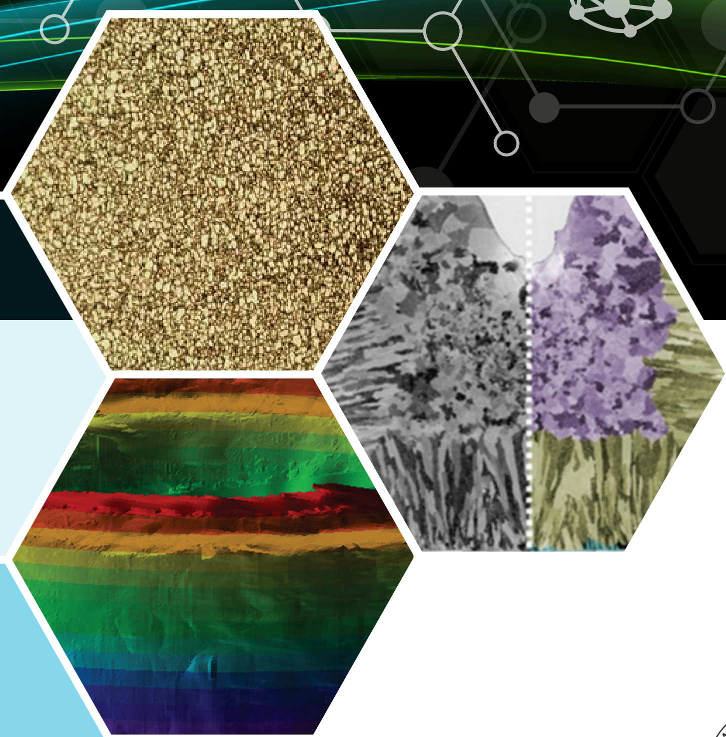
HYDROGEN
with Carbon Management

2023

ADVANCED ENERGY MATERIALS



PROJECT PORTFOLIO

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

DISCLAIMER

CONTENTS

HYDROGEN WITH CARBON MANAGEMENT

As part of the U.S. Department of Energy (DOE) Office of Fossil Energy's Hydrogen with Carbon Management (HCM) program, NETL research focuses on production and evaluation of carbon-neutral hydrogen (i.e., coupled to carbon capture and storage (CCS)) as a fuel and development of technologies to use carbon-neutral hydrogen from any source.

The HCM program's efforts are promoted by the Department of Energy (DOE) Hydrogen Shot, with a goal of reducing clean hydrogen costs by 80% to $1 per 1 kilogram (kg) within 1 decade (1-1-1) while expanding employment of the U.S. energy workforce. Seeking a cost-competitive decarbonized alternative to traditional fossil fuels, HCM has a research and development portfolio consisting of a new generation of carbon neutral or net-negative greenhouse gas emissions technologies. HCM comprises six subprogram activities: (1) Gasification Systems, (2) Advanced Turbines, (3) Reversible Solid Oxide Fuel Cells (R-SOFCs), (4) Advanced Energy Materials, (5) Sensors, Controls, and Other Novel Concepts, and (6) Simulation-Based Engineering.

In combination, these investments in innovation, informed by private-sector stakeholders, enable more comprehensive risk assessment and techno-economic analysis, increase the resiliency of the nation's energy infrastructure, and enable the adoption of cutting-edge data harnessing technologies for plant owners and operators.

Gasification Systems: The DOE Gasification Systems program is developing innovative modular designs for converting diverse types of carbonaceous feedstocks into clean synthesis gas to enable the low-cost production of clean hydrogen, electricity, transportation fuels, chemicals, and other useful products to suit market needs. Advancements in this area will help enable syngas-based technologies to play a role in economy-wide decarbonization in multiple energy sectors while remaining competitive in both domestic and international markets, and spur on the use of abundant domestic carbon feedstock resources, in turn contributing towards increased energy security and promoting justice through reviving depressed markets in traditional coal-producing regions of the United States.

Advanced Turbines: The NETL Advanced Turbines Program is focused on the development of advanced turbine technologies that will accelerate turbine performance, efficiency, and cost effectiveness beyond the current state of the art. The program will provide tangible benefits to the public in the form of options for eliminating CO_2 emissions, lowering the cost of electricity, and reducing emissions of criteria pollutants. The efficiency of combustion turbines has steadily increased as advanced technologies have provided manufacturers with the ability to produce highly advanced turbines that operate at very high temperatures. Further increases in efficiency are possible through the continued development of advanced components, combustion technologies, material systems, thermal management, and novel turbine-based cycles. The Advanced Turbines Program supports four key technologies that will advance clean, low-cost power production from fossil energy resources while providing options for CO_2 mitigation. These key technologies include: (1) Advanced Combustion Turbines, (2) Pressure Gain Combustion (PGC), (3) Turbomachinery for Supercritical Carbon Dioxide (sCO_2) Power Cycles, and (4) Modular Turbine-Based Hybrid Heat Engines. DOE's research and development in advanced turbines technology develops and facilitates low-cost advanced energy options for carbon-negative energy ecosystems.

Reversible Solid Oxide Fuel Cells (R-SOFCs): The NETL Reversible Solid Oxide Fuel Cell program maintains a portfolio of RD&D projects that address the technical issues facing the commercialization of solid-oxide fuel cell (SOFC) and Reversible Solid Oxide Fuel Cell (R-SOFC) technologies and pilot-scale test projects intended to validate the solutions to those issues. To successfully complete the maturation of these technologies from their present state to the point of commercial readiness, the program's efforts are channeled through three key technology areas, each of which has its respective research focus: (1) Cell Development, (2) Core Technology, and (3) Systems Development.

Advanced Energy Materials: The Advanced Energy Materials program drives to characterize, produce, and certify advanced alloys and high-performance materials that are key to realizing dispatchable, reliable, high-efficiency decarbonized power generation from hydrogen. In addition, the program aims to encourage change and stimulate innovation in the high-performance materials value chain to spur U.S. competitiveness and enable achievement of 2050 zero-emission goals. Materials of interest include those that enable components and equipment to perform in the high-temperature, high-pressure, corrosive environments of advanced energy systems with specific emphasis on durability, availability, and cost. The key focus areas of this program include (1) development of a robust domestic materials supply chain, (2) lifetime prediction and rapid repair critical to manage a flexible fleet of generators that enable high penetration of renewables into the grid, and (3) low-cost, high performance alloy development to enable meeting 2050 zero-emission goals.

Sensors, Controls, and Other Novel Concepts: The NETL Sensors, Controls, and Novel Concepts program conducts research and development for technologies that will provide pivotal insights into optimizing performance, reliability, and availability of integrated energy and carbon management systems. NETL develops, tests, and matures novel sensor and control technologies that are operable in next-generation energy systems, including hybrid plants incorporating components such as hydrogen-powered turbines and fuel cells, renewables, and energy storage applications. These sensors enable responsiveness to varying conditions in real time, maintaining high efficiencies and reducing emissions. This research will aid in the achievement of DOE goals which include net-zero carbon emissions in the energy sector by 2035 and a decarbonized wider economy by 2050.

Simulation-Based Engineering: NETL's Simulation-Based Engineering (SBE) program supports the development and application of innovative physics- and chemistry-based models and computational tools at multiple scales (i.e., atomistic, device, process, grid, and market) in order to accelerate development and deployment of clean, advanced fossil fuel technologies. The SBE program combines a multidisciplinary approach comprising technical knowledge, software development, computational power, data repositories, experimental facilities, and unique partnerships to support research into timely and accurate solutions for fossil and sustainable energy and carbon management systems. Analysis and visualization tools are manipulated to gain scientific insights into complex, uncertain, high-dimensional, and high-volume datasets. The information generated is then collected, processed, and used to inform research that combines theory, computational modeling, advanced optimization, physical experiments, and industrial input.

ADVANCED ENERGY MATERIALS

Power generation plants operate under extreme conditions from a materials standpoint. Future advanced generation facilities will be expected to withstand harsher environments due to higher demands for increased efficiency, quicker plant startups and turndowns, cycling, and alternative power source supplementation. To support these expectations, new materials are needed for these conditions and performance expectations.

