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Preparation and Testing of Corrosion- and Spallation-Resistant Coatings

University Turbine Systems Research Workshop
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Project Overview

- The University of North Dakota and the Energy & Environmental Research Center (EERC) are working with Siemens Power Generation to test a new method for joining high-temperature alloys for use in advanced high-hydrogen-gas-burning turbines.
- Will bond thin plates of oxidation- and spallation-resistant Kanthal APMT™ to high-strength CM247LC and Rene® 80 using evaporative metal (EM) bonding.
- Bonded parts, with and without thermal barrier coatings (TBCs), will be tested for oxidation, corrosion, and spallation resistance.

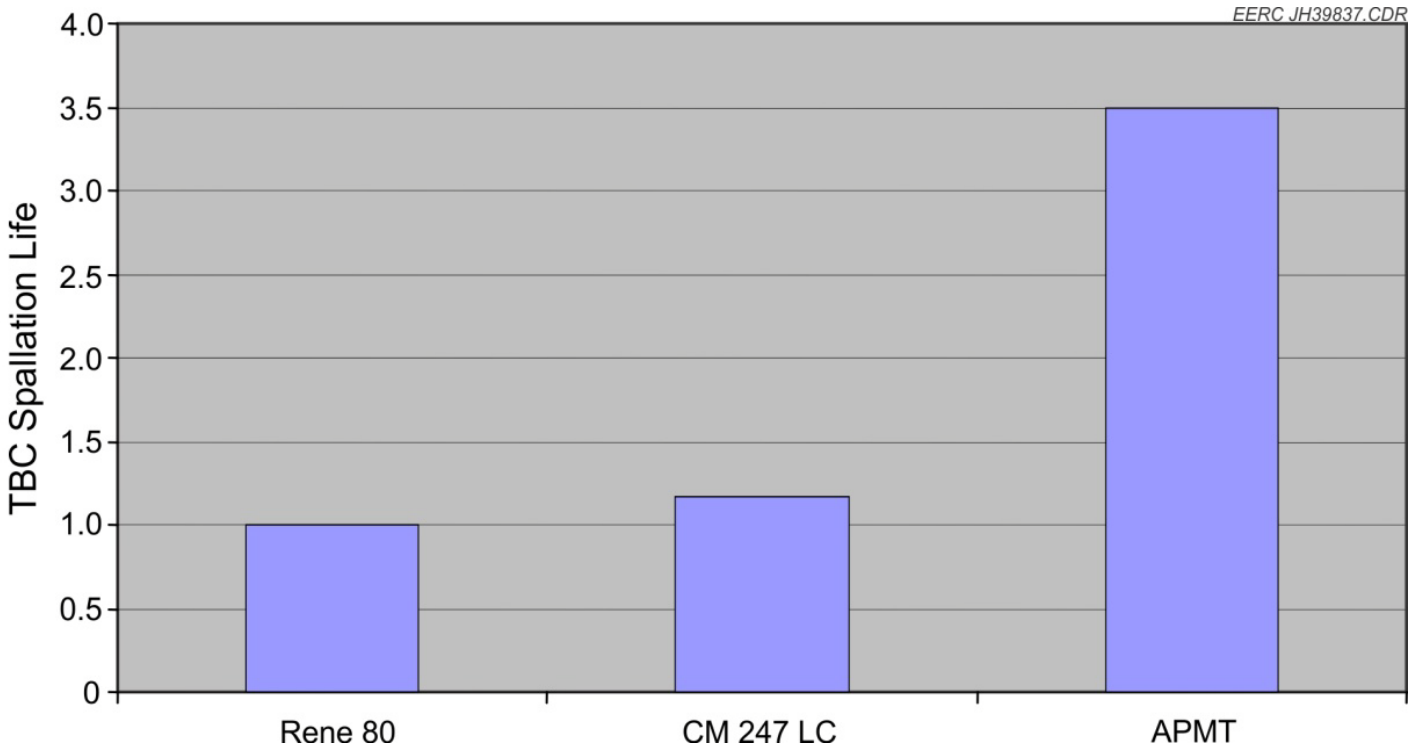
Alloy Compositions

Composition of Kanthal APMT in wt % – Dispersion-Strengthened						
	Cr	Al	Mo	Mn	Si	Fe
APMT	22	5	3	0.4	0.7	Balance

