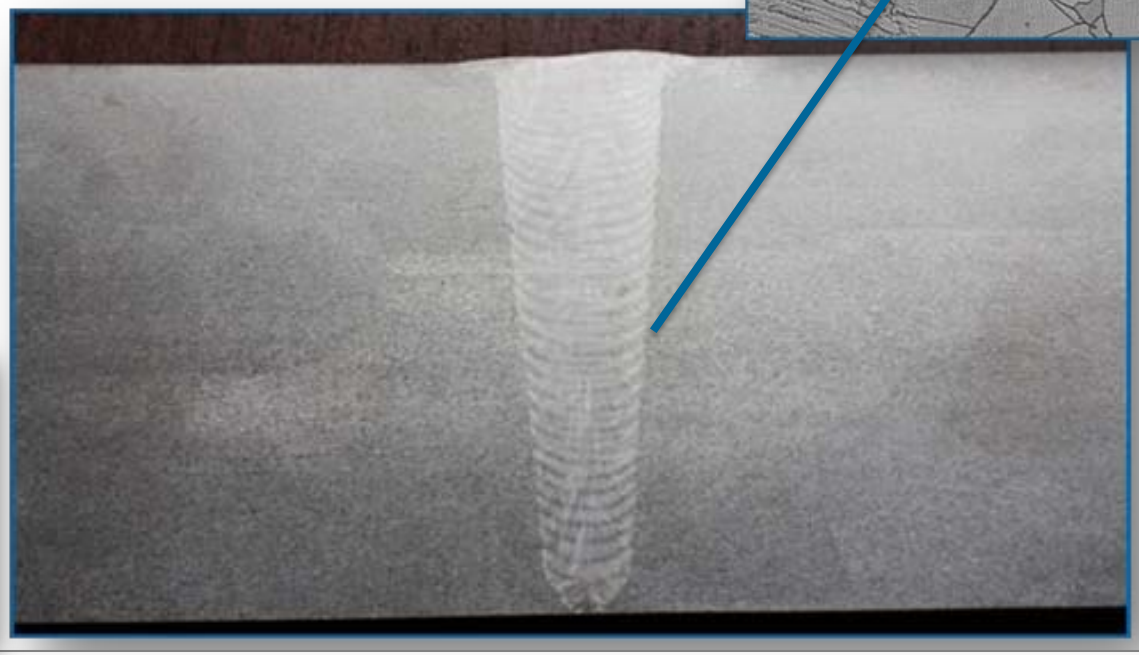
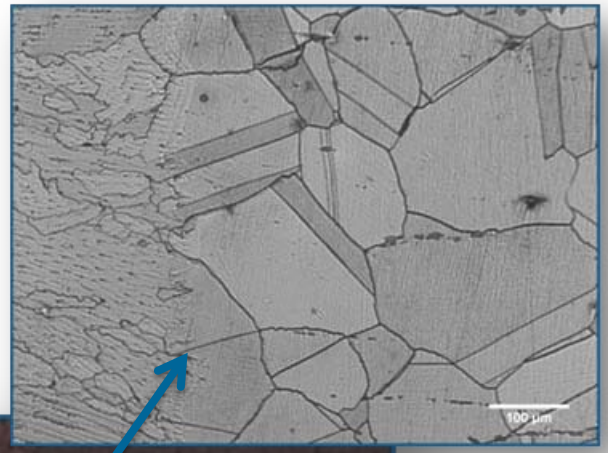
Alloy Selection for A-USC

- High-temperature (creep) strength
- Corrosion & Oxidation
- Fabrication
- Welding
- Cost







76mm (3”) wall thickness full circumferential pipe weld in Inconel 740H

B.A. Baker, et al. Welding and Repair Technology for Power Plants, Tenth International EPRI Conference. June 26-29, 2012 Marco Island, FL USA.

