DoE Award No. DE-FE31819

Additively Manufactured Graded Composite Transition Joints (AM-GCTJ) for Dissimilar Metal Weldments in Advanced Ultra-Supercritical Power Plant

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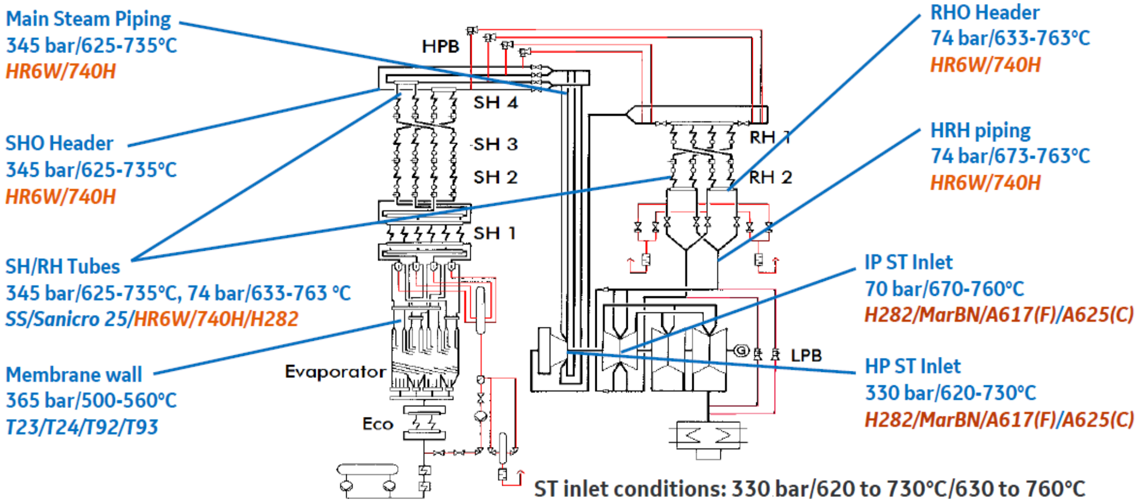
DMWs in A-USC and HRSG

AUSC power plant – boiler and turbine schematic

Potential Material Selections



ST inlet conditions: 330 bar/620 to 730°C/630 to 760°C

740H, H282, HR6W & A617/A625 for boiler outlet headers, piping and ST inlet are the material enablers

GE Steam: A-USC Mock Header

DMW:

1. Grade 91 – Austenitic Stainless Steel
2. Ni based alloy – Austenitic Stainless Steel

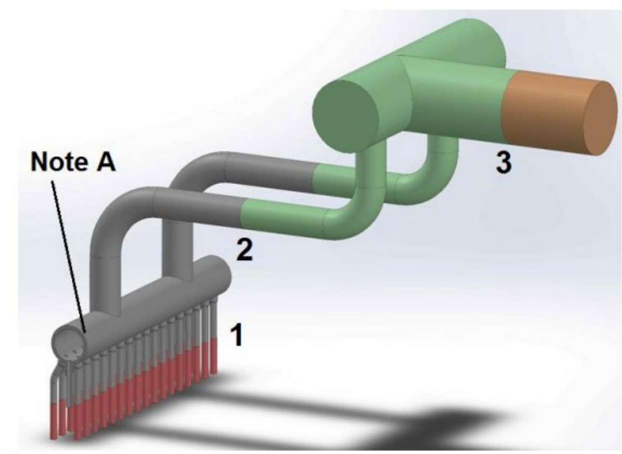


Figure 3-1
HRSG configuration highlighting potential DMW locations (1: tubing internal to the HRSG setting; 2: link piping; 3: outlet piping.)

Program on Technology Innovation: Guidelines and Specifications for High Reliability Fossil Power Plants—Best Practice Guideline for Manufacturing and Construction of Grade 91 Steel to Austenitic Stainless Steel Dissimilar Metal Welds 3002007221 Final Report, December 2017

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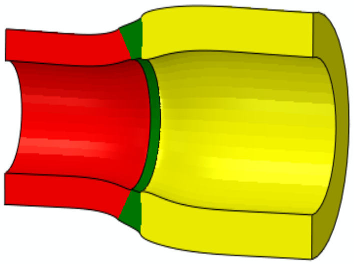
Mismatch of coefficient of thermal expansion and **thermal cycling:**



DMW with sharp material transition

- Mismatch of coefficient of thermal expansion between different materials lead to high strain range along the interface during thermal transients.
- Increasing demand in industry for flexible operation of steam boilers and more cycling capability of HRSGs.

Higher cycling requirements in power industry:

- Steam Boilers: A sample required number of cycles for a new unit

	Total # of cycles of 25 years
Cold Start	455
Warm Start	910
Hot Start	4550

- HRSGs: Typical required number of cycles for a cyclic operating CCPP

	Total # of cycles of 25 years
Cold Start	250
Warm Start	1250
Hot Start	4250

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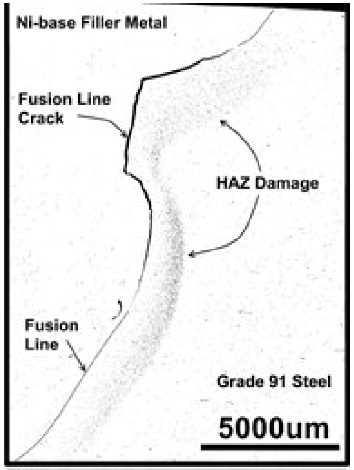
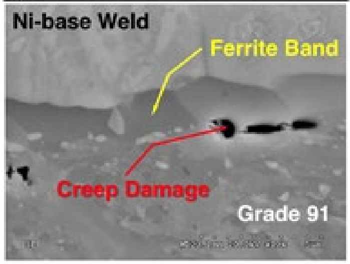
Current Dissimilar Metal Welds (DMWs)

Failures in DMWs @ the fusion boundary between Grade 91 and nickel based filler metal, often accompanied with considerable damages in the HAZ of Grade 91

HT exposure during PWHT or service causes carbon diffusion from the ferritic matrix toward the austenitic matrix. Leads to the formation of a carbon-depleted soft zone on the ferritic side and nucleation/growth of carbides on the ASS side that have very high hardness.