Composition of CM 247 LC in wt % – Gamma Prime-Strengthened													
	Fe	Ni	Cr	Al	Ti	Co	Mo	Ta	W	Nb	Hf	Mn	Si
CM247LC	–	Balance	8.1	5.6	0.7	9.5	0.5	3.2	9.5	0.1	1.4	–	–

Composition of Rene 80 in wt% – Gamma Prime-Strengthened												
	Cr	C	Mo	W	Ti	Nb	Co	Al	B	Fe	Zr	Ni
Rene 80	14.2	0.16	4.0	4.1	5.1	0.03	9.4	3.0	0.02	0.10	0.04	Balance

TBC Spallation Lifetimes



Testing at Siemens Energy Inc. shows that the spallation lifetime of TBCs on APMT is three times that of a similar coating on Rene 80 or CM247LC.

Alloy Oxidation Rates

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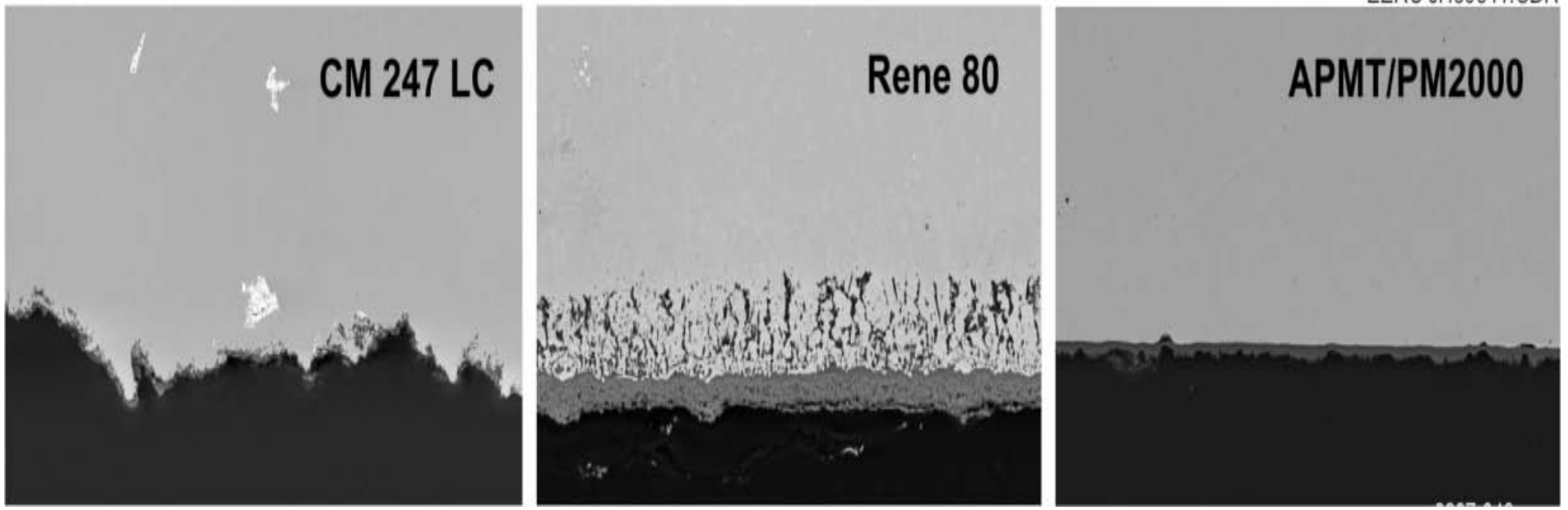
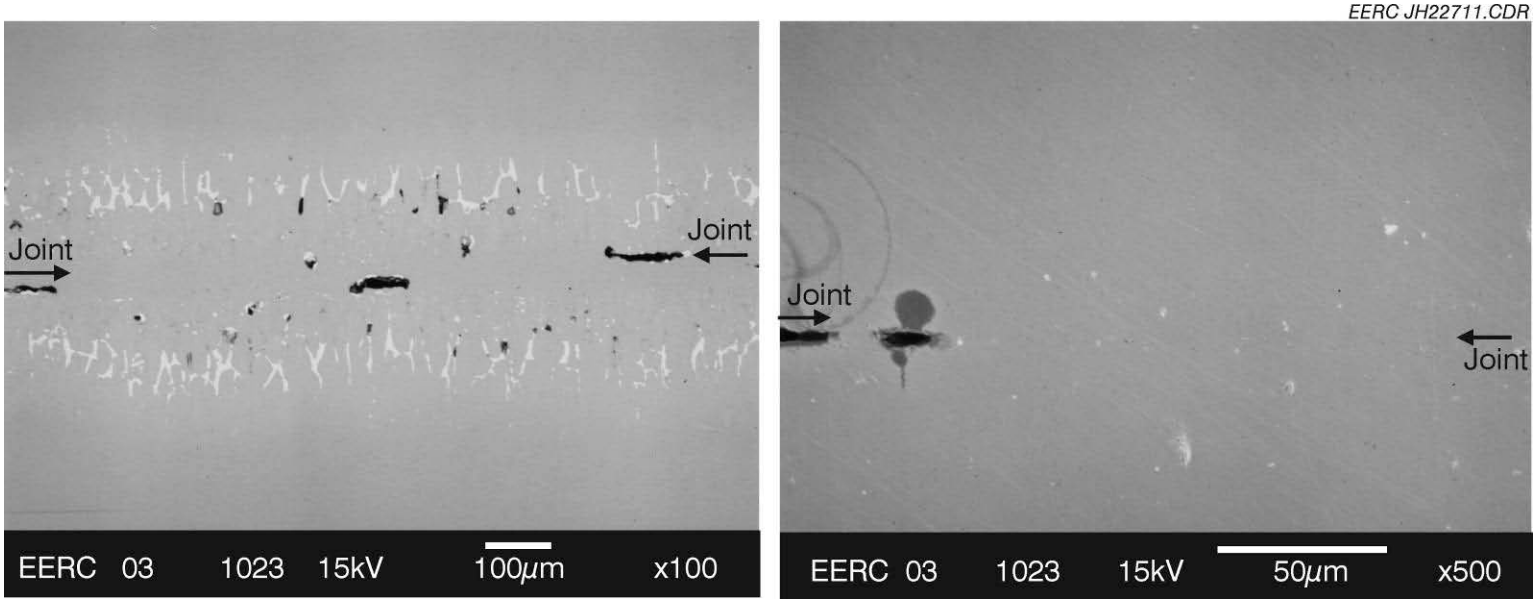