Advanced ultrasupercritical (AUSC) boilers, pressurized oxy-combustion boilers, pressurized gasifiers, and the advanced turbines for each of these types of plants will operate under higher temperatures and pressures, which promote rapid corrosion and degradation of subcomponent materials. Internal stresses in thick-walled components such as superheater headers, turbine casings, and turbine rotors, along with boiler tube scaling and turbine blade erosion, are critical material issues that must be addressed for reliable plant operation.

Advanced Energy Materials focuses on materials that will lower the cost and improve the performance of existing and advanced fossil-based power-generation systems. There are four research areas within AEM:

- Advanced Manufacturing
- Advanced Structural Materials for Harsh Environments
- Computational Materials Design
- Hydrogen Production

Specific Technology Objectives:

- Develop computational materials modeling to enable rapid design and simulation of new and novel alloy materials. Computational design of materials has the potential to produce major breakthroughs.
- Develop superalloys and ferritic materials for use in AUSC conditions of 760 degrees Celsius (°C) and 350 bar pressure (5,000 psi) to reduce costs, improve corrosion and erosion resistance, increase material strength, and reduce wall thickness.
- Develop functional materials for energy storage and high-performance materials with mechanical properties that can perform reliably at temperatures well over 1,000 °C.
- Develop advanced metallic and ceramic coatings, including nanomaterials, to provide thermal barrier protection for turbine blades, combustor components, and tubing.
- Develop validated computational models capable of simulating and predicting performance of materials in various types of transformational power plants.

This project portfolio report showcases 23 Advanced Energy Materials projects within the Hydrogen with Carbon Management Program of the Technology Development Center. Each of the pages reporting on projects describes the technology, the program goals, and overall benefits.

ADVANCED MANUFACTURING

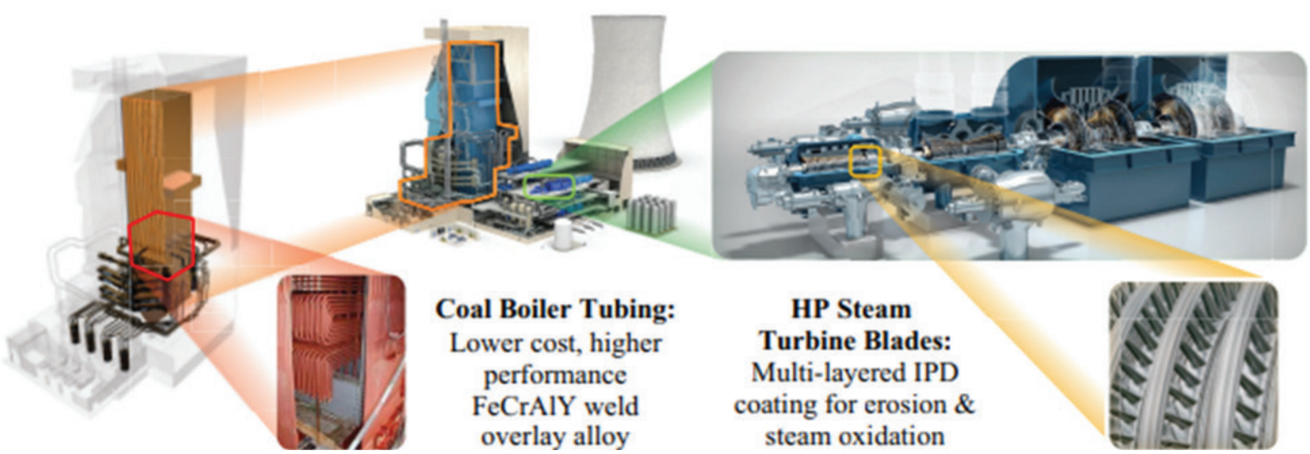
Advanced Coating Compositions and Microstructures to Improve Uptime and Operational Flexibility in Cyclic, Low-Load Fossil Plants

Performer	**General Electric (GE) Company**
Award Number	FE0031911
Project Duration	09/01/2020 – 08/31/2023
Total Project Value	$ 5,549,995
Collaborators	GE Steam Power, Inc.; University of Tennessee
Technology Area	Plant Optimization Technologies

This project addresses two principal factors that drive outages in the fossil power plant fleet: corrosion at the outer diameter of boiler tubing and solid particle erosion in high-pressure (HP) steam turbine blades. The overarching objective is to produce coatings that mitigate these damage mechanisms and provide a comprehensive solution to improve fleet reliability and operational flexibility. GE Research will lead a team of researchers to leverage a century of fleet experience and exciting new results obtained from DOE-funded nuclear materials research to develop cost-effective weld overlay compositions for boiler tubing and multi-layered ion plasma deposition coatings that deliver improvements in both erosion and oxidation resistance in high temperature steam for HP turbine blades. Deep technical expertise and world class characterization capability will be provided by Oak Ridge National Laboratory and the University of Tennessee. The team will work collaboratively through a robust, logical project map to achieve the objectives listed below, identified based on the funding announcement and direct input from GE:

- Enable a 25%-50% increase in time between outages for both boilers and HP turbines.
- Eliminate or significantly reduce the nickel content in weld overlay to mitigate cost.
- Provide adequate oxidation resistance for HP turbine inlet steam at >620 °C and >220 bar.
- Apply coatings to actual components, using today's production-scale methods.

Decreased component cost, increased performance, and extended time between outages are direct value propositions for the fossil energy fleet. For the U.S consumer, project success could lead to increased grid reliability (fewer unexpected outages), decreased levelized cost of electricity, and reduced environmental impact due to low loading/load following to accelerate penetration of renewables.

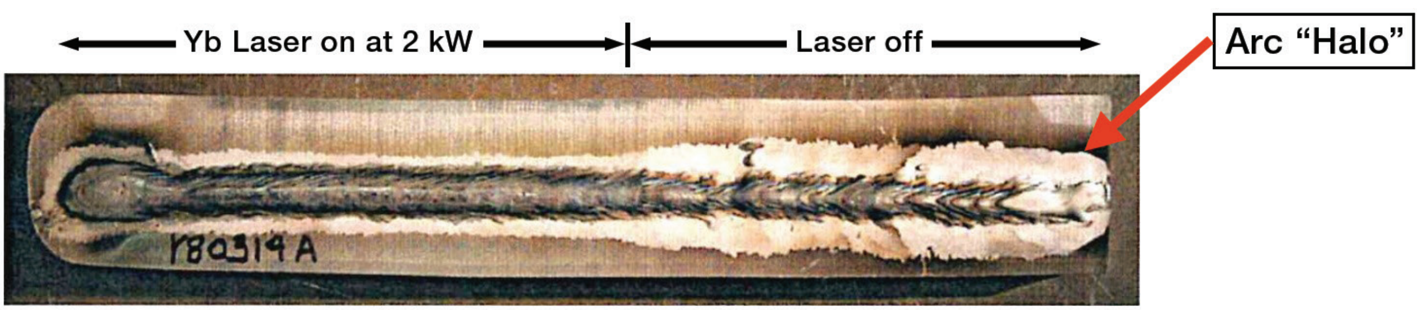


Multi-pass Hybrid Laser Arc Welding of Alloy 740H

Performer	**Idaho National Laboratory (INL)**
Award Number	FWP-B100-19010
Project Duration	10/01/2019 – 09/30/2023
Total Project Value	$ 1,294,000
Technology Area	Plant Optimization Technologies

Idaho National Laboratory will employ hybrid laser arc welding techniques to initially weld thick weld groove land areas (approximately 0.5" thick) using deep laser penetration tactics that, among other features, incorporate a laser wobble head to stabilize the "keyhole" region of the laser weld. Subsequently, the remaining narrow weld groove will be rapidly filled with filler metal using hybrid laser arc welding. The laser wobble head will also be used in this step to improve sidewall tie-in and reduce welding defects, resulting in an overall improvement to the weld strength reduction factor. Finally, the project team will make a complete weld in 3"-thick plate Inconel alloy 740H. Total welding time will be compared with conventional welding practices and welds will be characterized for microstructure and mechanical properties, including long-term (approximately 10,000 hours) creep testing.