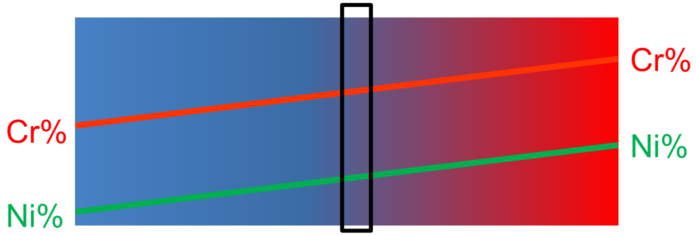
Under imposed residual, external, and thermal stresses caused by the CTE mismatch between different alloys of the DMW, creep and/or creep fatigue cracks can occur along the fusion boundary and HAZ.





AM-Graded Transition Joints (GTJs)

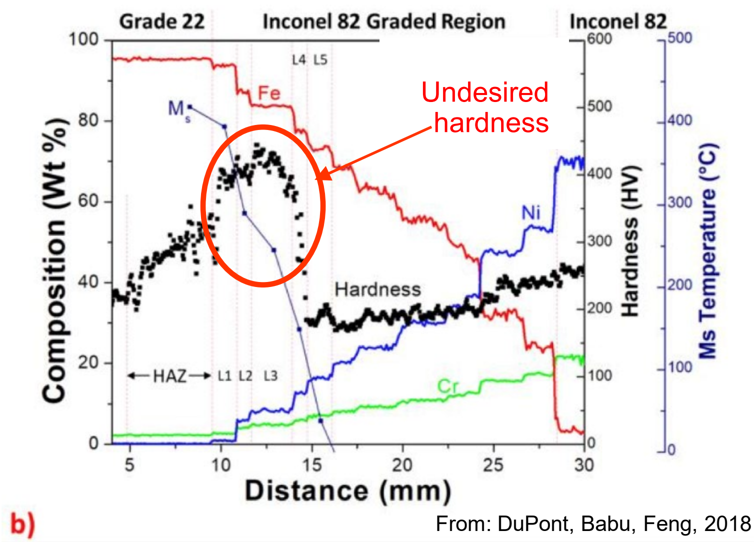
"Conventional" melting based AM



Grade 91
0.08C-9Cr-1Mo-0.4Ni

0.08C-14Cr-4Ni-0.5Mo:
microstructure?

SS304
0.08C-18Cr-8Ni



From: DuPont, Babu, Feng, 2018

- "Conventional" AM (wire or powder) approach melts alloys A&B completely together
  - A critical issue is the continuous transition in composition creates complex and often undesired microstructure

Advantages of AM-GCTJ

- Solid-state Process, composites material" transition with constituents of known chemistry (such as P91, SS304, A182) mixed in controlled proportion
    - •Solved the critical drawbacks of undesired/unpredictable phases/microstructure in conventional AM approach to fabricate the transition joint
- 100% smooth transitions
- Welding happens at A-A, and B-B, no DMWs
- Minimize scale-up issues expected to manufacture large quantity of joints

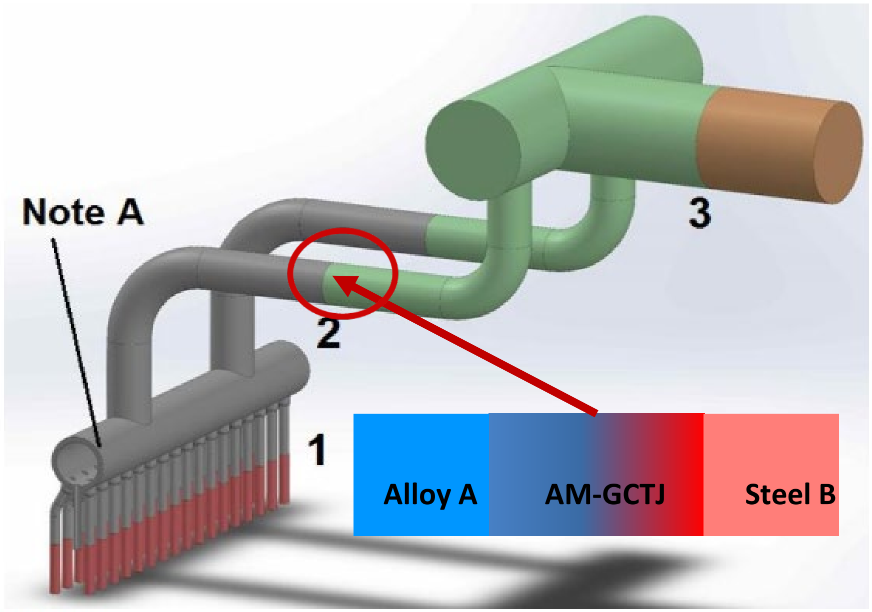


Figure 3-1
HRSG configuration highlighting potential DMW locations (1: tubing internal to the HRSG setting; 2: link piping; 3: outlet piping.)

Illustration of DM weld in power plants

* U.S. Patent Appl. No. 62/704,965 – Method to Produce an Additively Manufactured-Graded Composite Transition Joint

PROJECT OBJECTIVES – PHASE I

(1) To develop and demonstrate at the lab-scale the additively manufactured graded composite transition joints (AM-GCTJ) for dissimilar metal weldments (DMW) in next generation advanced ultra-supercritical (A-USC) coal-fired power plants, that can significantly improve the microstructural stability, creep and thermal-mechanical fatigue resistance, as compared with their conventional counterparts;

(2) To prepare for Phase II of the project, in which we will manufacture and test the components with AM-GCTJ, to advance the technology readiness level to TRL-7, and manufacturing readiness level to MRL 6-7, for targeted commercial applications identified by GE Steam Power, the primary industry partner of the project team