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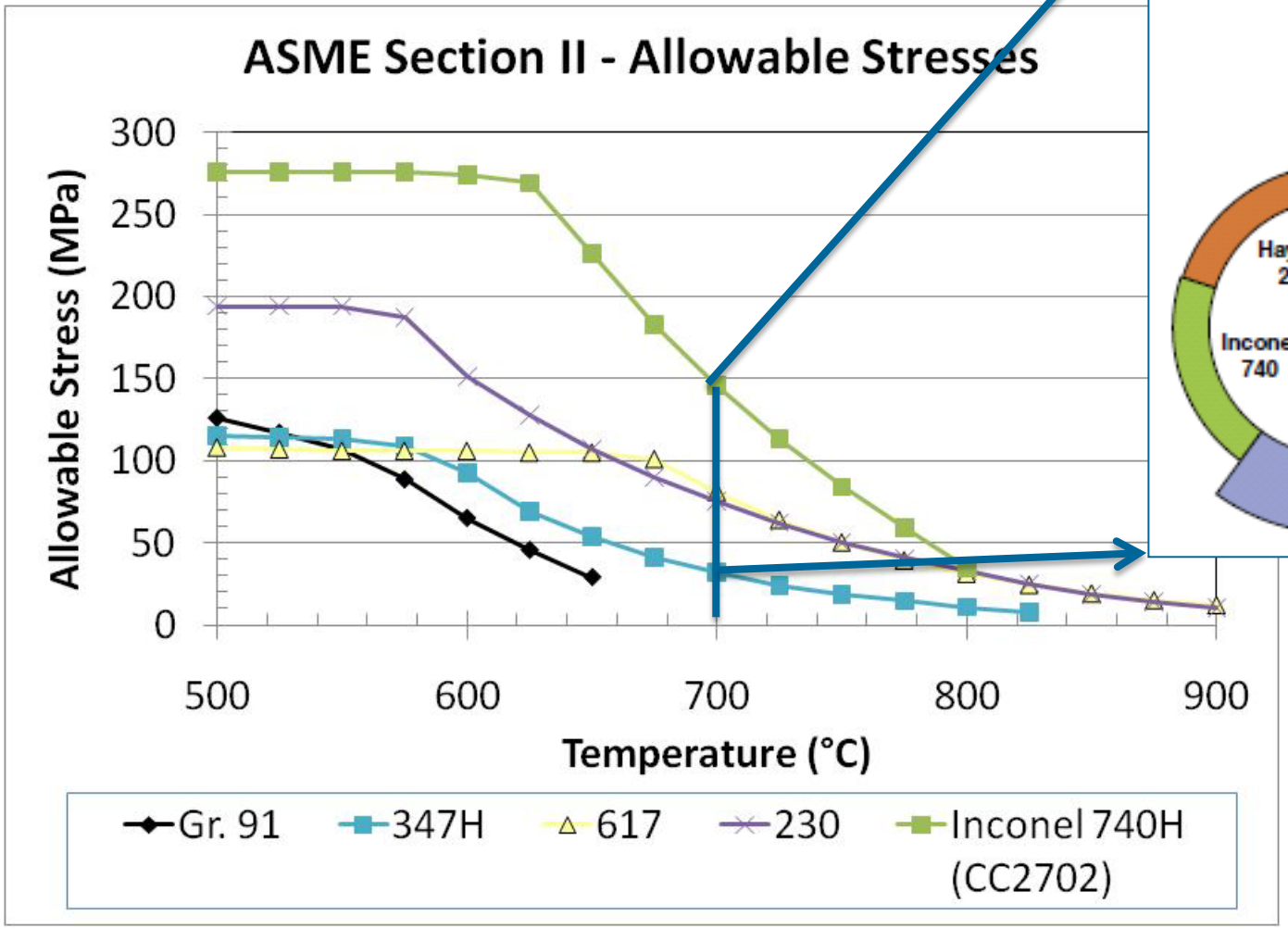
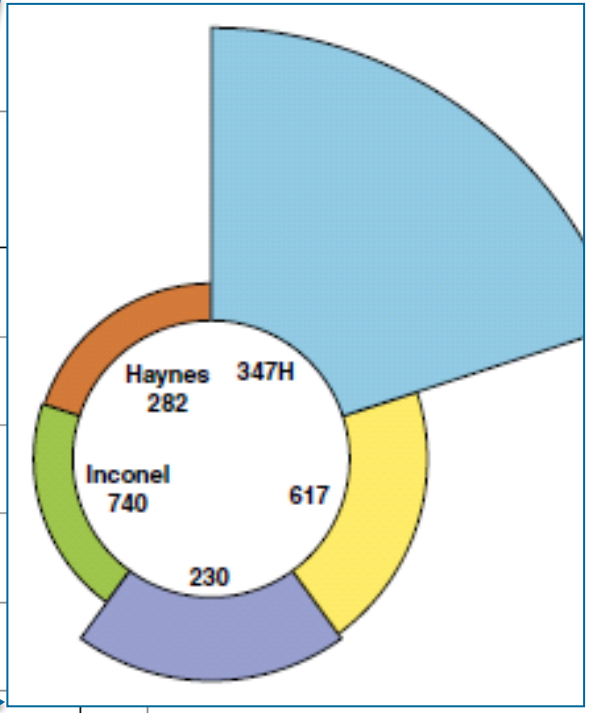
Comparison between two leading candidates: 740H & 617