The oxidation rate of APMT is much lower than for CM247LC or Rene 80.

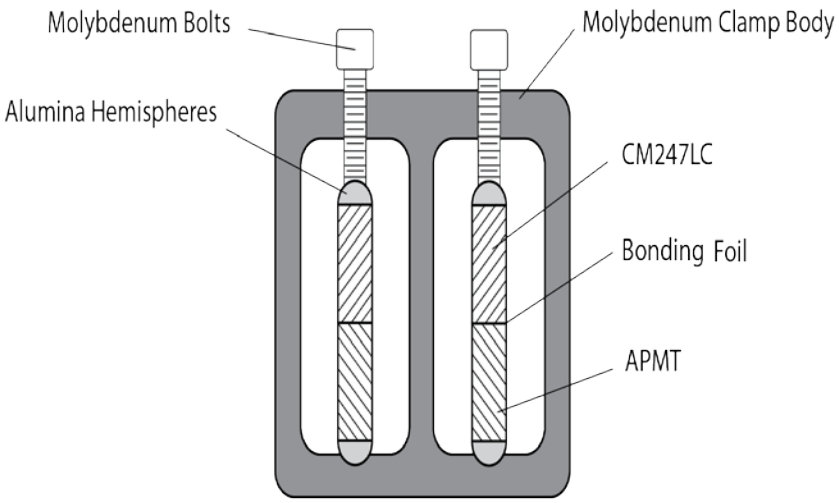
Transient Liquid-Phase (TLP) Bonding – Previous Work



- Welding of advanced alloys is not possible because critical structures are destroyed.
- TLP bonding uses a reactive braze that diffuses away from the joint.
- Bonding alloys need to have low melting points, be soluble, and not form intermetallics.