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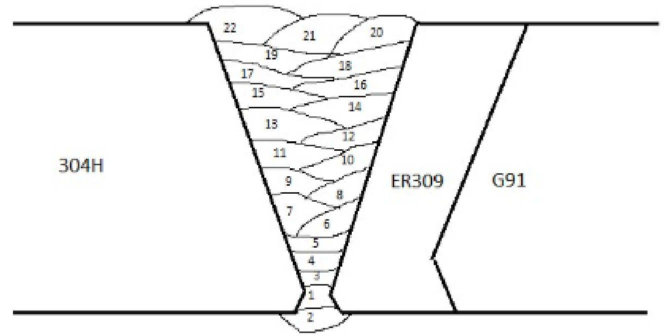
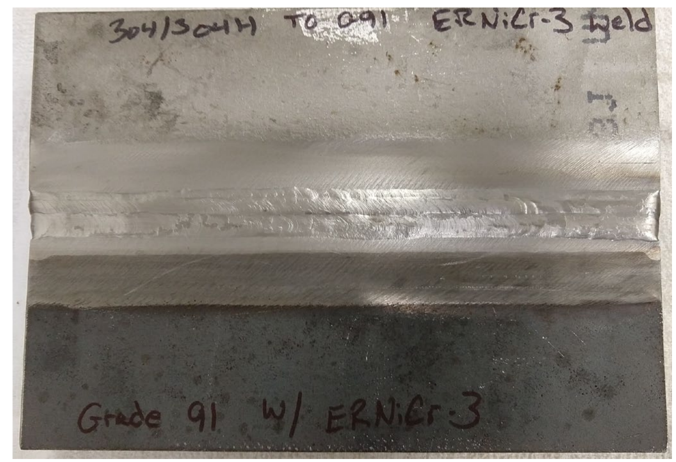
DMW and AM-GCTJ