This work seeks to reduce the time it takes to weld thick sections of Inconel 740H by up to a factor of two and improve weld quality. This project could provide a foundation for the acceptance of hybrid laser arc welding as a high-productivity joining method, reducing overall construction costs and construction time.



The benefits of laser stabilization in hybrid laser arc welding on Inconel 740H.

Rapid SiC: Room Temperature Roll-to-Roll Production of Polymer-Derived SiC Fibers

Performer	**Luna Innovations**
Award Number	SC0022875
Project Duration	06/27/2022 – 03/26/2023
Total Project Value	$ 247,767
Technology Area	Plant Optimization Technologies

Combustion turbines, which have enabled numerous advances as diverse as hypersonic flight and energy production, have higher fuel-to-power efficiencies when operated at high temperatures.1 For example, the DOE advanced turbine program demonstrated turbines operating over 1400°C display 35-40% higher efficiency compared with traditional turbines operating between 800–1000°C.1 Ceramic matrix composites (CMCs) have emerged as promising advanced materials to enable turbines to operate at temperatures over 1400°C.2 However, the prohibitive cost of silicon carbide (SiC) fibers used to reinforce CMCs has restricted their broader implementation in combustion turbine applications. Given this, there is a critical need to produce high-quality SiC fibers at lower costs. Luna Labs USA, LLC has partnered with Dr. Jeffery Morse at the University of Massachusetts – Amherst (UMA) to prepare high-quality, low-cost SiC fibers.

High-temperature materials, such as CMCs, are enabling new technologies that improve efficiency and performance in power generation, marine applications, aircraft propulsion, space vehicles, and more. For example, increasing the maximum operating temperature of a combustion turbine from 1260 to 1420°C allows turbines to operate at over 50 – 60% efficiency. This increased energy-to-fuel conversion efficiency results in an increase in the net present value (NPV) of natural gas turbines and, in turn, reduces the overall cost of electricity.

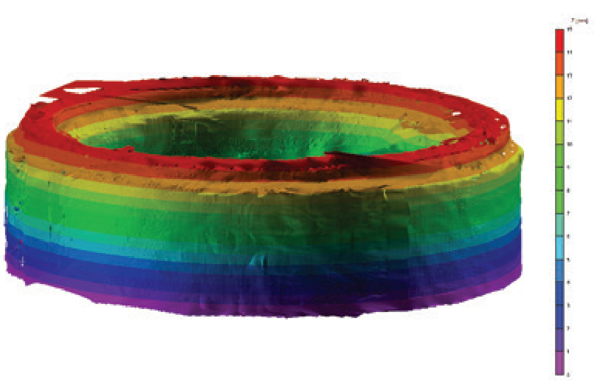
Development of Functionally Graded Transition Joints to Enable Dissimilar Metal Welds

Performer	**Oak Ridge National Laboratory (ORNL)**
Award Number	FWP-FEAA151
Project Duration	07/01/2019 – 09/30/2023
Total Project Value	$ 1,025,000
Technology Area	Plant Optimization Technologies

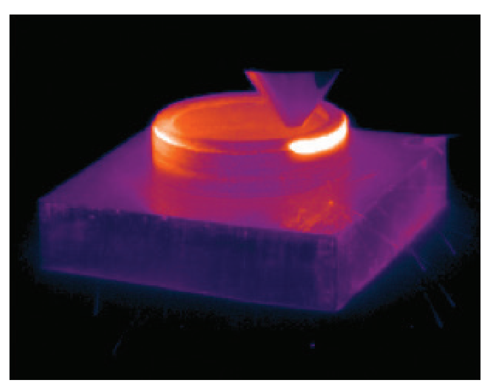
Oak Ridge National Laboratory will weld dissimilar metals using functionally graded transition joints that exhibit high resistance to creep and fatigue and high microstructural stability. The primary focus of the project will be on joining ferritic steels to austenitic steels, in particular alloys that are relevant in coal-fired power plants. A key aspect of the R&D activities will be determining optimum compositional profiles of the transition joint, which will be achieved using computational materials science and engineering. Another key aspect will be avoiding sharp changes in the carbon chemical potential of the joint region. The project entails the integration of several interrelated tasks to achieve project objectives.

- Design optimization of chemistry/microstructure transitions in graded transition joints to minimize carbon diffusion and the formation of stresses induced by thermal expansion mismatch.
- Optimization of processing methods to fabricate the graded transition joint and in situ process monitoring for development. The effect of using powders or wires as feedstock on manufacturability and costs will be addressed, as well as practical aspects of deploying the technology to the field.
- Evaluation of mechanical performance of the transition joints using ex situ and in situ testing as a function of processing parameters, and comparison with historic creep rupture properties of dissimilar metal welds.

The successful completion of this project will set the stage for subsequently developing an ASME code case for wide industrial acceptance and utilization of this technology



In-situ Imaging of joint during fabrication. Color corresponds to vertical height.

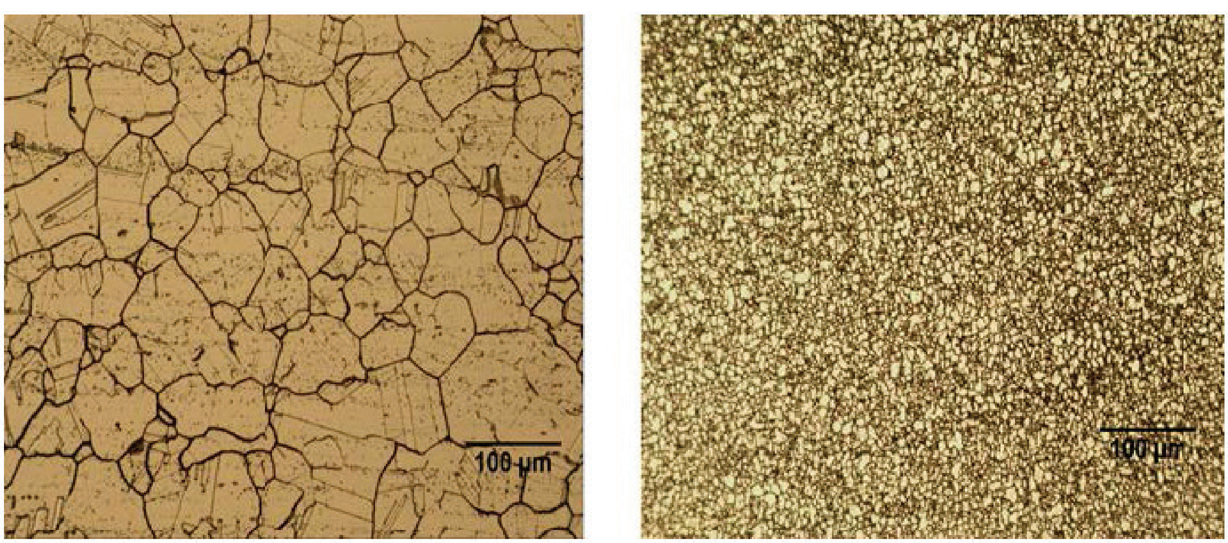


IR image showing temperature distribution with build height.

Integrated Process Improvement using Laser and Friction Stir Processing for Nickel Alloys used in Fossil Energy Power Plant Applications

Performer	**Pacific Northwest National Laboratory (PNNL)**
Award Number	FWP-71843
Project Duration	10/01/2018 – 03/31/2023
Total Project Value	$ 1,120,000
Technology Area	Plant Optimization Technologies

The goal of this project is to determine the advantages of laser and friction stir processes when applied to the processing of nickel-based alloys used in extreme operating environments found in fossil energy power systems. This project will investigate and demonstrate an integrated approach using both laser processing (LP) and friction stir welding and processing (FSW/P) to join, repair, and return to service nickel alloy castings and wrought fabrications such as hot gas path components in gas turbine applications. The integrated approach will use laser cleaning followed by friction stir welding, which may be a low-cost and robust way to increase the service life of these alloys and components used in fossil energy applications (e.g., gas and steam turbines, advanced ultrasupercritical plants, and sCO_2 heat exchangers).



