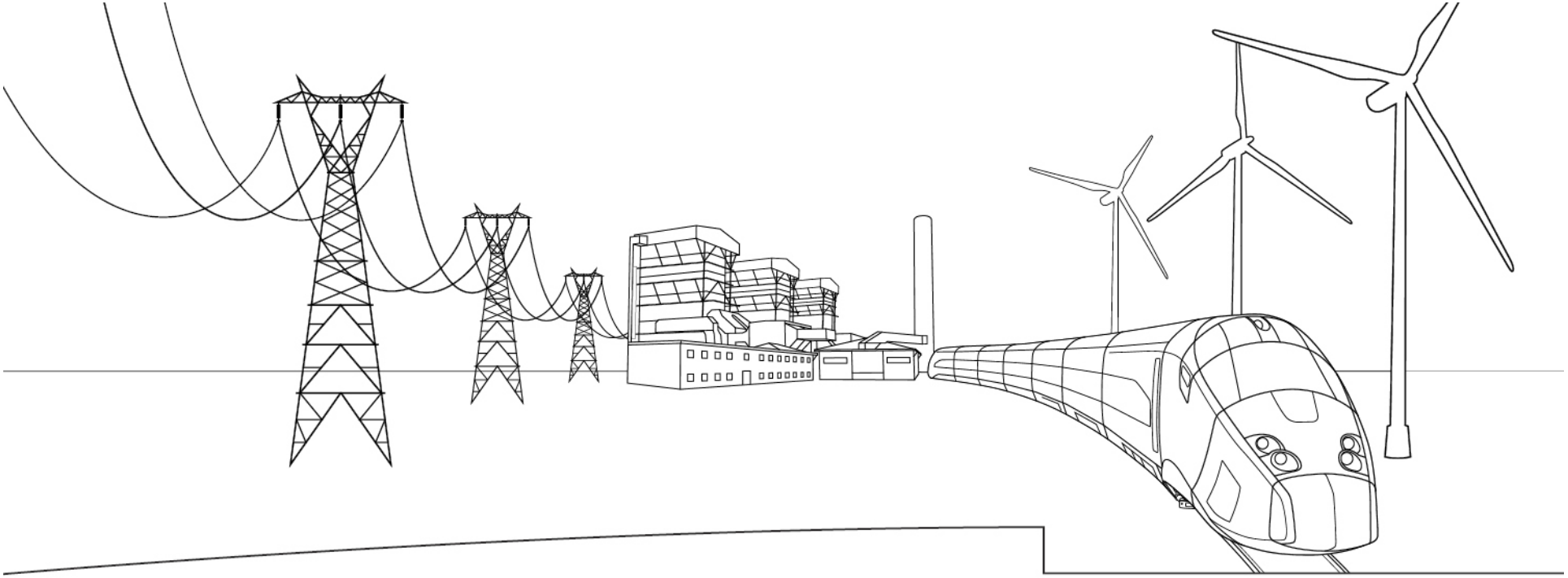

Advanced Ultrasupercritical (AUSC)

Tube Membrane Panel Development

Jim Pschirer

Critical Technology Manager, Boiler Pressure Parts and Mechanical Integration

2015 NETL Crosscutting Meeting, Pittsburgh

04/29/2015

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Shaping the future

AUSC Tube Membrane Panel Development
Agenda

- **Project Objective and Background**
- Project Team and Approach
- Project Selections and Decisions
- Project Current Status and Going Forward

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Tube Membrane Panel Development
Statement of Objective

- The objective of this Project is to develop and prove the manufacturability of welded tube membrane panels made from high performance materials suitable for the AUSC steam cycles of a fossil-fired boiler. (ex. T92, HR6W, IN617, 740)

Straight flat panels in shop

Project Kick-Off Nov. 2014 Project Complete Sept. 2016.