AM-GCTJ

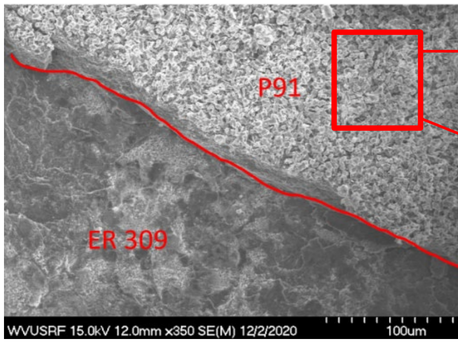
Conventional DM Weld

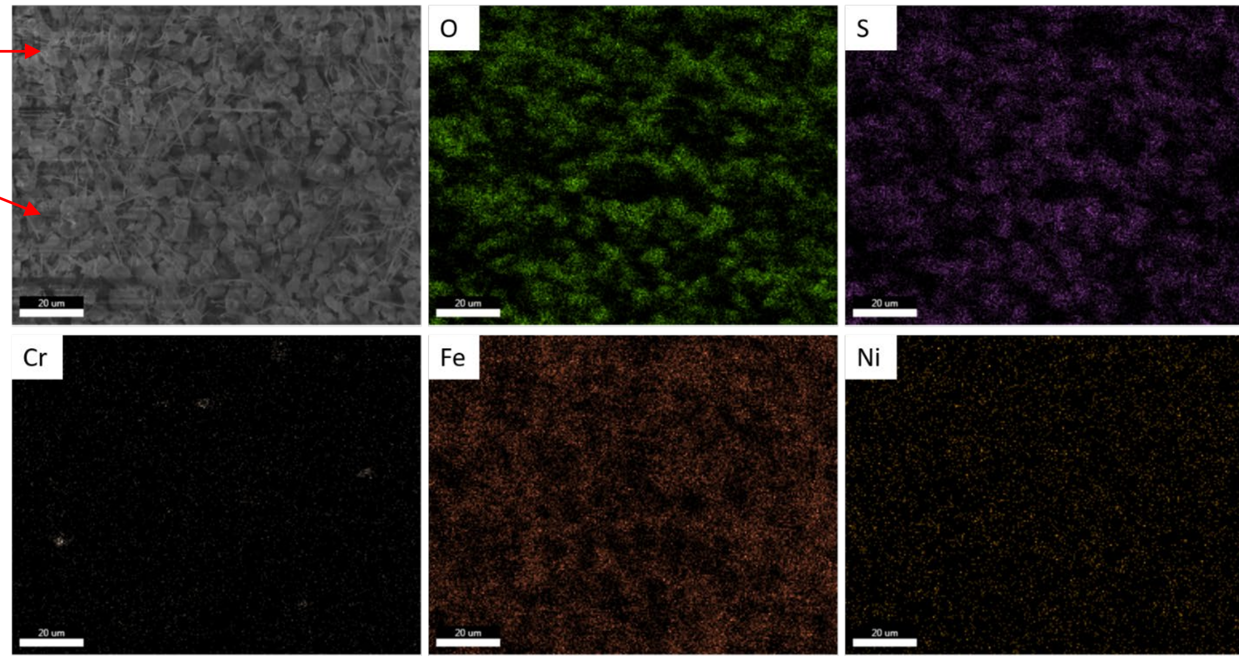




Fabricated 2 types of welds using either SS309 or A182 weld wire

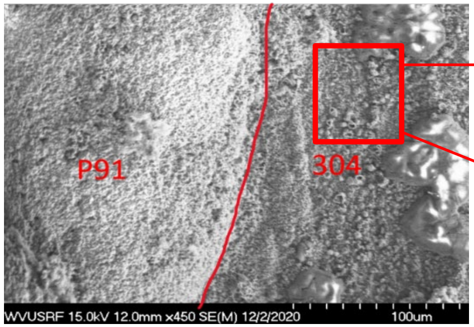
Hot Corrosion in Coal Ash - DMW

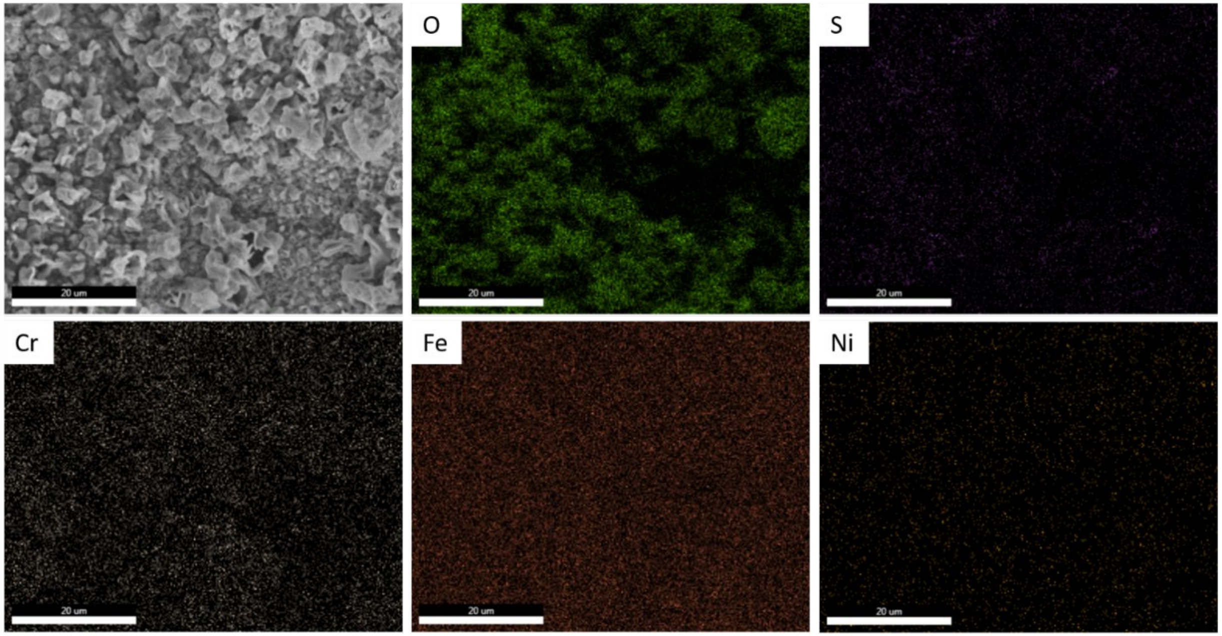




Temperature - 650 °C
Time – 30 days
Coal Ash - 10% Na_2SO_4, 10% K_2SO_4, 10% Fe_2O_3, 35% Al_2O_3 and 35% SiO_2
Gas - 1 vol. % SO_2, 4 vol. % O_2, 15 vol. % CO_2 & 80 vol. % N_2

Hot Corrosion in Coal Ash – AM-GCTJ





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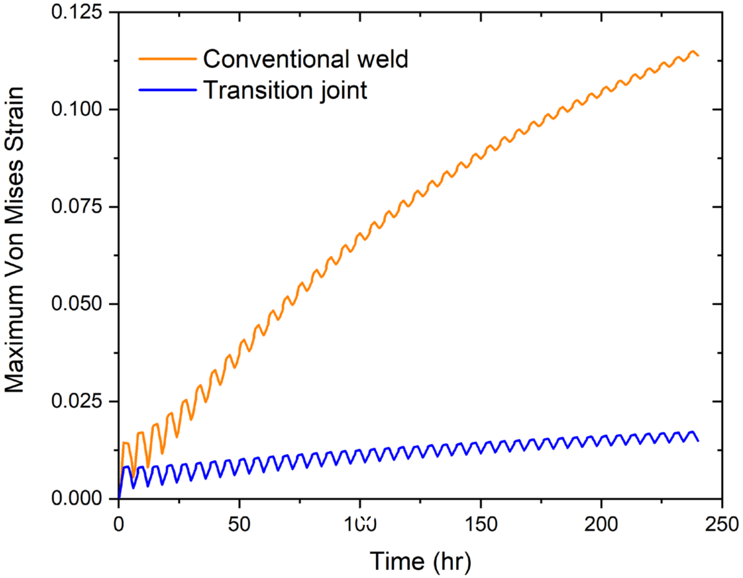
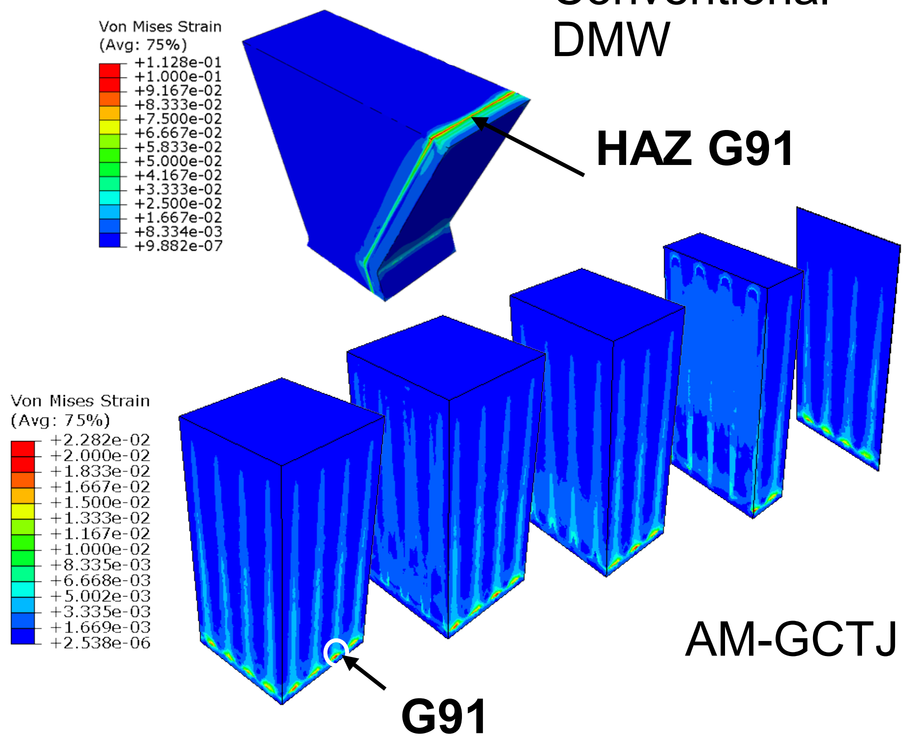
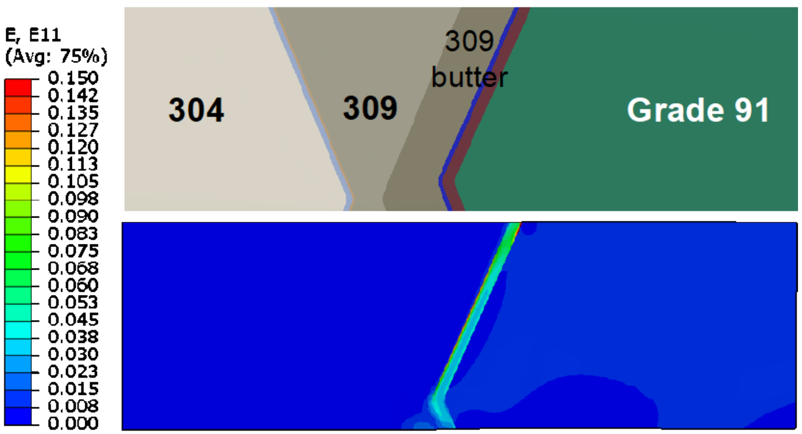
ORNL's ICWE Modeling Tool being Used to Design and Optimize the AM-GCTJ