Higher Allowable Stress for Inconel 740H = Thinner Pipe Walls

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Fabrication: Pipe Extrusion Lengths

Minimum Wall Thickness	8-in (203mm) I.D.	11-in (279mm) I.D.	14-in (355mm) I.D.	17-in (431mm) I.D.	20-in (508mm) I.D.	23-in (584mm) I.D.	26-in (660mm) I.D.	29-in (736mm) I.D.
1.0-in (25.4mm)	40 - 40ft (12.1m)	40 - 40ft (12.1m)	33 - 36ft (10m)	35 - 38ft (10.6m)	27 - 27ft (8.2m)	19 - 34ft (5.7m)	26ft (7.9m)	25ft (7.8m)
1.5-in (38.1mm)	40 - 40ft (12.1m)	32 - 34ft (9.7m)	23 - 34ft (7m)	26 - 26ft (7.9m)	19 - 22ft (5.7m)	19 - 25ft (5.7m)	25ft (8.8m)	18ft (5.4m)
2.0-in (50.8mm)	36 - 36ft (10.9m)	23 - 35ft (7m)	22 - 26ft (6.7m)	19 - 19ft (5.7m)	17 - 23ft (5.1m)	16 - 18ft (4.8m)	18ft (5.4m)	18ft (5.4m)
2.5-in (63.4mm)	27 - 35ft (8.2m)	18 - 28ft (5.4m)	22 - 22ft (6.7m)	19 - 24ft (6m)	17 - 19ft (5.1m)	19ft (5.7m)	18ft (5.4m)	14ft (4.2m)
3.0-in (76.1mm)	26 - 30ft (7.9m)	23 - 36ft (7m)	18 - 25ft (5.4m)	15 - 19ft (4.5m)	18ft (5.4m)	16ft (4.8m)		
3.5-in (88.8mm)	30 - 30ft (9.1m)	20 - 20ft (6.1m)	18 - 21ft (5.4m)	16ft (4.8m)	16ft (4.8m)			
4.0-in (101.5mm)	23ft (7m)	23ft (7m)	18ft (5.4m)	18ft (5.4m)	14ft (4.2m)			
4.5-in (114.2mm)								
Possible Alloy Nimonic 263, 617CCA or Inconel 740H Sizes					Other Possible Inconel 740H Sizes			

Extrusion Dimensions courtesy of Wyman Gordon Pipe & Fitting

Lower flow stress for Inconel 740H allows for longer extrusions and/or larger diameter pipes compared to 617

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Full-Scale Pipe Extrusions Have Confirmed Benefit of Lower Flow Stress for 740H

- Special Metals (Huntington, WV) & Wyman-Gordon (Houston, TX) Project

not consortium funded

- 15-inch (381mm) O.D. X 8-inch (203mm) I.D. X 34-1/2 feet (10.4m) long
- Larger forging window for Inconel 740 compared to CCA617 *(same size pipe extrusion was shorter, 8.9m)*

Inconel® 740H Pipe after Extrusion at Wyman-Gordon Pipe & Fittings

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Basis for Calculations: Dimensions - EPRI Report: 1015699

(download free at: www.epri.com)