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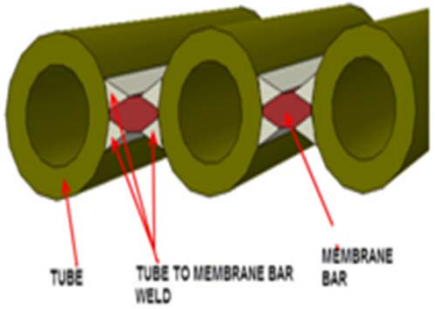
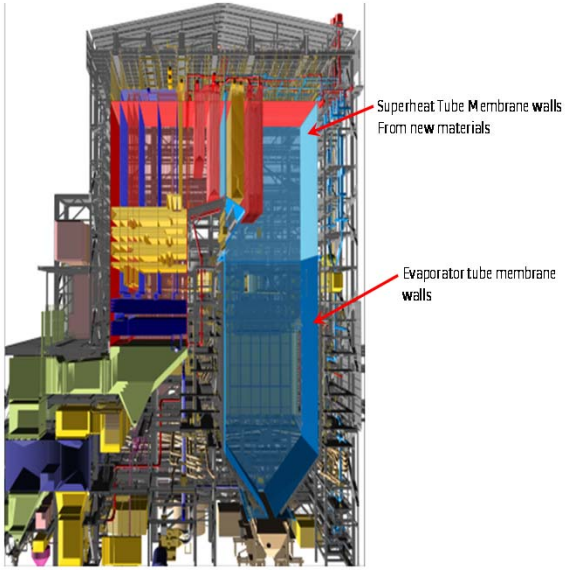
Tube Membrane Panel Development Definitions

Definitions of some of the terms that will be used during this presentation:

- AUSC Steam cycle- Outlet steam temperatures and pressures greater than 700°C (1300°-) / 4000 psi. NETL Target 760°C (1400° F/ 5000 psi.)
- Welded furnace walls, which are frequently referred to as waterwalls, provide the enclosure around a combustion chamber. The upper section of the combustion chamber of an AUSC boiler, **Membrane Panels**.
- Membrane/Fin- Bars, usually rectangular in shape, that are welded to the tube. These bars perform several functions
  1. Along with the tubes form the gas seal of the gas chamber
  2. provide heat transfer surface
  3. provide structural support





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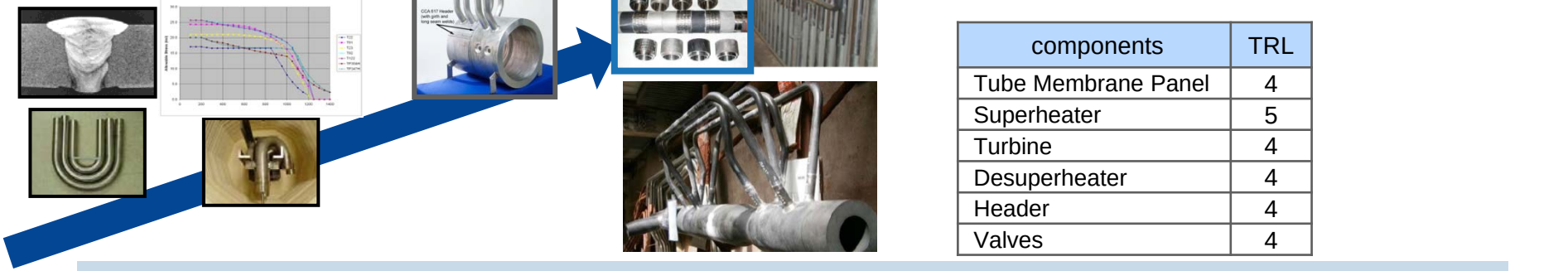
Advanced Ultrasupercritical Development through Demo

Technology Readiness Levels

Roadmap to AUSC Demo

2000 | 2005 | 2010 | 2015 | 2020 | 2025

Materials Development	Component Mockup	Steam Loop at Plant Barry	AUSC-COMTEST	AUSC Demonstration
Laboratory TRL 2 to 3	**Proof of Concept TRL 4**	**Component Test TRL 4 to 5**	**System TRL 6 to 8**	**Overall TRL to 9**



components	TRL
Tube Membrane Panel	4
Superheater	5
Turbine	4
Desuperheater	4
Header	4
Valves	4

Current DOE-sponsored programs designed to bring components to TRL 5;
AUSC-COMTEST will bring system to TRL 7 or 8

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Tube Membrane Panel Development
Technical Background

- A U.S. industry consortium led the development of materials to enable the use of advanced steam cycles in coal-based power plants since 2001 and with co-funding by the U.S. Department of Energy - NETL and the Ohio Coal Development Office.