- Designed AM-GCTJ to significantly reduce the strain accumulation at critical locations during thermal cyclic loading
- It will also significantly improve the creep failure life – predicted failure will be shifted to Grade 91 base metal



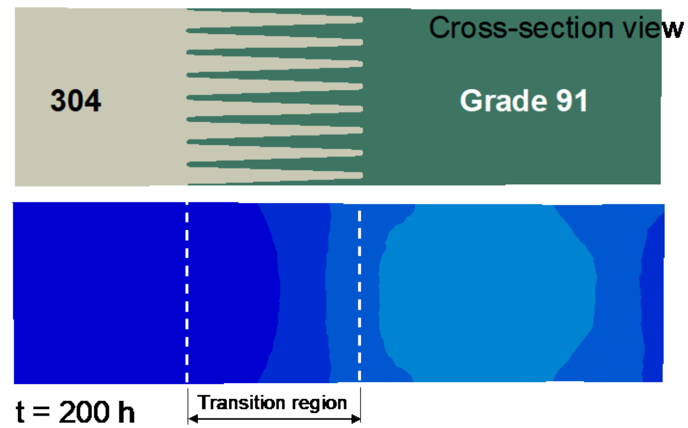


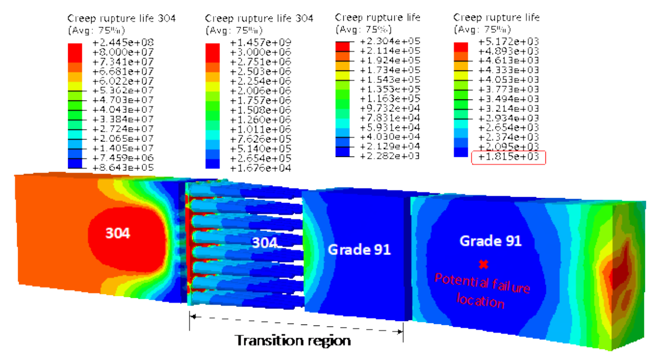
ICWE Prediction of Creep Strain Accumulation and Rupture Life at 650 °C and 90 MPa



t = 200 h

Predicted life of conventional DMW: 230 hrs,
failure at the weld interface in the G91 HAZ





The predicted failure is in G91 base metal. Predicted rupture life is **1815** hours

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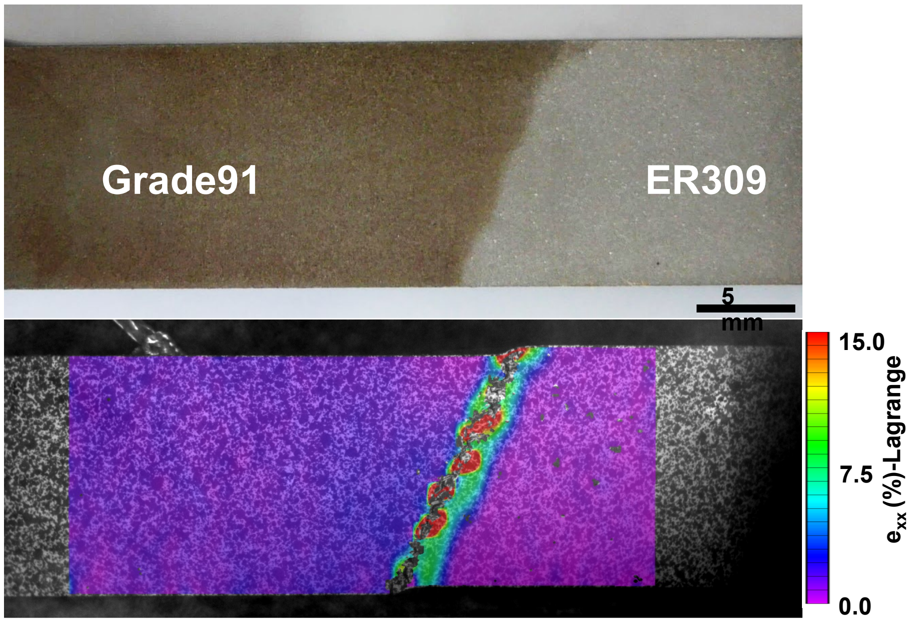
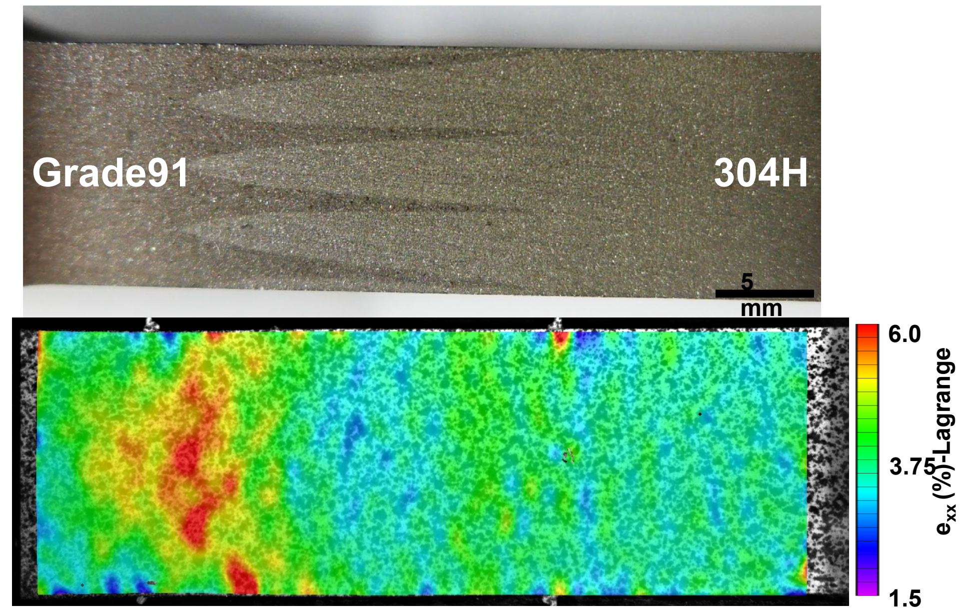
Actual Creep Test – DMW vs Transition Joint (650 °C and 90 MPa)