Haynes 282 microstructure comparison of base material (left) and FSW weld nugget (right).

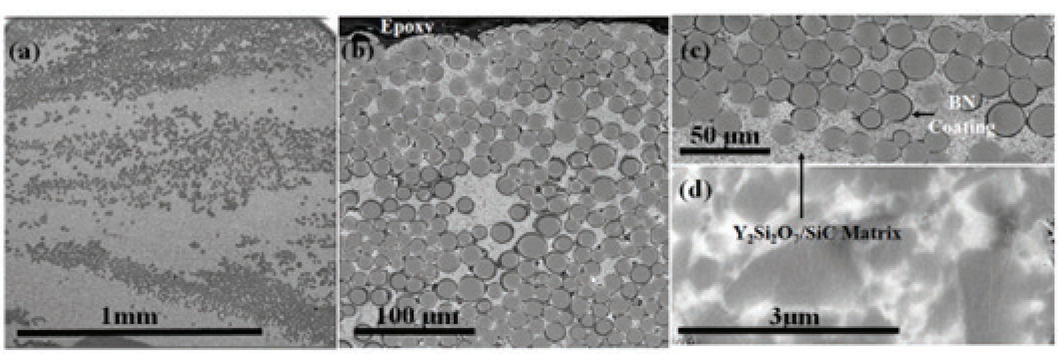
Enhancing Ceramic Matrix Composite (CMC) Temperature Performance in High-Hydrogen Environments using Field Assisted Sintering Technology

Performer	**Pennsylvania State University (PSU)**
Award Number	FE0032226
Project Duration	01/01/2023 – 12/31/2024
Total Project Value	$ 843,750
Technology Area	Plant Optimization Technologies

The overall objective of this project is to significantly improve the temperature performance by at least 150° C of ceramic matrix composite (CMC) materials in high-hydrogen environments using field assisted sintering technology (FAST). FAST is a relatively new material synthesis technology that allows for novel materials to be processed at significantly shorter fabrication times by using high-density electrical currents to drive rapid, high-intensity heating.

The project objective will be achieved using the following methodology: FAST-derived CMCs in conjunction with advanced ceramic coatings will be developed to adapt to higher-temperature combustion with higher-humidity contents as a result of the high-hydrogen fuel. The fabricated samples will be tested at a range of combustor operating conditions with up to 100% hydrogen fuel to understand the impact of different CMC formulations and combustion gas environments on the material performance.

The anticipated outcome of this project is a lab-scale demonstration that the FAST-based manufacturing technology can enable high-density silicon carbide (SiC)-based CMC parts with superior water vapor recession resistance, such that their upper use temperature can significantly exceed that of state-of-the-art nickel superalloys and conventional SiC/SiC CMCs, and thus enable an increase in combined-cycle combustion turbine efficiency by up to two percentage points. This will result in reduced fuel consumption and emissions.

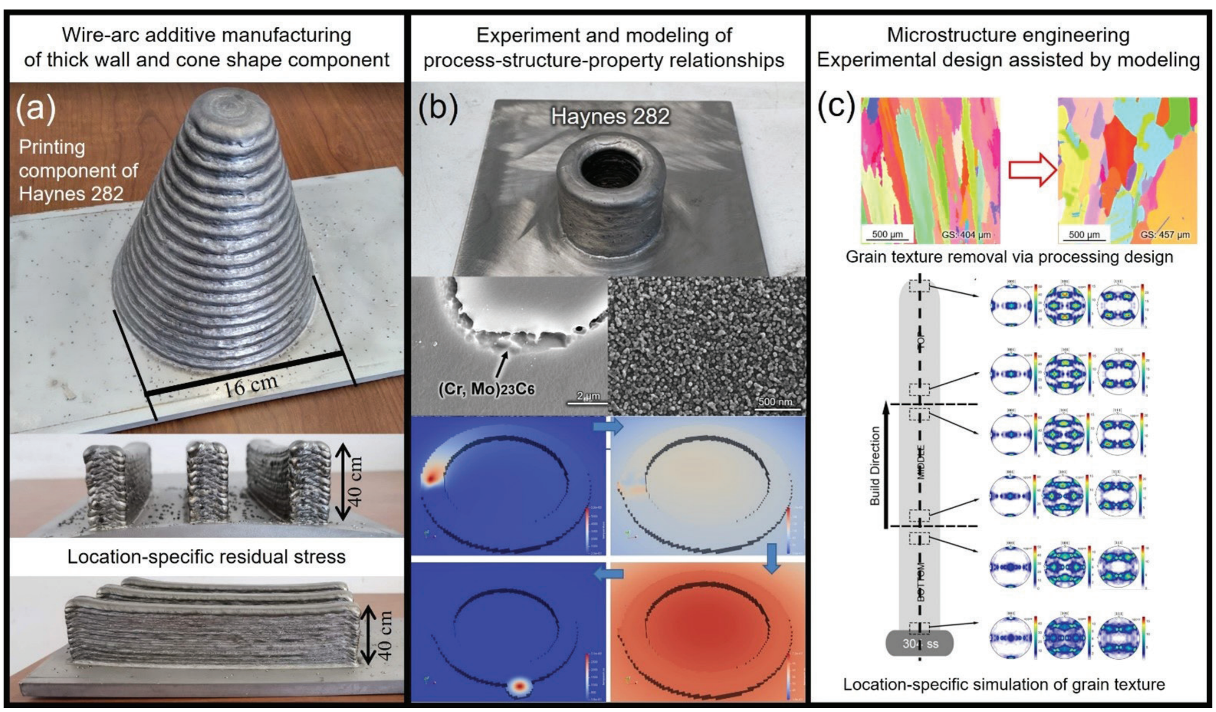


CMC microstructure.

Wire Arc Additive Manufacturing of Advanced Steam Cycle Components Using Location Specific Design Enhanced by High-Throughput Experiments and Machine Learning

Performer	**University of Pittsburgh**
Award Number	FE0026825-06-19
Project Duration	02/01/2021 – 01/31/2023
Total Project Value	$ 640,225
Collaborator	University of Pittsburgh
Technology Area	Plant Optimization Technologies

The research team at the University of Pittsburgh (Pitt) will perform location specific design for Wire Arc Additive Manufacturing (WAAM) of Haynes 282 superalloys through the extended ICME (Integrated Computational Materials Engineering) platform with further enhancement by machine learning (ML) and high throughput experiments on process-structure-property relationships. The location-specific ICME design will significantly improve the overall quality of thick wall (> 1 inch) components with complex shape fabricated by WAAM. This project could enable applying the WAAM technology to fabricate or repair advanced steam cycle components with desirable strengths at elevated temperatures for the efficient operation of advanced fossil energy power plants. An extended ICME design framework for WAAM of part scale components will be delivered through this project and can be readily extended to other high-performance alloys.Additively Manufactured Graded Composite Transition Joints for Dissimilar Metal Weldments in Ultra-Supercritical Power Plant.