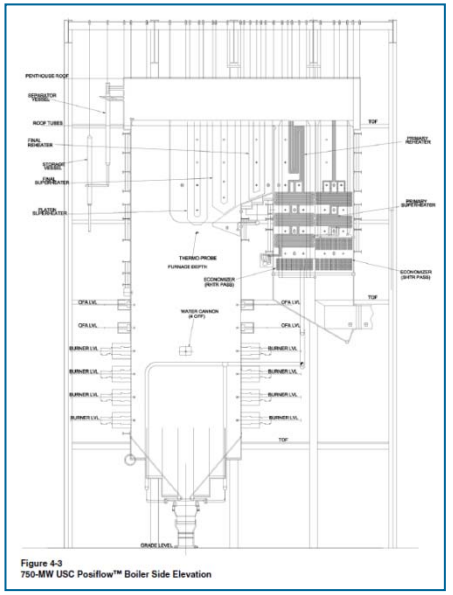
Figure 4-3
750-MW USC Posiflow™ Boiler Side Elevation

- 750 MW A-USC Plant Design: Single Reheat (685/705°C)
- Proposed Piping System Dimensions:
  - 2 Main Steam (MS) Pipes: 250mm (9.8”) ID
  - 2 Hot Reheat (HRH) Pipes: 467 mm (18.4”) ID
  - Minimized boiler to turbine piping length = 128m (421ft)
- This study:
  - Temperatures: 704/704°C (1300/1300°F) and 732/760°C (1350/1400°F)
  - Same MS & HRH pipe ID (equivalent steam flow)
  - Examine 1 versus 2 pipes
  - Assume same piping length

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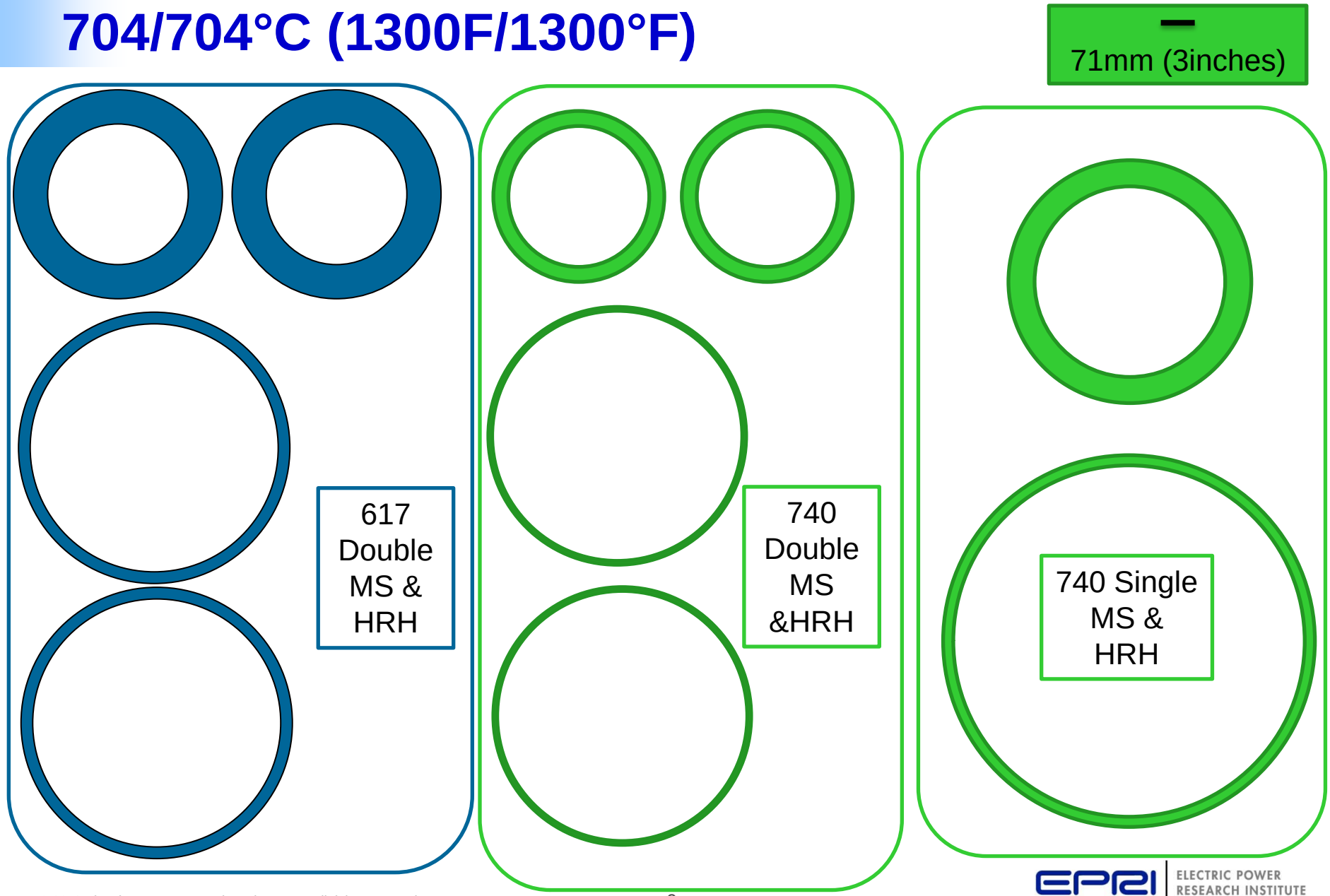
Piping System Comparison: 704/704°C (1300F/1300°F)