Failed at **214** hrs in the G91 HAZ near the interface



Minimal strain localization on the transition joint at 200 hrs. Failed after **1259** hrs near the G91 base metal. Over 5.8x improvement of creep life

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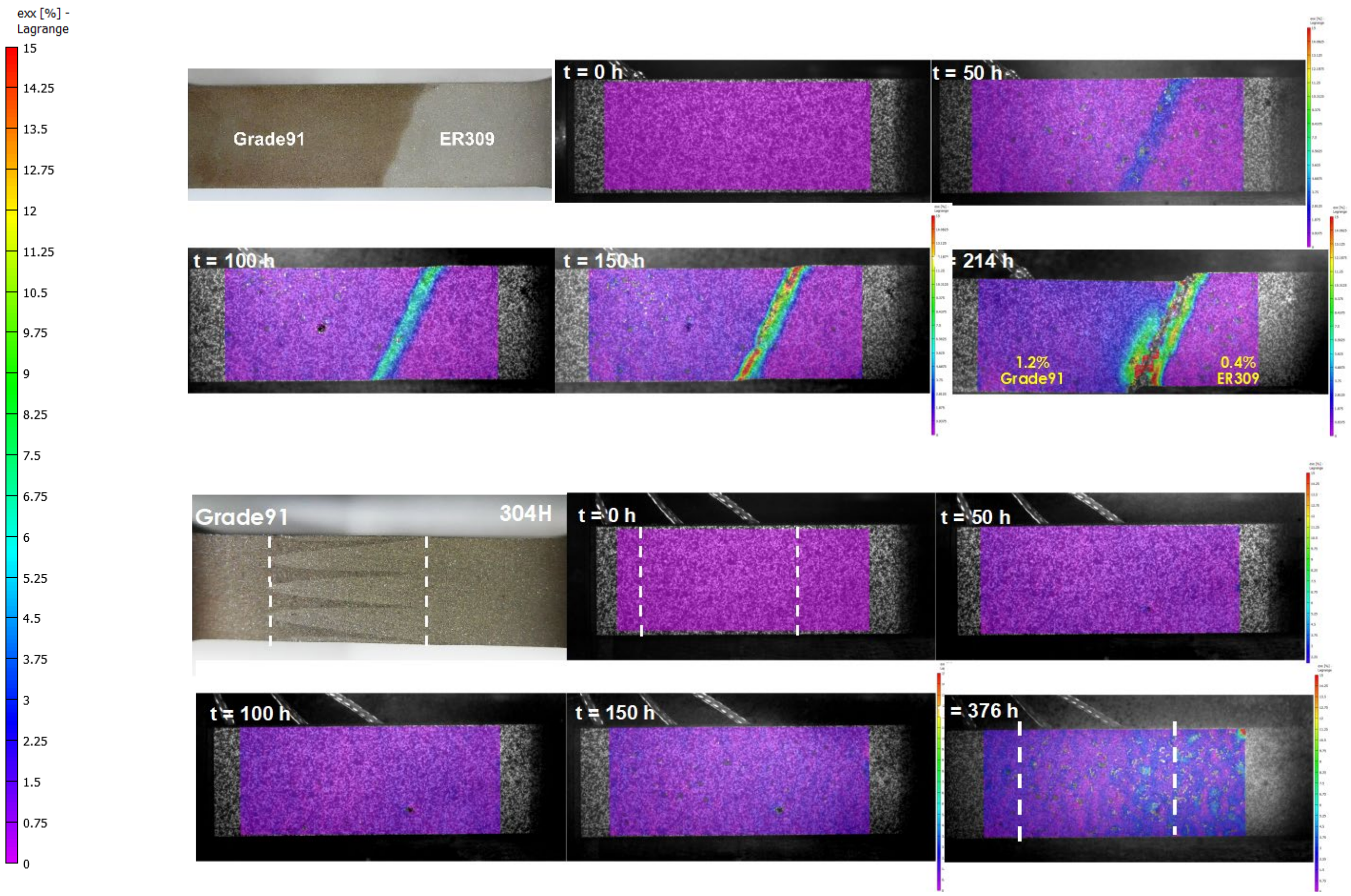
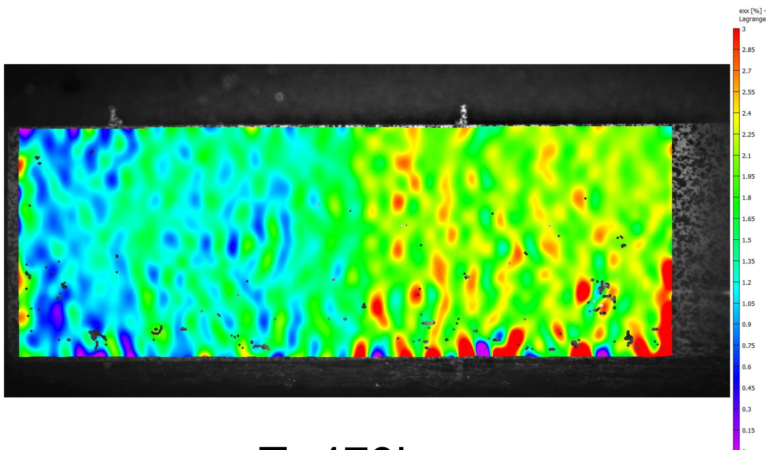
DIC Measurement of Creep Strain Evolution and Localization