- Gap Identified: February 2003 Topical Report, "Boiler Materials for Ultra Supercritical Coal Power Plants", written by Alstom:
  - "Application of T92 alloy for the construction of waterwalls is technically challenging and requires advanced manufacturing techniques that need to be fully developed yet. Nevertheless, implementation of this alloy or similar alternate is **necessary** to enable higher pressure cycle designs".

- From Power Engineering June 2014 publication:

  From this article the challenge remains to identify candidates and prove manufacturability.

For boilers operating in the 650°C to 700°C range, materials with a higher allowable stress will be required. Potential candidate materials include T91, T92 and T122. The use of these materials for membrane water walls will be a challenge since they require post-weld heat treatment (PWHT).

- Why the Gap still exists? Efforts of the various international developments have focused only on the Nickel alloy research.

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Tube Membrane Panel Development
Potential Significance

- Using today's "traditional" alloys (T22, T23, T24…) for abusive conditions, whether during manufacturing or during service, has contributed significantly to the favorable service experience of the boiler fleet.

Boiler wall layout in Shop

- AUSC membrane panel may not have the same tolerance for these abusive conditions. The panels constructed from advanced materials require special care during fabrication to retain obtain their superior properties and characteristic microstructures.

- For this reason it is imperative that issues associated with the fabrication of membrane-welded panels fabricated using advanced alloys be investigated and manufacturing verified so that potentially disruptive problems can be identified and technically feasible resolutions of those problems developed as part of the effort.

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AUSC Tube Membrane Panel Development
Agenda

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- Project Selections and Decisions
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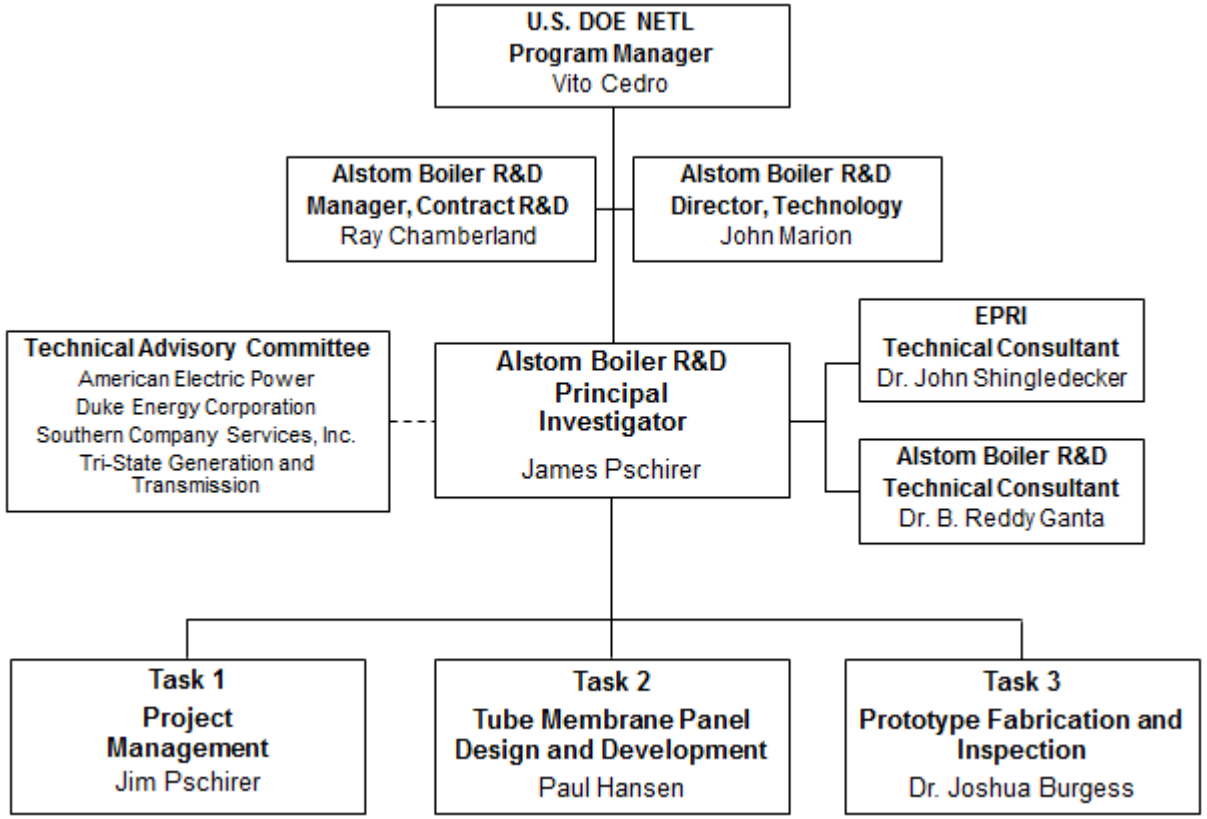
Tube Membrane Panel Development Project Team