Articulated Clamping System

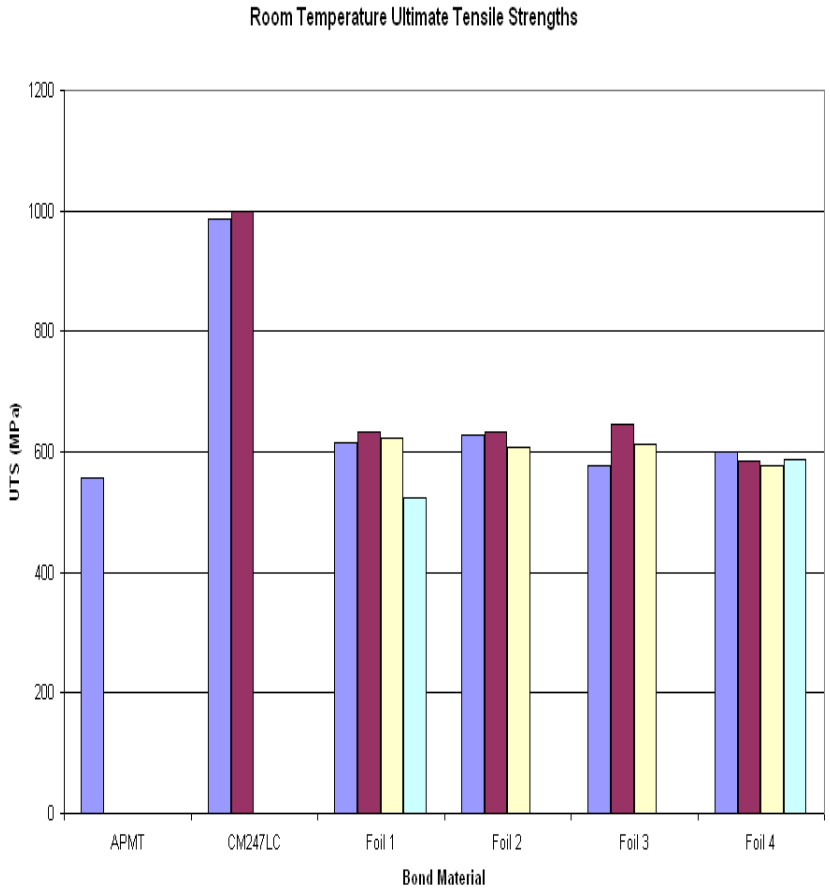
- Initial tests done with rods polished flat.
- Clamp made from low-CTE metal (Mo).
- Ceramic hemispheres used to articulate the pieces, which is necessary because of the thinness of the foils.
- Later joints done with thin sandwiches of APM® and APMT and with complex curves.



Clamping System for Joining APMT to CM247LC

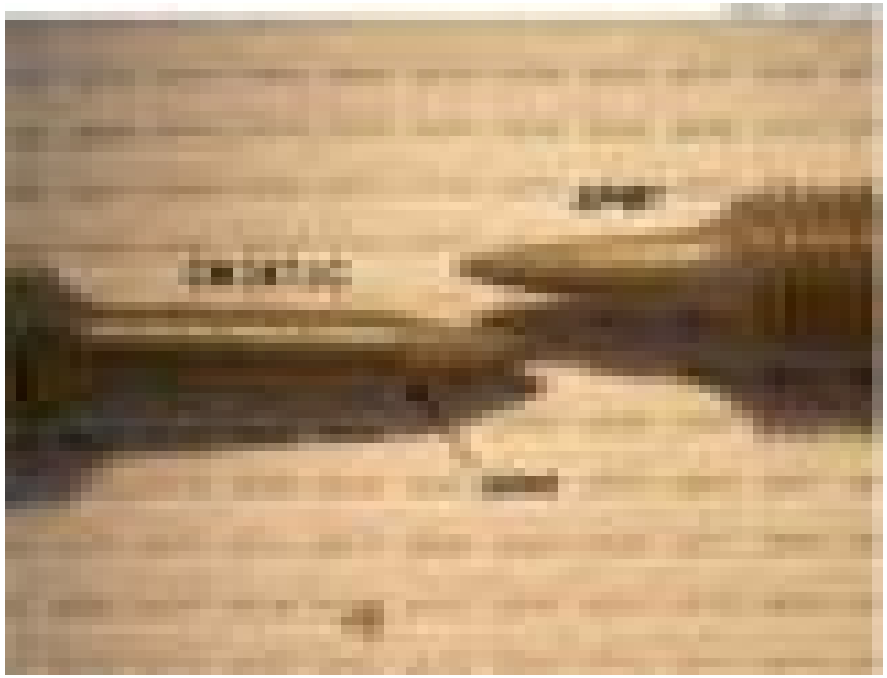
Room-Temperature Tests of Multiple Joining Metals

- Room-temperature ultimate tensile strength results for joints made with four joining alloys.
- All samples broke within the APMT, showing the joints are stronger than the APMT.