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Summary of Piping System Comparison

- 617 Piping System Requires 2 Pipes
- Calculations for 617 single pipe resulted in:
  - Excessive Wall thickness >100mm (4in), or
  - Beyond Extrusion Dimensions (outside forging window)

Material	Temperature	Minimum Total Piping Length Required	MS Dimensions (mm)		HRH Dimensions (mm)		Total Mass of MS+HRH
(# of pipes)	°C (°F)	meters	ID	Wall Thick	ID	Wall Thick	kg
617 (2)	704/704 (1300/1300)	256	249	71	467	23	227,420
740H (2)		256	249	36	467	13	108,548
740H (1)		128	353	51	660	18	109,045
617 (2)	732/760 (1350/1400)	256	249	97	467	41	361,453
740H (2)		256	249	48	467	25	179,819
740H (1)		128	353	69	660	36	179,647

Significant Piping Mass Saving with Inconel 740H

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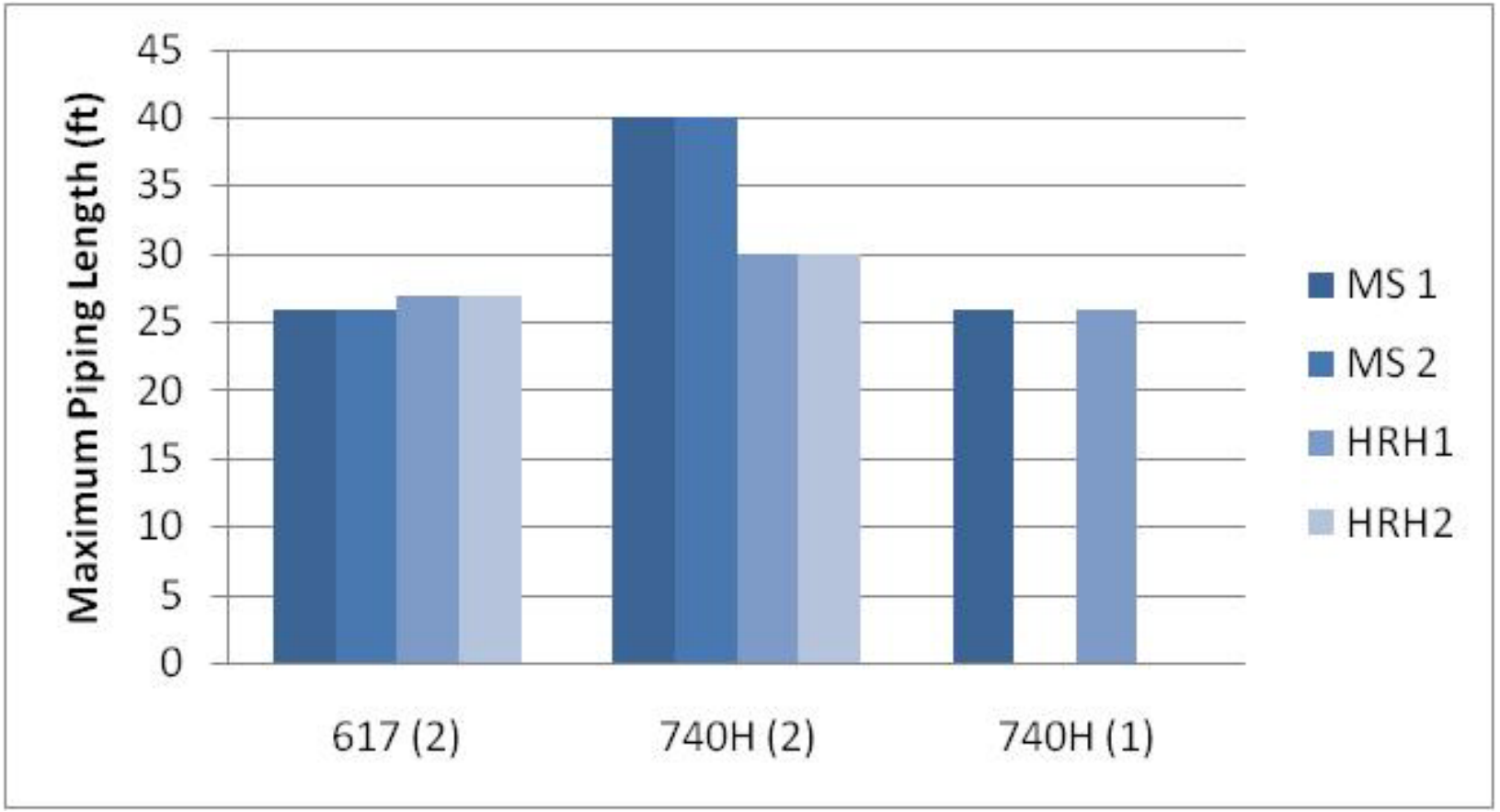
Piping System Comparison: 704/704°C (1300F/1300°F)