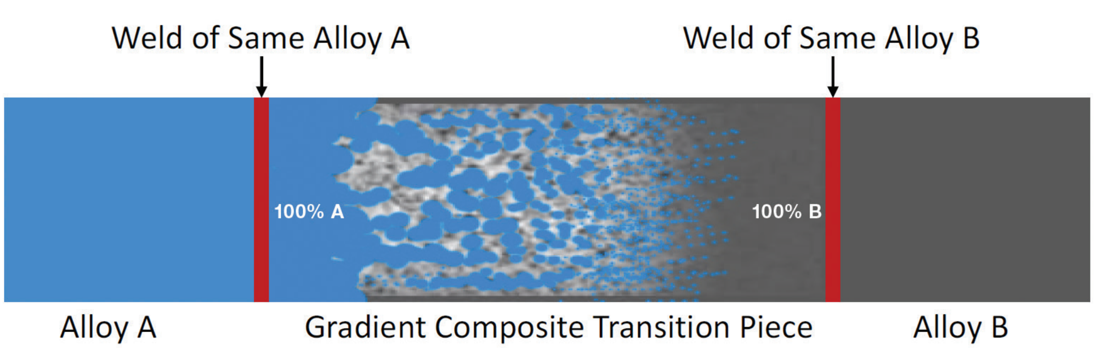
Additively Manufactured Graded Composite Transition Joints for Dissimilar Metal Weldments in Utra-Supercritical Power Plant

Performer	West Virginia University	Oak Ridge National Laboratory (ORNL)
Award Number	FE0031819	FWP-FEAA372
Project Duration	10/01/2019 – 09/30/2024	10/01/2019 – 09/30/2021
Total Project Value	$ 7,289,004	$ 310,000
Total Project Value (All)	$ 7,599,004	
Collaborators	Carpenter Powder Products; General Electric; Oak Ridge National Laboratory	
Technology Area	Plant Optimization Technologies	

The objective of this project is to develop and demonstrate at lab scale the additively manufactured graded composite transition joints (AM-GCTJ) for dissimilar metal weldments (DMW) in next-generation advanced ultra-supercritical (AUSC) coal-fired power plants, that can significantly improve the microstructural stability, creep, and thermal-mechanical fatigue resistance as compared with their conventional counterparts.

Conventional DMW interfaces of P91/Super 304H and Super 304H/282 will be characterized by neutron diffraction measurement at Oak Ridge National Laboratory (ORNL)'s Spallation Neutron Source (SNS) under simulative thermal cyclic conditions to understand the thermal stresses and establish the baseline. In collaboration with the experimental microstructure characterization and creep and thermal creep fatigue testing tasks, the ORNL's integrated computational weld engineering (ICWE) model framework will be used to simulate the microstructure and property variations and their effects on the thermal stresses in the AM-GCTJ.

The successful completion of this project will develop cost-effective and readily scalable AM-GCTJ that practically eliminates the coefficient of thermal expansion mismatch and sharp compositional transition associated with DMW. The AM-GCTJ will significantly improve the high-temperature mechanical properties as compared with their conventional DMW counterparts. This is not only a key technology advancement toward the development of next generation AUSC plants, but also may extend the lifetime of current fleets that have been through frequent cycling.



Concept of additively manufactured graded transition joint.

Carbon Management with Advanced Materials: An Assessment of Experimental and Computational Capabilities

Performer	**University of California - Riverside**
Award Number	FE0032208
Project Duration	10/01/2022 – 09/30/2023
Total Project Value	$ 200,000
Technology Area	University Training and Research

The overall goal of this project is to conduct a scoping study and university-wide self-assessment to evaluate how the Recipient's current capabilities, expertise, personnel, and facilities/equipment align with Department of Energy (DOE) Fossil Energy and Carbon Management (FECM) goals (particularly decarbonization).

This assessment will identify gaps in capabilities and provide a discussion on what would enable the Recipient to be better prepared for potential future competitive solicitations focused on FECM-supported technologies.

Conformal Coatings on Additive Manufactured Robust Alloys for Significant Mitigation of Oxidation, Erosion, and Corrosion

Performer	**West Virginia University Research Corporation**
Award Number	FE0032068
Project Duration	09/15/2021 – 09/14/2024
Total Project Value	$ 400,000
Technology Area	University Training and Research

The project will develop novel high-temperature alloys from nickel (Ni)-based alloys that further integrate additive manufacturing (AM) fabrication, creating novel nanoscale oxide precipitation for strengthened mechanical integrity and enhanced oxidation resistance, and subsequent application of conformal protective coatings on the additive manufactured alloys. To increase the strength and oxidation resistance of nickel alloys, erbium and titanium oxide (Er_2O_3 and TiO) precipitants will be added to the AM powders for the Inconel 625 alloy and result in dense nano-oxide precipitation of Er_2O_3 and $Er_2Ti_2O_7$, which will result in a solution-strengthened novel Ni-based alloy. Furthermore, a conformal protective oxide coating layer will be simultaneously applied on both the internal and external surface of the additive manufactured heat exchangers with complex geometry using atomic layer deposition (ALD). The ALD layer will be conformal, uniform, pin-hole free, dense, and ultra-thin with negligible weight gain to increase both the oxidation and corrosion resistance at elevated temperatures.

The project is organized into 5 Tasks. Task 1 is project management. Task 2 is devoted to introducing the dense precipitates into the Ni-based alloys through AM. Task 3 is devoted to ALD coating of the newly additive manufactured 3D printed Ni-based alloys and ALD repairing and recoating the alloys after oxidation exposure. Task 4 is the oxidation resistance testing of the additive manufactured and ALD coated Ni-based alloys. Task 5 is the comprehensive physical properties testing, and nanostructure analysis of the additive manufactured alloys (including the ones with precipitates), ALD coated alloys, and the alloys after exposure to the oxidation and corrosion environments.

The developed high-temperature materials are expected to possess superior strength, high resistance to external surface oxidation, internal surface carburation, and corrosion, and can be applied to heat exchangers for operation in supercritical carbon dioxide at high temperatures (over 750 °C) and pressure (30 MPa). For after-service heat exchangers that have damaged surfaces, the ALD coating can also be utilized to repair/refurbish the heat exchanger parts that may have been impacted by surface oxidation and dramatically increase their lifetime and reduce costs.

ADVANCED STRUCTURAL MATERIALS FOR HARSH ENVIRONMENTS

Robust Dissimilar Metal Friction Welded Spool for Enhanced Capability for Steam Power Components

Performer	**General Electric (GE) Company**
Award Number	FE0031907
Project Duration	09/01/2020 – 08/31/2023
Total Project Value	$ 6,249,846
Technology Area	Plant Optimization Technologies

General Electric Company will undertake a three-year, $6.25 million project to improve the durability of dissimilar metal welds (DMWs) for boiler and heat recovery steam generator (HRSG) applications with reduced maintenance costs and enhanced capability of plant cycling operations. The Recipient will develop a durable friction-welded dissimilar-metal spool utilizing the higher capability transition material of a nanostructured ferritic alloy (NFA) and an oxidation protective coating across weld joints that can be retrofitted to the existing fleet. The spools will be friction-welded in the shop, allowing for controlled friction-welding procedures, post-weld heat treatment, and non-destructive evaluation (NDE). These spools can then be welded with same-metal fusion welds as replacements or upgrades in the field. Improved joint durability will enable at least a fivefold increase in the number of cold starts and reduce unplanned outages from DMW failures.

Improving the durability of the DMW joints reduces the number of unplanned outages and associated maintenance costs. The improved properties of the joint provided by friction welding and an NFA transition piece can enable an increased number of cold starts and more cycling of the boiler and HRSG systems. Preliminary evaluation of a friction-welded spool showed a fivefold increase in the number of cycles before failure of the joint compared to a baseline traditional DMW. This improvement in life and DMW reliability would lead to less unplanned downtime and longer maintenance windows.