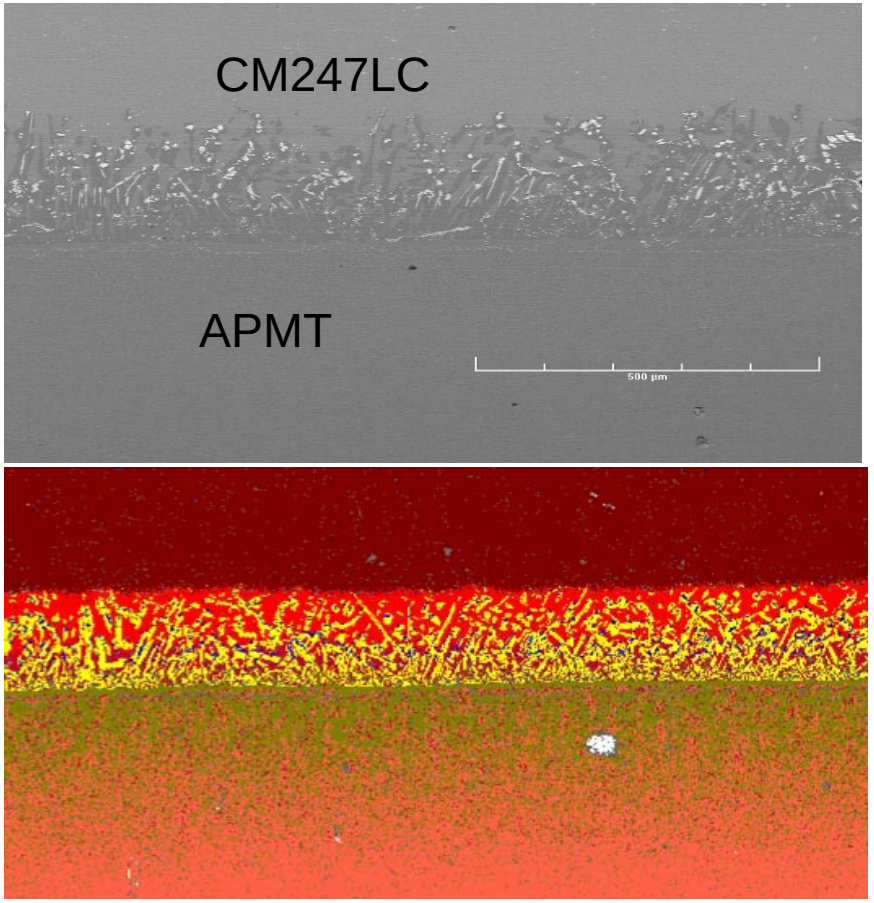
950°C Stress Rupture Tests of EM-Bonded Rods

- Stress rupture tests done at 950°C using 20 MPa, the 100-hour APMT rupture stress.
- Samples broke within the APMT, not the joint.
- APMT was much weaker than anticipated.



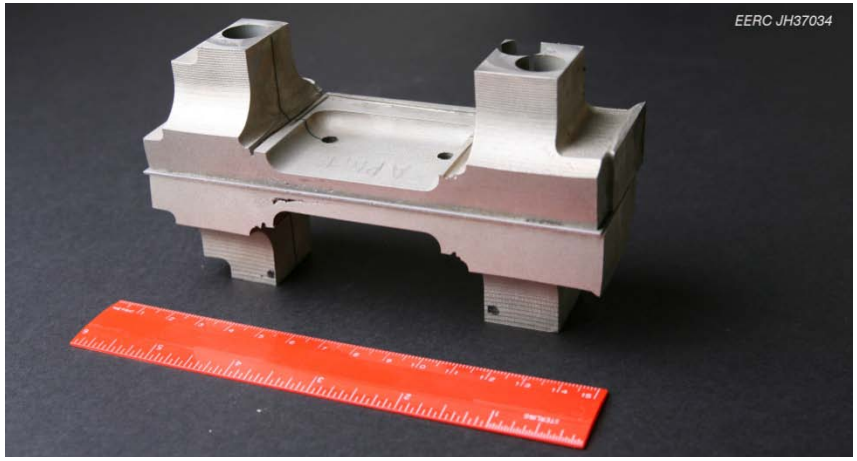
Microstructure of EM Joints

- Scanning electron microscopy photo top, x-ray map on bottom.
- Needle growth and interdiffusion create a joint stronger than the APMT.
- Nickel diffuses up to 700 µm into APMT.
- Iron diffuses 200 µm into the CM247LC.