- Alstom team comprised of members of Boiler R&D in Windsor Ct. and the Materials Lab in Chattanooga Tn.
  - Manufacturing of the Panels will be done in the Manufacturing Plant in Chattanooga Tn.

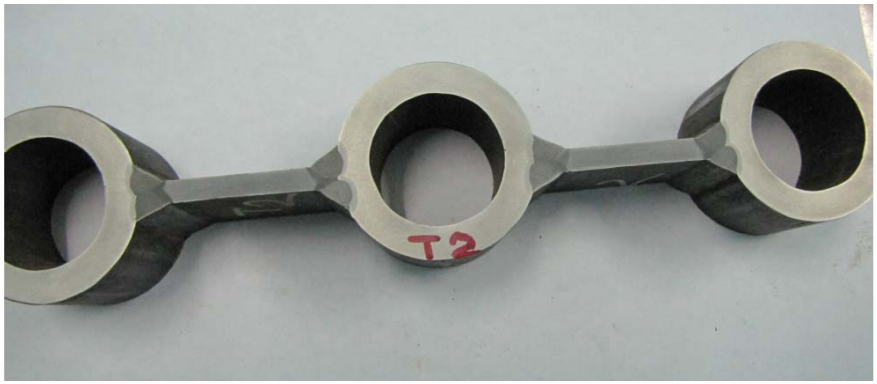
Tube Membrane Panel Development
Technical Approach

Alstom has divided the tube membrane panel development Project into three major Tasks with a number of Subtasks

Task 1.0 Project Management and Reporting

Task 2.0 Tube Membrane Panel Design and Fabrication Development

Task 3.0 Prototype Fabrication and Inspection



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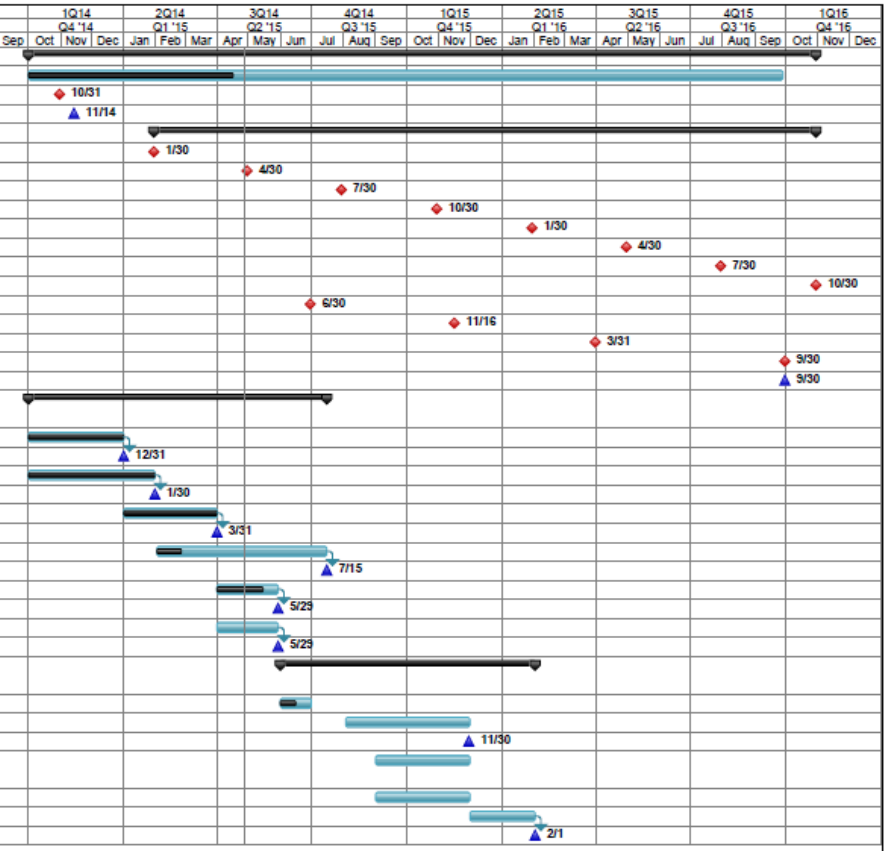
Tube Membrane Panel Development
Project Milestones