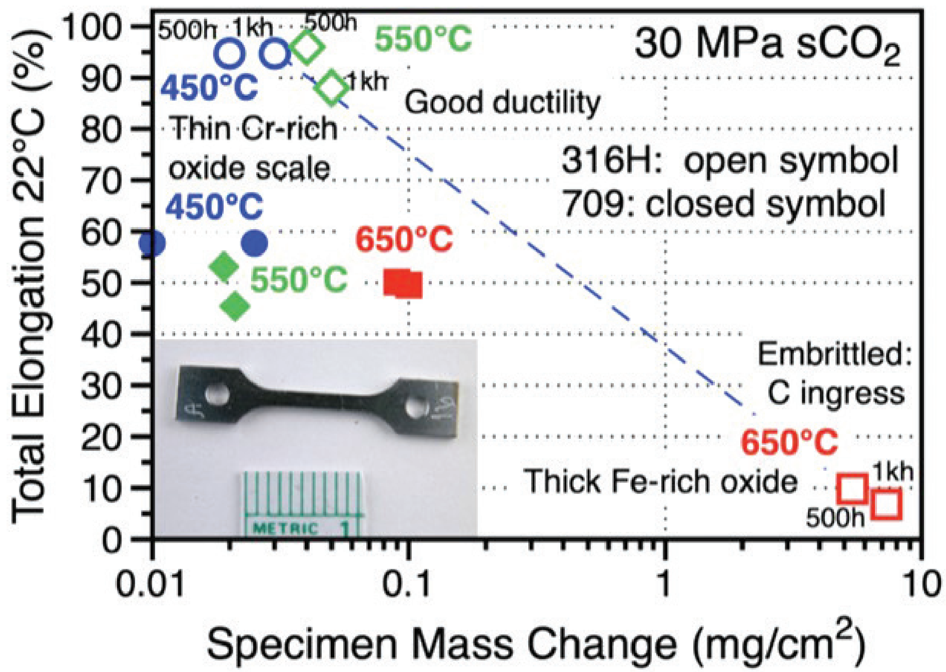
Rotary friction welded T91 to 304H tube.

Effect of Impurities on Supercritical Carbon Dioxide Compatibility

Performer	**Oak Ridge National Laboratory (ORNL)**
Award Number	FWP-FEAA144
Project Duration	10/01/2019 – 09/30/2023
Total Project Value	$ 1,650,000
Technology Area	Plant Optimization Technologies

This project will study the effect of impurities (e.g., O_2, H_2O) on compatibility of structural materials in supercritical carbon dioxide (sCO_2) Brayton cycle systems, particularly for direct-fired systems. For economically scaling up to commercial power production, the increased use of Fe-based alloys is needed and impurity studies at (450-650 °C) will determine operating limitations for 9-12% Cr and austenitic steels. In addition to measuring reaction rates and characterizing reaction products, post-exposure room-temperature tensile properties will be used to quantify compatibility as a function of temperature, time, and impurity level. After establishing baseline behavior, coatings and shot peening will be evaluated to increase the maximum temperature capability of Fe-based structural alloys. This information will be used to continue the development of a lifetime model for various classes of structural alloys with and without surface modifications. Previously, high O_2 impurity levels (0.25-1%) have been found to increase reaction rates of both Fe- and Ni-based alloys at 750 °C/300 bar (30 MPa). Further work is needed to isolate O_2 and H_2O effects including the use of isotopic tracers. An additional project goal is to understand creep behavior of thin-walled sections for Fe- and Ni-based alloy heat exchangers.

Supercritical CO_2 (sCO_2) is of increasing interest in a broad range of energy applications, especially for waste heat recovery but also to replace water/steam. If sCO_2 systems could be scaled up from the current <10 MW size this would enable use in power generation in coal, natural gas (bottoming cycle), nuclear (power and propulsion), and concentrated solar power systems. The advantages of sCO_2 are (1) low critical temperature and pressure (31 °C/73.8 bar), (2) single phase over a wide temperature and pressure range, (3) high thermal capacity and density leading to smaller turbomachinery, and (4) low work for recompression (e.g., compared to He). Closed Brayton cycle systems (like sCO_2) operate at higher pressures to increase efficiency, and these higher pressures require new designs for airfoils, seals, and heat exchangers while typically lowering the working fluid temperature significantly compared to combustion turbines. These new designs may necessitate new materials or processing methodologies. Materials are a key concern for the scale-up to commercial size, particularly the use of lower-cost steels where applicable. Recently, unique experimental equipment was developed at ORNL for simulating controlled impurity levels in sCO_2 conditions. Initial testing was conducted at 750 °C/300 bar and found accelerated corrosion rates compared to research-grade sCO_2, particularly for Fe-based alloys. The next phase of this study is examining steels at lower temperatures where they have sufficient strength. The initial results suggest that all of the candidate steels are showing faster corrosion rates with the addition of impurities and the next phase of coating evaluations is needed.

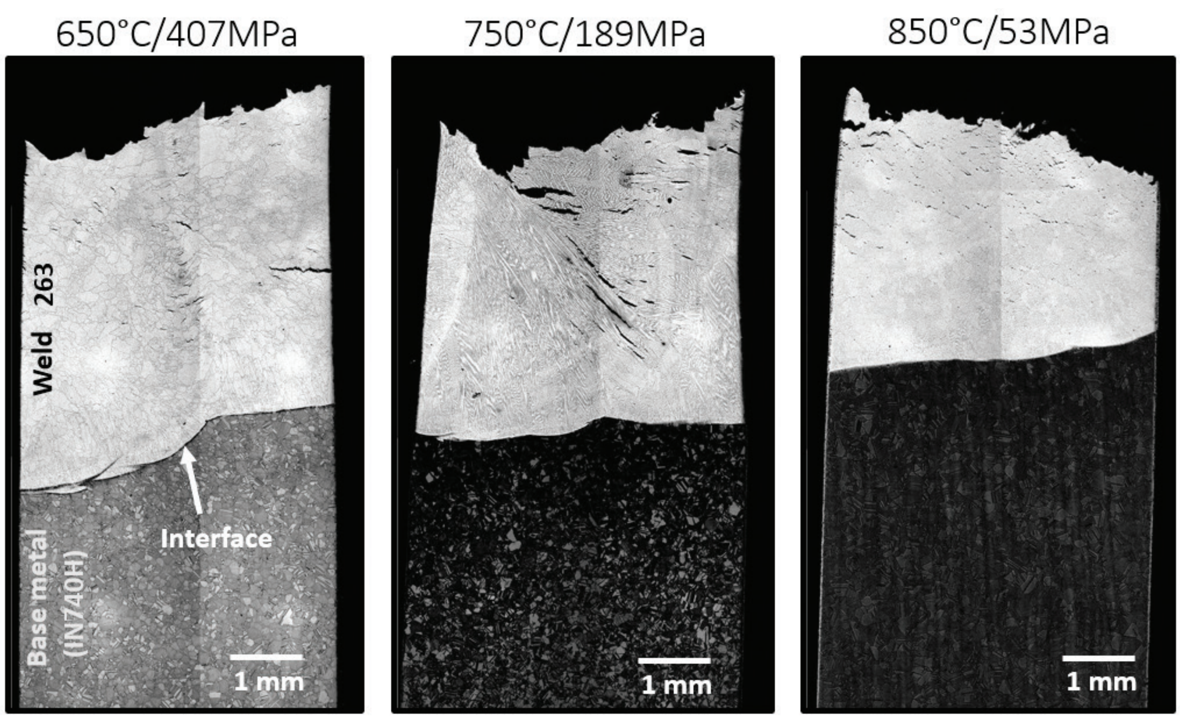


Specimen mass change plotted versus the post-exposure room temperature ductility (total elongation in tension with a strain rate of 0.015/min per ASTM E8-13). The open symbols are for type 316H stainless steel and the closed symbols for alloy 709 with 20Cr-25Ni.

Evaluating Ni-Based Alloys for A-USC Component Manufacturing and Use

Performer	**Oak Ridge National Laboratory (ORNL)**
Award Number	FWP-FEAA152
Project Duration	10/01/2019 – 09/30/2023
Total Project Value	$ 1,615,000
Technology Area	Plant Optimization Technologies

This project evaluated advanced nickel (Ni)-based alloys to support the manufacturing and use of components under advanced ultra-supercritical (AUSC) steam conditions, which range up to 760 degrees Celsius (°C; 1400 °F) and 35 megapascals (MPa; 5000 psig). In particular, this project focused on evaluating materials from near-to-full-scale components, such as Haynes 282 large rotor forging, half-valve body casting, and steam turbine nozzle carrier casting, to provide (a) insights into potential manufacturability issues related to large-scale components made from Ni-based alloys and (b) engineering data and support for actual AUSC plant design. In addition, this project contains substantial efforts in weld characterization and long-term creep testing of Ni-based alloy weldment, which should provide useful data for filler metal selection and future ASME code qualification efforts for cast Haynes 282 weldment.