Joining Thin Layers to Actual Turbine Structures

- Joined actual turbine ring segments of CM247LC with APMT sheet in between.
- Demonstrates the ability to cover large areas of superalloys with oxidation- and spallation-resistant APMT using EM bonding.
- Joints were stronger than the APMT.



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Current State of the Art

- EM bonding has been successfully used to bond CM247LC to APMT.
- All failures were within the FeCrAl, usually well away from the diffusion-affected zone.
- Articulated contacts between the clamp and parts being joined are necessary because the joining foil is so thin.
- Can bond curved surfaces.
- Surface preparation is simple blasting with silica beads.

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Task 1 – Determine diffusion rates of evaporative metal through APMT, CM247LC, and Rene 80 as functions of temperature.

- Prepare bonded rods at different temperatures and times.
- Cross-section bonded rods, and measure bonding metal concentration gradients.
- Develop diffusion rate equations as functions of temperature.

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Task 2 – Model bonding pressure distributions in complex joints.

- Model pressures at the bond line at temperature.
- Test model results at room temperature with pressure paper.
- Design clamping system.

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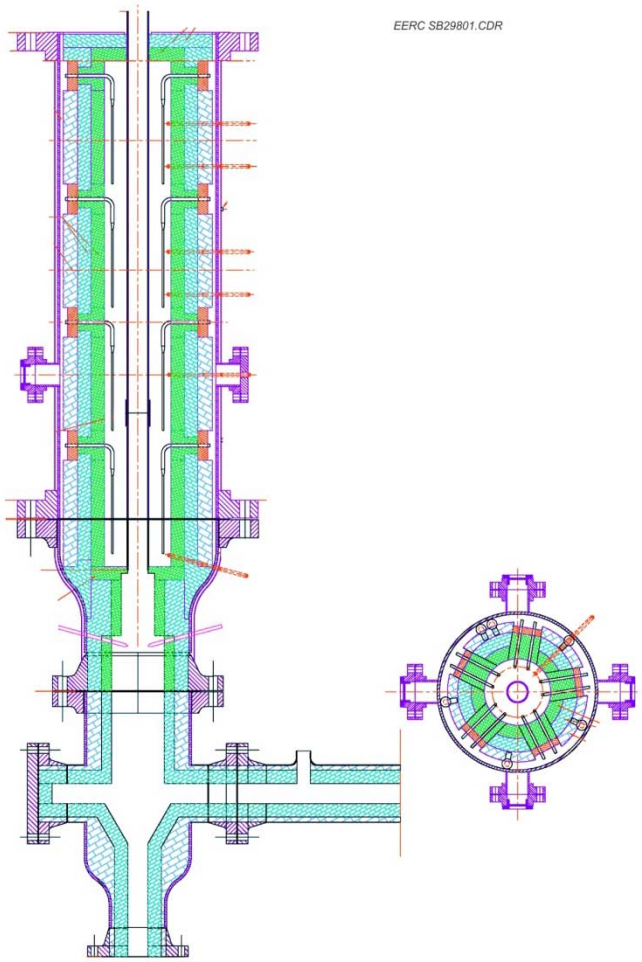
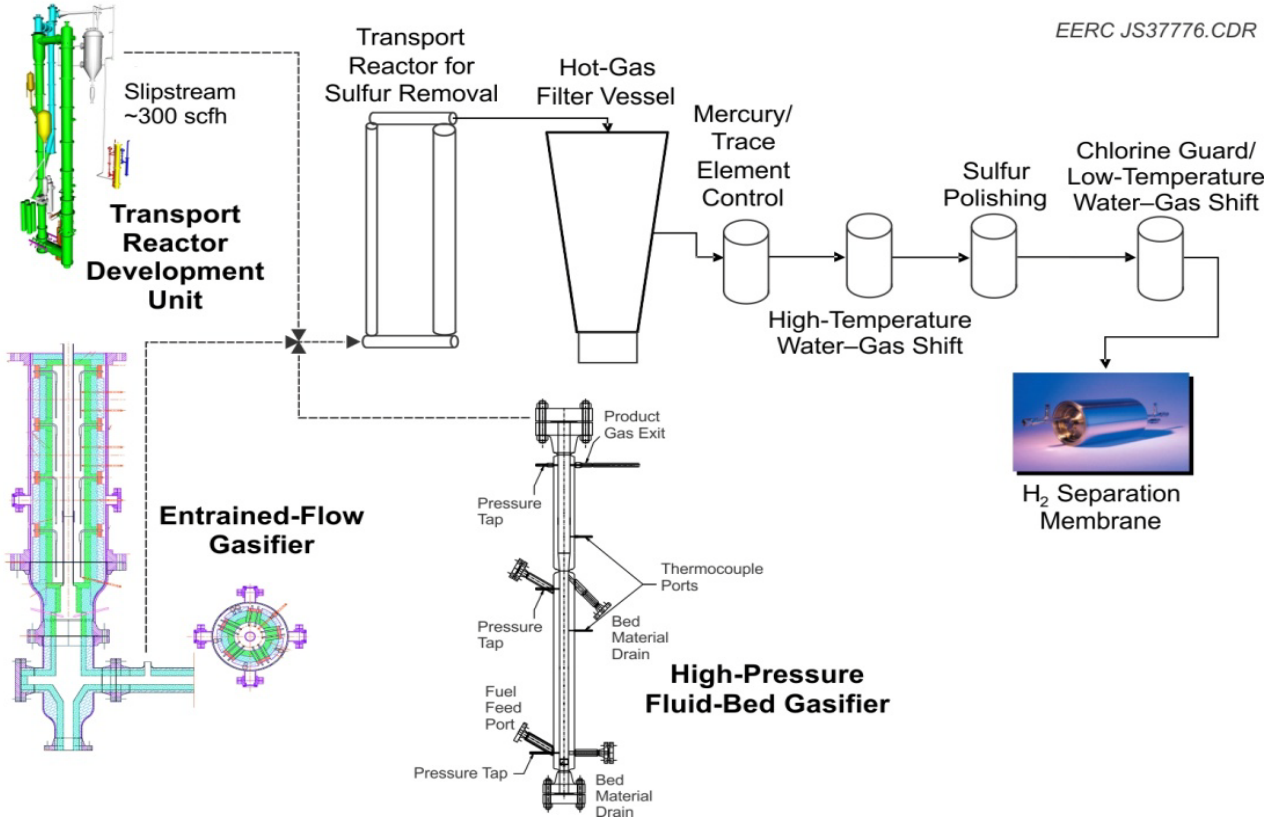
Task 3 – Characterization of combusted syngas contaminants.

- Information to be used in designing later corrosion testing – contaminants will not be similar to gasifier fly ash.