ID	Task Name	% Complete	Duration	Start	Finish
1	**Task 1.0 - Project Management and Planning**	**27%**	**546 days**	**Wed 10/1/14**	**Sun 10/30/16**
2	Task 1.0: Project Management and Planning	27%	523 days	Wed 10/1/14	Tue 9/27/16
3	M1 - D1: Updated Project Management Plan	0%	0 days	Fri 10/31/14	Fri 10/31/14
4	M2: Project Kickoff Meeting	100%	0 days	Fri 11/14/14	Fri 11/14/14
5	**M3 - D2: Quarterly Progress / Financial Reports**	**0%**	**459 days**	**Fri 1/30/15**	**Sun 10/30/16**
6	Q1 Reports	100%	0 days	Fri 1/30/15	Fri 1/30/15
7	Q2 Reports	0%	0 days	Thu 4/30/15	Thu 4/30/15
8	Q3 Reports	0%	0 days	Thu 7/30/15	Thu 7/30/15
9	Q4 Reports	0%	0 days	Fri 10/30/15	Fri 10/30/15
10	Q5 Reports	0%	0 days	Sat 1/30/16	Sat 1/30/16
11	Q6 Reports	0%	0 days	Sat 4/30/16	Sat 4/30/16
12	Q7 Reports	0%	0 days	Sat 7/30/16	Sat 7/30/16
13	Q8 Reports	0%	0 days	Sun 10/30/16	Sun 10/30/16
14	M4 - D3: Task 2 Topical Report	0%	0 days	Tue 6/30/15	Tue 6/30/15
15	M5 - D4: Annual Progress Report	0%	0 days	Mon 11/16/15	Mon 11/16/15
16	M6 - D5: Task 3 Topical Report	0%	0 days	Thu 3/31/16	Thu 3/31/16
17	M7 - D6: Final Report	0%	0 days	Fri 9/30/16	Fri 9/30/16
18	M8: Project Closeout Meeting	0%	0 days	Fri 9/30/16	Fri 9/30/16
19	**Task 2.0 - Tube Membrane Panel Design and Fabrication Development**	**63%**	**206 days?**	**Wed 10/1/14**	**Wed 7/15/15**
20	Task 2.1: Develop Project Specifications	100%	66 days	Wed 10/1/14	Wed 12/31/14
21	M9: Completion of Technical Project Specification	100%	0 days	Wed 12/31/14	Wed 12/31/14
22	Task 2.2: Down Select Candidate Materials	100%	88 days?	Wed 10/1/14	Fri 1/30/15
23	M10: Down Select Alloys	100%	0 days	Fri 1/30/15	Fri 1/30/15
24	Task 2.3: Perform Engineering Design of the Tube Membrane Panel	100%	64 days?	Thu 1/1/15	Tue 3/31/15
25	M11: Completion of tube membrane design	0%	0 days	Tue 3/31/15	Tue 3/31/15
26	Task 2.4: Develop Manufacturing Procedures	15%	118 days?	Mon 2/2/15	Wed 7/15/15
27	M12: Develop Manufacturing procedures	0%	0 days	Wed 7/15/15	Wed 7/15/15
28	Task 2.5: Develop Manufacturing Drawings	75%	43 days?	Wed 4/1/15	Fri 5/29/15
29	M13: Detailed Design Drawings	0%	0 days	Fri 5/29/15	Fri 5/29/15
30	Task 2.6: Develop Non Destructive Examination Test Plan	0%	43 days?	Wed 4/1/15	Fri 5/29/15
31	M14: NDE Test Plan	0%	0 days	Fri 5/29/15	Fri 5/29/15
32	**Task 3.0 - Prototype Tube Membrane Panel Fabrication and Inspection**	**4%**	**177 days?**	**Mon 6/1/15**	**Mon 2/1/16**
33	Task 3.1: Procure Materials for Prototype Tube Membrane Panel	50%	22 days?	Mon 6/1/15	Tue 6/30/15
34	Task 3.2: Fabricate Prototype Tube Membrane Panels	0%	86 days?	Mon 8/3/15	Mon 11/30/15
35	M15: Fabricate membrane panels	0%	0 days	Mon 11/30/15	Mon 11/30/15
36	Task 3.3: Perform Non Destructive Examination of Fabricated Panels Prior to PWHT (if required)	0%	65 days?	Tue 9/1/15	Mon 11/30/15
37	Task 3.4: Perform Heat Treatment of Fabricated Panels	0%	65 days?	Tue 9/1/15	Mon 11/30/15
38	Task 3.5: Perform Non Destructive Examination	0%	46 days?	Tue 12/1/15	Mon 2/1/16
39	M16: Perform Final NDE of Membrane Panels	0%	0 days	Mon 2/1/16	Mon 2/1/16