Piping Lengths (runs) Are Increased by Using 740H

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Raw Material Cost Comparison

- Nickel-based alloy costs are highly variable
  - Ni, Mo, etc. raw material prices can be volatile
- Assumed delivered piping costs of:
  - $55 USD/kg ($25/lb)
  - $77 USD/kg
  - $110 USD/kg
- Same price & density estimated for 617 and 740H

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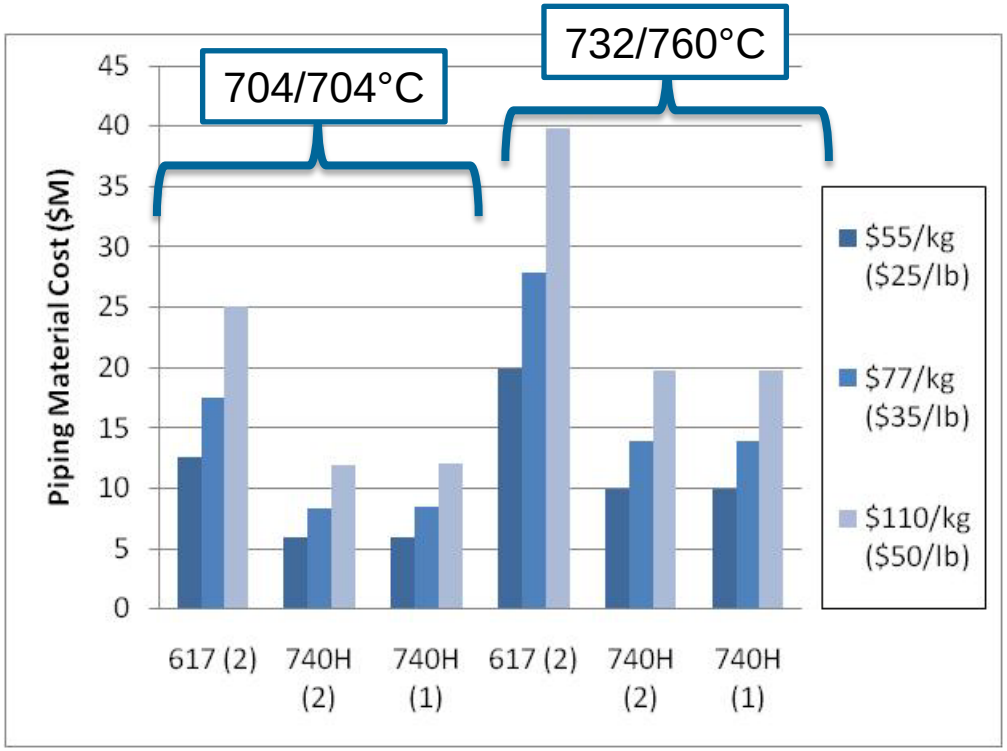
Piping System Cost Comparison