- Collection of microcontaminants in combusted syngas created in a pilot-scale gasifier.
- Analysis of captured microcontaminants by SEM.
- Data will be made available to other researchers.



Systems Available for Task 3 Work



- Three gasifiers are available at the EERC – focus on entrained-flow gasifier
- Several different gas cleanup options are available.
- Work will piggyback on runs paid for by other projects.

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- Task 3 - Possible contaminants are hot or cold cleanup dependent.
  - Given high level of gas cleaning we expect little to no large (>2 micron) fly ash.
  - Entrained flow gasifiers produce larger levels of submicron fume than other gasifiers which has a different composition than flyash.
  - Highly volatile elements include Cl, Br, V, Hg, and S of which most, but not all, is collected in gas cleanup systems.
  - Moderately volatile elements include alkali metals and As, Ge, Sb, B, F, Cd, Se, Zn and Sn.
  - Cr, Ni, Fe and Se have been detected downstream of gas cleanup systems.
  - Cr, Ni, Fe form volatile carbonyls through reaction of the syngas with system piping.

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- Task 4 – Preparation of APMT-plated superalloy turbine parts.
  - Use data from Tasks 1 and 2 to design clamping system and time–temperature heat treatment.

- Task 5 – Environmental testing of plated turbine parts.
  - Oxidation and spallation testing at Siemens Energy.
  - Corrosion testing at the EERC.

- Task 6 – Reporting.

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