Project On Schedule for Completion Sept 2016

Project: AUSC Tube Membrane Panel
Date: Mon 4/27/15

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Progress
Split	External Tasks	Inactive Summary	Manual Summary	Deadline
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

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AUSC Tube Membrane Panel Development
Agenda

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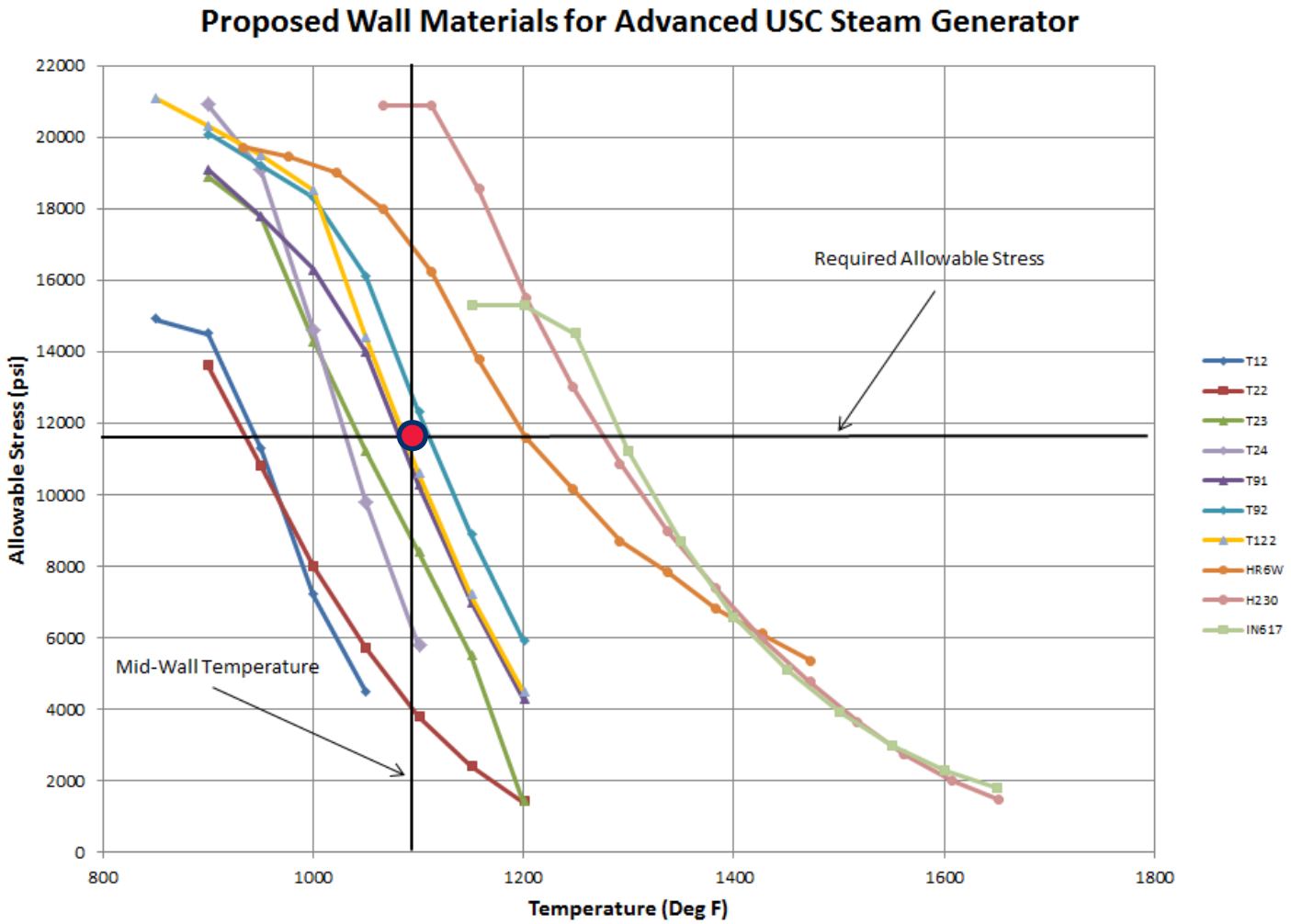
Tube Membrane Panel Development
Material Selection