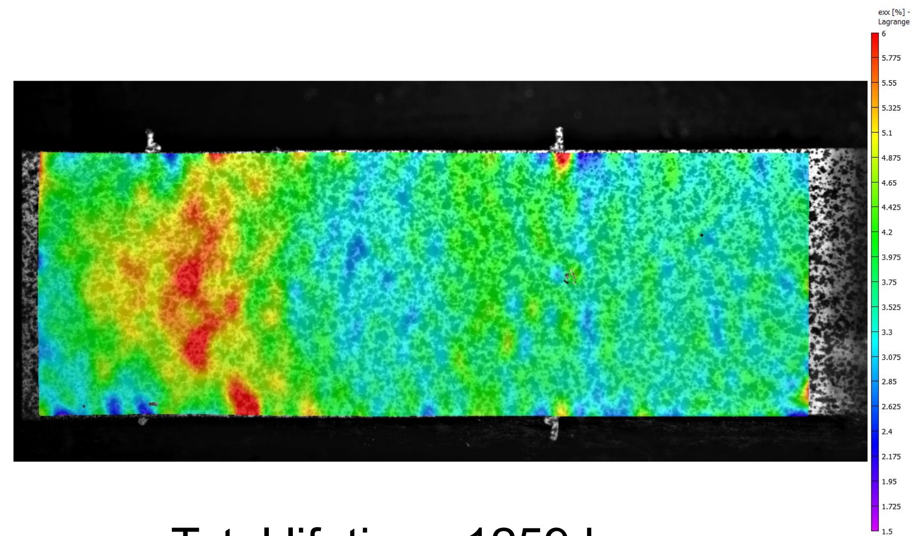
Conventional DMW

AM-GCTJ

Grade91-304H Transition Joint (650C-90MPa)



T=479hrs



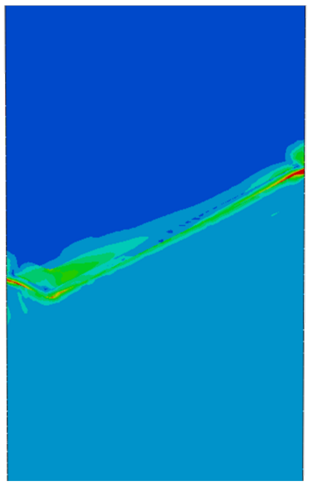
Total lifetime: 1259 hrs

650C, 90MPa	Conventional DM	AM-GCTJ
Model Prediction	230 hrs, at G91 interface	1815 hrs, in G91 base metal (near interface)
Actual Test	214 hrs, at G91 interface	1259 hrs, near G91/Transition Joint interface

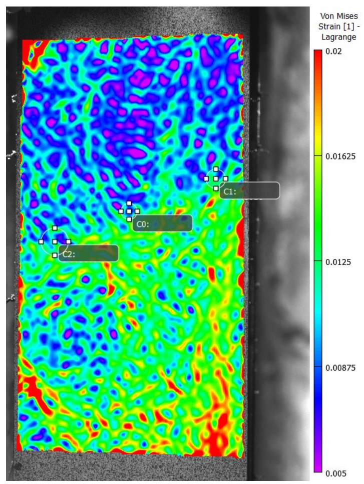
Model Captured Essential Features of Strain Distributions in Thermal Cyclic Loading (25-650°C, 2-2-2 h)

Conventional DMW

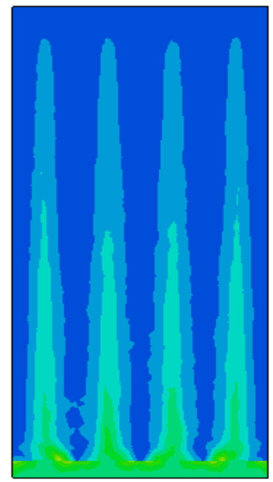
AM-GCTJ



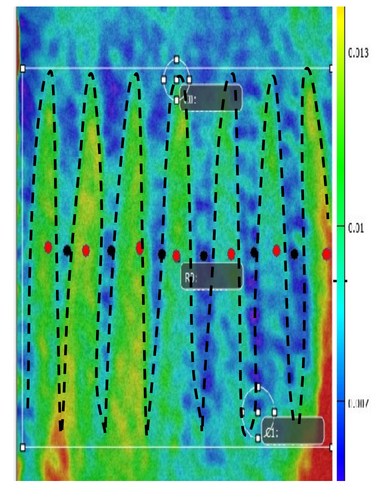
Model prediction



DIC measurement



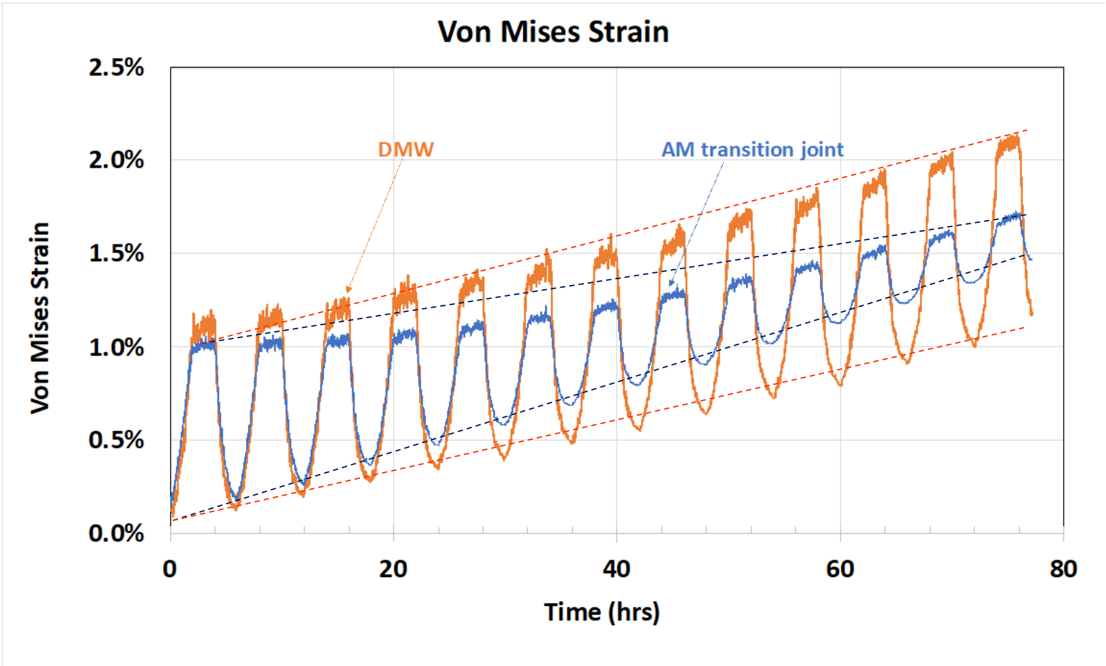
Model prediction



DIC measurement

Experimental Measurement of Strain Evolution during Thermal Cyclic Test (On-going)