- Delivered pipe cost for 617 is 2 times greater than 740H
- $55/kg ($25/lb) cost are consistent with EPRI Report 1015699 which estimated delivered piping costs of $5-16M USD for piping system



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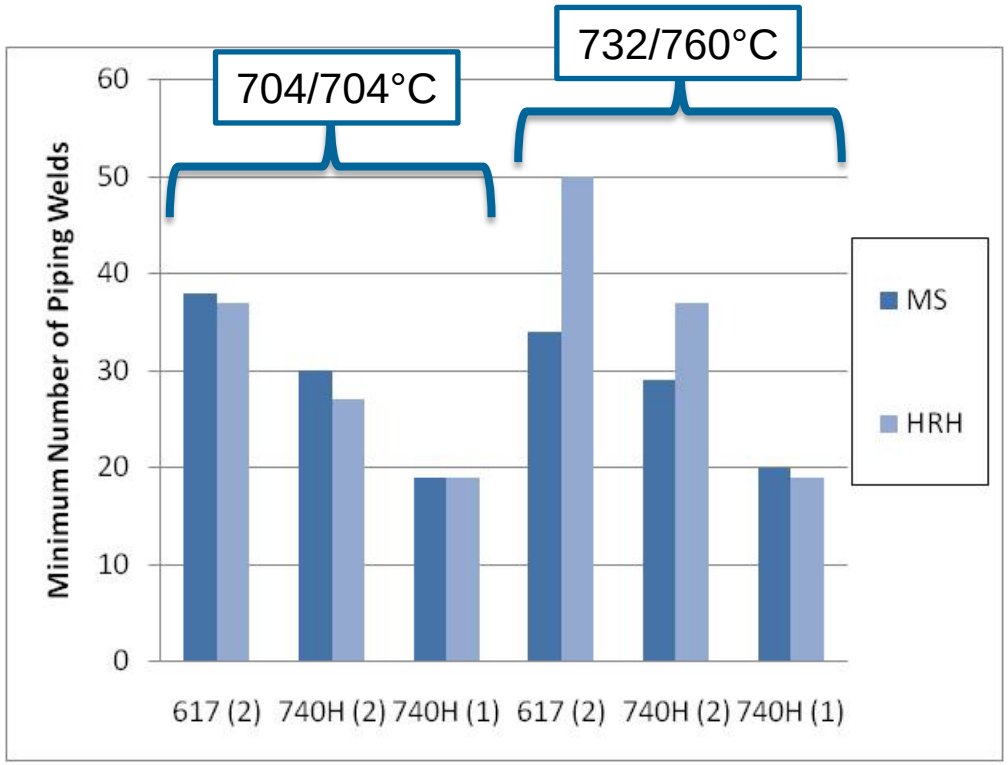
How Many Welds?

- Multiple steam lines lead to increased costs:
  - More welds to make
    - Productivity
    - Weld Metal
  - More welds to inspect
  - More potential locations for life management
- Inconel 740H can reduce the number of welds needed
- Single piping system = 50% less welds



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Welding Costs

Configuration	Temp.	Total Welds		Estimated Weld Metal Cost	Estimated Welding Time
	(°C)	MS	HRH	USD	hrs
617 (2)	704/704	38	37	$37,360	598
740H (2)		30	27	$12,185	195
740H (1)		19	19	$17,715	283
617 (2)	732/760	34	50	$66,494	1,064
740H (2)		29	37	$24,869	398
740H (1)		20	19	$32,595	522

Welding Costs (weld metal cost & welding time) decrease by using 740H

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Summary

- Alloy cost is a major consideration for materials selection for an A-USC system because nickel-based alloys are more expensive than traditional materials
- US DOE/OCDO A-USC Consortium research has developed the materials technology and long-term data to support the use of high-strength nickel-based alloys
- In the example presented here (an A-USC piping system), the use of a high-strength alloy (alloy 740H) allows for significantly reduced costs by minimizing material usage which:
  - Allows for thinner pipe walls
  - Allows longer runs of pipe to be made
  - Reduces the amount of welding and fabrication

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Together…Shaping the Future of Electricity

Acknowledgements

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