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Project Decisions To Date

Tubing Selection:

- Two materials selected, T92 and HR6W.
  - **T92** in-line with the Topical Report, “Boiler Materials for Ultra Supercritical Coal Power Plants” as well as other published papers.
  - 2nd material, **HR6W**. Chosen for several reasons
    - Approved by ASME.
    - Choosing another CSEF material was not truly giving the designer a choice, the materials are so similar the welding and handling would be basically the same
    - The design temperature in the region of the boiler could be modified and surface transferred to another location but the choice still remains another CSEF material.
    - Austenitic materials not in line with Code for “Wetted” service
    - Use of the HR6W pushes to use of Ni Alloys, which once mastered can provide reference for some of the higher Ni Alloys such as 617.

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Project Decisions To Date

- Selection of membrane bars for T92
  - A Ferritic SS edge bars was chosen so a field PWHT would not be required
  - The remainder of the panel will use a 91 fin bar because 92 is not readily available in bar plate form.
- Selection of fillers and flux suitable for 92
- Selection of configurations such as width and thickness, weld penetration, opening, and overall panel width in line with Alstom Manufacturing and Design Standards.
  - At this time there is no evidence that current practice will not meet the objective.

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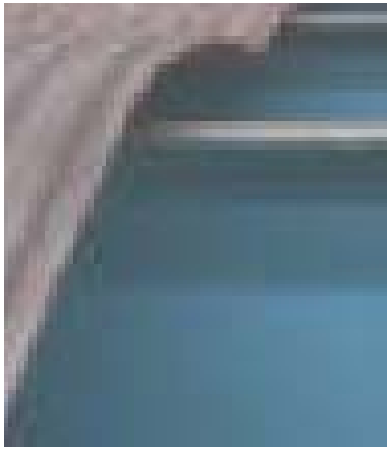
What are we looking for

- Control of weld penetration to satisfy mechanical and heat transfer requirements
- Control of the deformation to acceptable tolerances.
  - Panels routinely require straightening in the workshop after welding and heat treatment, the question to be answered is can the shop then meet the required dimensional tolerances for successful site installation?

Bowing



Camber

- Can existing shop handling procedures be used as-is without adding excessive controls that will add cost and schedule.
- A CSEF steel will be prone to cracking in the coarse-grained HAZ due to hydrogen-delayed cracking. The inherent restraint of a membrane-welded panel will magnify the potential significance of this problem.
- The importance of preheating and its maintenance through the welding process could cause a number of handling and shop processing issues that will substantially increase cost.

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Inspection

- A non-destructive inspection will be performed recording results for items such as:
  - hardness of weld and HAZ
  - overall weld shrinkage
  - tube ovality
  - Tube-to-membrane bar weld to verify that no cracking in the weld, bars, or tube
  - distortion of panel prior to and after PWHT

  - The panels will be inspected again after “shop handling” for any cracking in welds, bars, or tubes.

Additional Inspections may be requested by PI during fabrication stages

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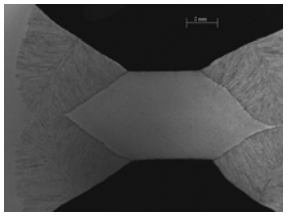
What are we looking for?