- Initial observations from in-situ DIC measurement:
  - Considerable reduction of thermal cyclic strain range with AM-GCTJ



AM-GCTJ: averaged over the transition region
Conventional DMW: averaged over P91/SS304 interface region

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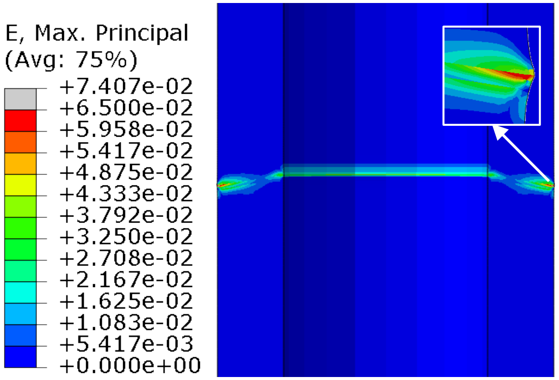
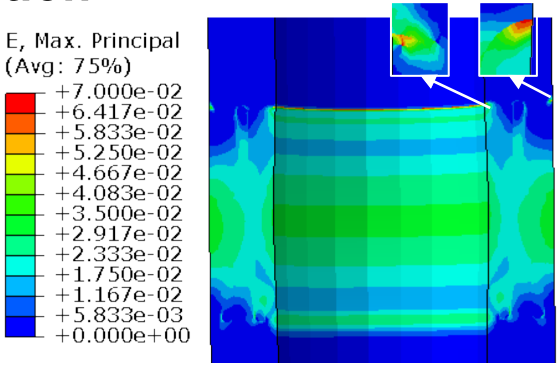
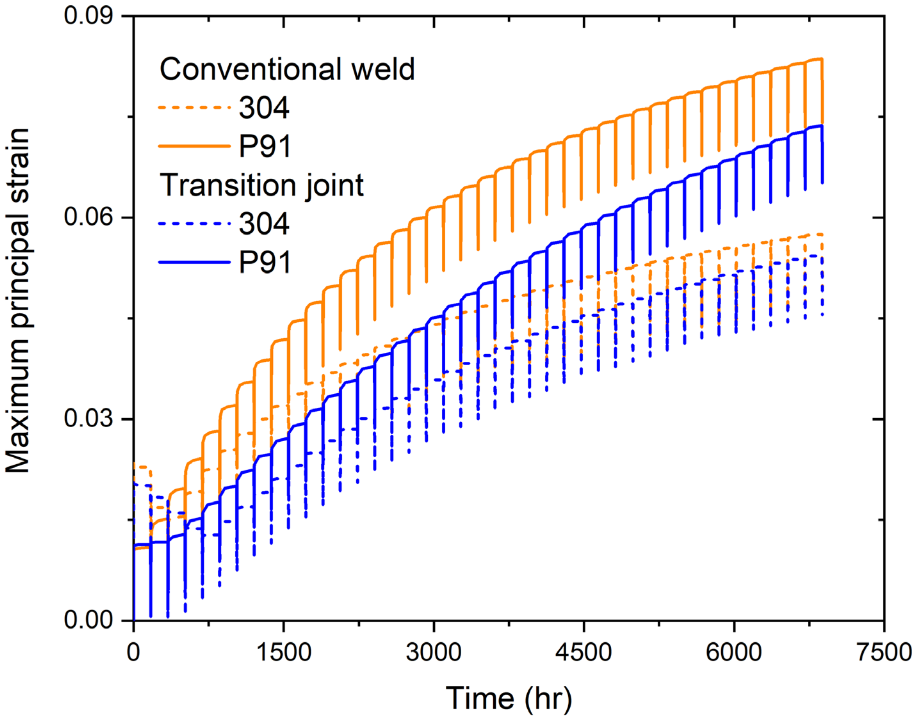
Pipe: Conventional DMW vs AM-GCTJ

- **Conventional weld**



- **Transition joint**





Results after 40 thermal cycles

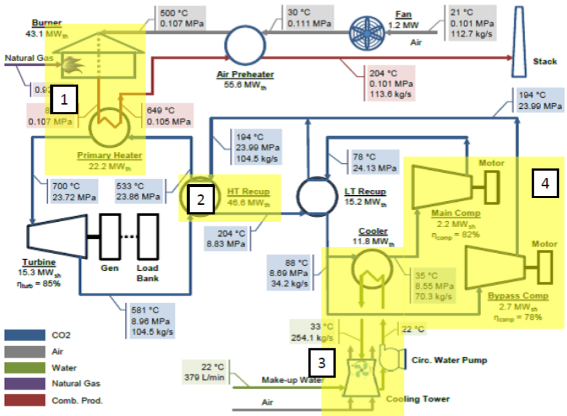
Summary

- We designed and fabricated a new class of AM-GCTJ
  - Avoid unknown & often undesired complex composition in the conventional AM-GTJ
  - Shows similar corrosion performance in coal ash as conventional DMW
  - Reduce the maximum strain & strain range, and (can) improve thermal mechanical fatigue life of DMW during cyclic operation of thermal-electric power plants
  - Significantly improve creep properties, as compared with convention DMW
- AM-GCTJ has broad applications in various energy systems, AUSC, Gas, CSP, NE, etc.

Phase II Plan

- Further optimize design and manufacturing
- Move up both TRL & MRL
- Detailed TEA
- Start code case
- Be ready for commercial applications

Original proposed 10 MWe
Recuperated Brayton cycle



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CES Combustion Engineering Solutions
SwRI Southwest Research Institute
N University of Nebraska Lincoln

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