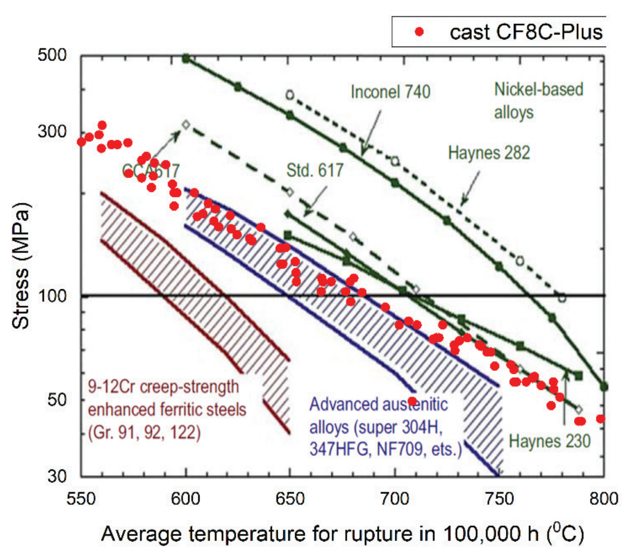
Cross-section view of creep rupture specimens of Inconel 740H cross-weld made with alloy 263 filler metal.

Low Cost High Performance Austenitic Stainless Steels for A-USC

Performer	**Oak Ridge National Laboratory (ORNL)**
Award Number	FWP-FEAA133
Project Duration	10/01/2019 – 09/30/2023
Total Project Value	$ 2,040,000
Collaborator	Electric Power Research Institute (EPRI)
Technology Area	Plant Optimization Technologies

This project evaluated the behavior of high-temperature materials to qualify low-cost alloys for steam turbine designs required for operation under advanced ultra-supercritical (AUSC) steam conditions (760 °C and 345 bar/1400 °F and 5000 psig steam), and in ensuring that any limitations of current materials are overcome. This project focused on obtaining long-term creep properties of full- or near-full-sized components of extruded tubes and pipes or other parts fabricated from the CF8C-Plus alloy for component testing in an actual AUSC power plant environment (ComTest).

The key to enabling higher efficiencies/lower emissions is the availability of materials capable of operation in steam at the higher temperatures and pressures. In particular, the limiting temperature for current steam turbines is set by the strength of the material used for the turbine casings, which are constructed from large castings that have complex shapes to accommodate the turbine vanes and blades; typically, assembly involves welding together several castings. To meet these requirements, the alloy used must develop the required strength in the as-cast state (since the size of the castings and the large changes in section thickness restrict the ability to control post-casting heat treatments) and have good weldability. The alloys used for current steam turbine casings are 2-10%Cr ferritic steels, for which the maximum temperature capability is approximately 620 °C (1,148°F). For higher temperatures, austenitic steels typically are the next choice, but the thermal fatigue properties of most cast austenitic steels are unsuitable for this application. However, cast CF8C-Plus steel has outstanding fatigue and thermal fatigue resistance, so this steel might be useful for such applications.



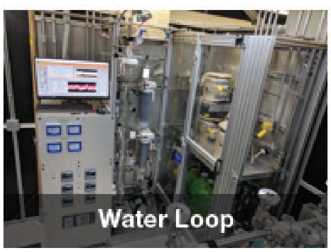
Comparison of 100,000 h creep-rupture strength as a function of temperature between cast CF8C-Plus and other alloy classes.

Steamside Oxidation Issues in Current Coal-Fired Boilers

Performer	**Oak Ridge National Laboratory (ORNL)**
Award Number	FWP-FEAA150
Project Duration	08/01/2019 – 09/30/2023
Total Project Value	$ 550,000
Technology Area	Plant Optimization Technologies

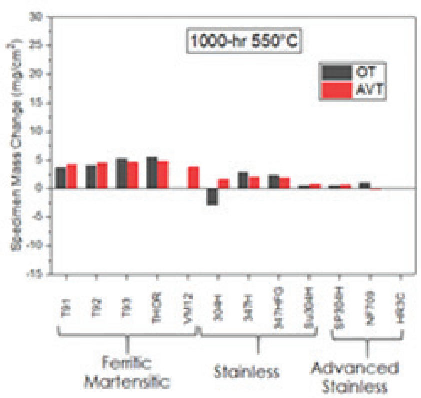
The primary goal of this project is to develop a steamside oxidation model that will incorporate important real-world parameters such as water chemistry, pressure, and scale adhesion for current coal-fired boiler systems and cover growth and exfoliation. The initial focus will be on evaluating the temperature-dependent effect of oxygen content and the role of amines on the oxide scale morphologies to enable a quantitative analysis of the adhesion and exfoliation behavior of both ferritic and austenitic steels. A better understanding of the underlying mechanisms will allow a realistic lifetime prediction of currently employed materials under a range of partial- and full-load duty cycles and suggest avenues for the deployment of surface modifications including coatings and shot peening.

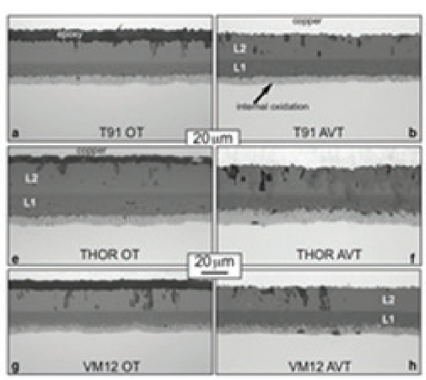
Testing



- 275 bar water, 50-h cycles, 550-650°C
- Feritic-martensitic and austentic steels
- **Controled water chemistry:** OT (100ppb O_2), AVT (<10 ppb O_2)
- **Additions:** 2 film forming products (amines)

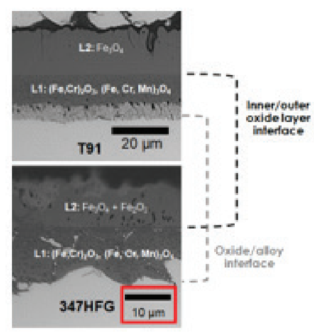
Oxidation Behavior

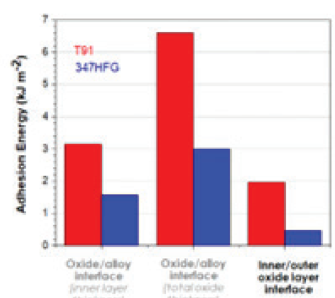




Water chemistry did not significantly influence specimen mass change

Microstructural Analyses





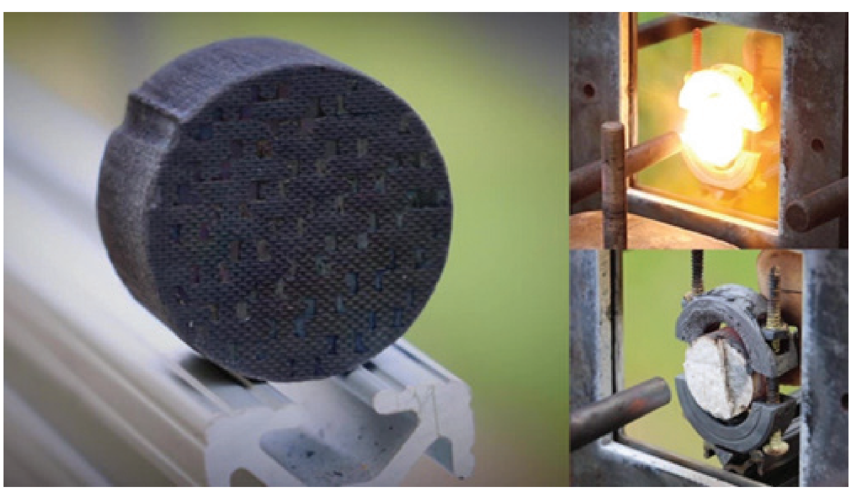
In-situ SEM tensile testing resulted in lowest adhesion energies for the inner/outer interference that coresponds well to observed failure interface