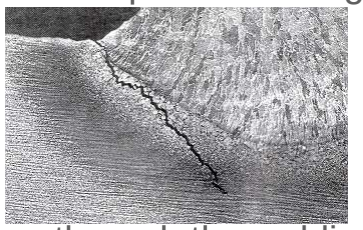
- **Weld Parameters**
  - Control of weld parameters to satisfy mechanical and heat transfer requirements



- **Deformation**
  - Control of the deformation to acceptable tolerances.
  - Panels routinely require straightening in the workshop, the question to be answered is can the shop then meet the required tolerances for successful site installation?

- **Handling**
  - Can existing shop handling procedures be used as-is

- **Cracking**
  - A CSEF steel is susceptible to cracking in the coarse-grained HAZ due to hydrogen-delayed cracking. The inherent restraint of a membrane-welded panel will magnify the potential significance of this problem.



- **Preheating**
  - The importance of preheating and its maintenance through the welding process could cause a number of handling and shop processing issues that will substantially increase cost.

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AUSC Tube Membrane Panel Development
Agenda

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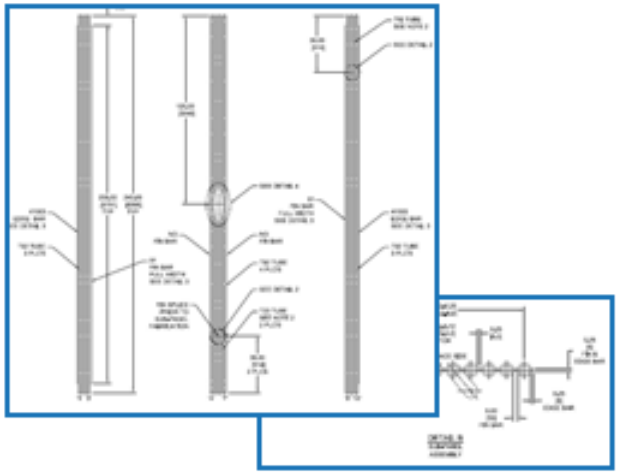
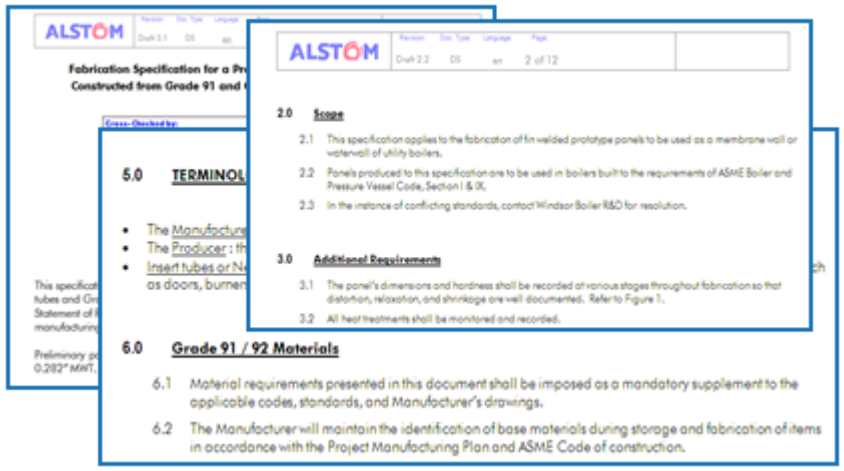
Tube Membrane Panel Development
Current Project Status

- Status to date:
  - Overall Project Specification Complete.
  - Two Materials have been Selected T92 and HR6W.
  - Specification and drawings T92 panel fabrication Complete.
  - Specification for HR6W in draft form, drawings in draft
  - Quotation for supply of HR6W tube being sought
  - T92 tube in manufacturing facility and in lab for mock-ups





Specifications and Drawings will be updated/revised based on Lab mockups

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Going forward

- Fabricate mock-up T92 panels to set parameters such as weld travel speed, heat input, obtain hardness readings, determine weld shrinkage, wire and flux…
- Complete purchase of HR6W and accept delivery
- Select Filler, Flux, and membrane bars for HR6W
- Fabricate and test T92 prototype panels in manufacturing facility
- Fabricate HR6W mock-up panels in lab

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We are looking forward to a successful Project and thank The DOE-NETL for this opportunity.

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