Ceramic Matrix Composites for H_2 Combustion

Performer	University of Central Florida
Award Number	FE0032228
Project Duration	01/19/2023 – 01/18/2025
Total Project Value	$ 998,706
Technology Area	Plant Optimization Technologies

Gas turbines for power generation are under transition to hydrogen-based combustion systems to achieve net-zero or net-negative carbon emissions. A transition to hydrogen-based fuel combustion must also coincide with other technological advancements in gas turbines. The project will investigate a new ceramic matrix composite (CMC) material, YSZ/Si(B)CN (YSZ = yttria stabilized zirconia) coated or interlayered with multi-layered nano-ceramic composites assembled at the molecular level, in a hydrogen combustor similar to modern gas turbine combustors. The project scope of work is to develop CMC materials and their manufacturing techniques towards high temperature performance and high resistance to environmental degradation in hydrogen combustion environments, provide an experimental assessment of high-temperature CMC materials in hydrogen-based fuels combustion under gas turbine relevant conditions, and develop a high-fidelity analysis platform that can adequately evaluate the thermo-mechanical performance of CMC materials with direct consideration of environmentally induced material degradation due to chemical reaction and physical material configurational changes..

The work will provide critical knowledge regarding CMC materials design and manufacturing for hydrogen-burning gas turbines components. The project will methodically explore CMC material performance and generate data to identify the best strategies to optimize the performance of CMC materials for hydrogen-based energy production to eliminate carbon emissions. The project will address these specific challenges in design, manufacturing, testing, and modeling of advanced CMC materials in an actual hydrogen combustion facility. The combustor can emulate loading conditions experienced in modern gas turbine combustors. Hence, experimental measurements of materials at elevated pressures (P >10 atm) and load conditions (T >1500°C) will provide knowledge that is directly applicable to original equipment manufacturers.



Flame exposure test of Ceramic Matrix Composite under an oxy-acetylene torch

COMPUTATIONAL MATERIALS DESIGN

Advanced Materials Development

Performer	**National Energy Technology Laboratory (NETL)**
Award Number	FWP-1022406
Project Duration	04/01/2018 – 03/31/2023
Total Project Value	$ 16,665,122
Technology Area	Advanced Energy Materials

NETL's Research and Innovation Center's Advanced Alloy Development Field Work Proposal (FWP) is focused on developing high-performance materials to improve efficiencies in the existing fleet and enable advanced fossil energy systems. NETL uses an integrated materials engineering approach that incorporates computational alloy design with best-practice manufacturing (modified as needed to achieve microstructure and performance objectives) with focused performance evaluation and characterization. Research is conducted to develop and validate computational algorithms for designing advanced alloys and for predicting alloy performance over multiple length scales and multiple time scales relevant to advanced fossil energy power systems.

The Advanced Alloy Development FWP has five distinct research themes:

Systems Engineering & Analysis (SE&A)—Provide techno-economic and market studies on fossil fuel power generation plants operating at the elevated conditions [e.g., advanced ultrasupercritical (AUSC) Rankine cycles] enabled by advanced alloys, identifying applications, and quantifying the cost and performance improvements relative to the commercial state of the art.

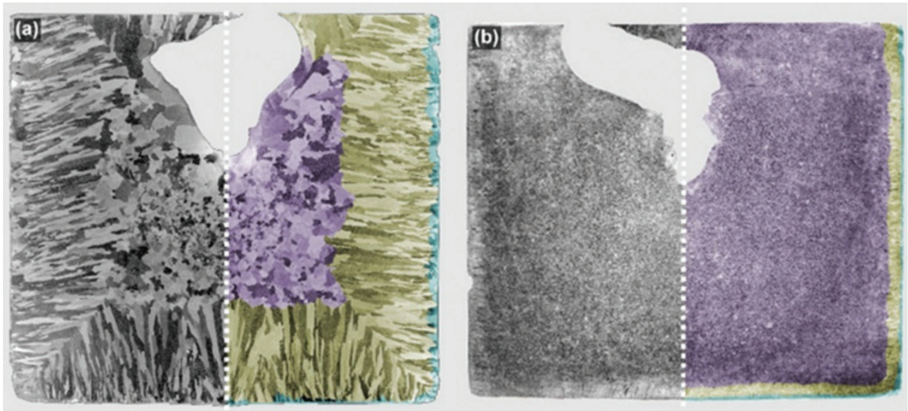
Computational Design and Simulation—Use computational materials modes, multi-scale characterization simulations of microstructural features, and cutting-edge data analytics to guide and accelerate alloy design and manufacturing development.

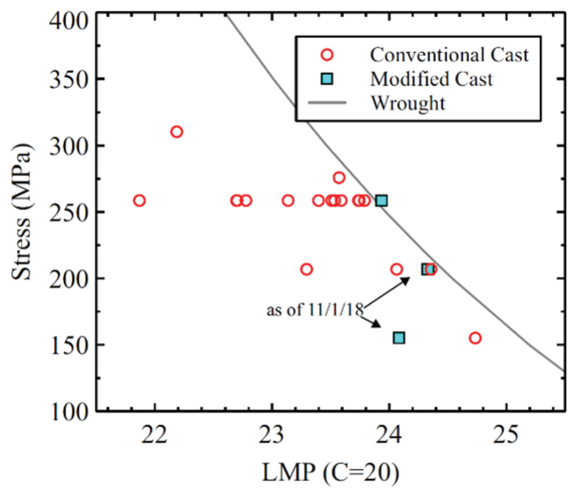
Processes, Manufacturing, and Properties—Develop and demonstrate at pilot industrial scale improved manufacturing processes to produce advanced alloys with improved service life performance.

Materials for sCO_2 Power Cycles: Alloy Performance—Determine whether available AUSC power plant materials are suitable for fossil fuel supercritical carbon dioxide (sCO_2) service in terms of temperature and stress, and if they are, assess the potential physical and mechanical consequences of their use.

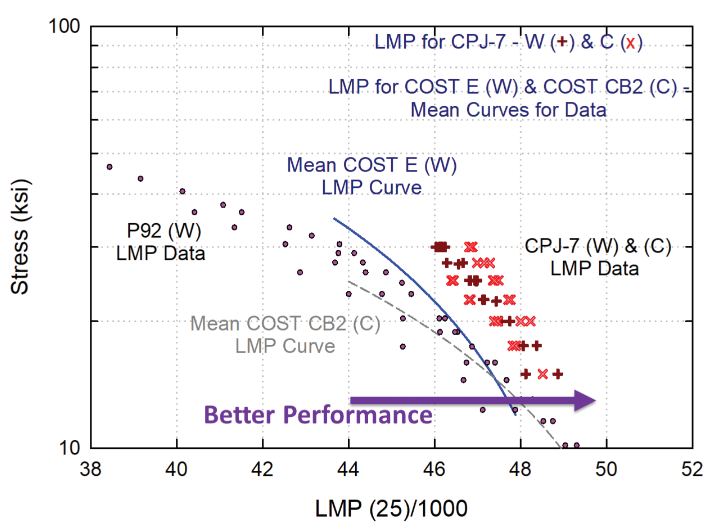
Materials for sCO_2 Power Cycles: Materials and Manufacturing Issues Associated with Heat Exchangers for sCO_2 Power Cycles—Assess materials selection and joining processes for compact heat exchanger designs to (1) reduce equipment size and (2) enhance heat transfer between the high-temperature and low-temperature working fluids in sCO_2 power cycles.

The structural materials and manufacturing processes researched in this FWP are needed to lower the cost and improve the performance of fossil-based power-generation. Additionally, the development and utilization of computational simulation and broad-based data analytic tools can further reduce the time and cost of developing advanced energy systems.





Cast Version of Alloy 740. A modified casting route was developed that leads to a more homogeneous grain size distribution throughout the casting (b compared to a) and better properties. Creep testing is ongoing, but results indicate that the modified cast materials behave in a manner similar to the wrought material.



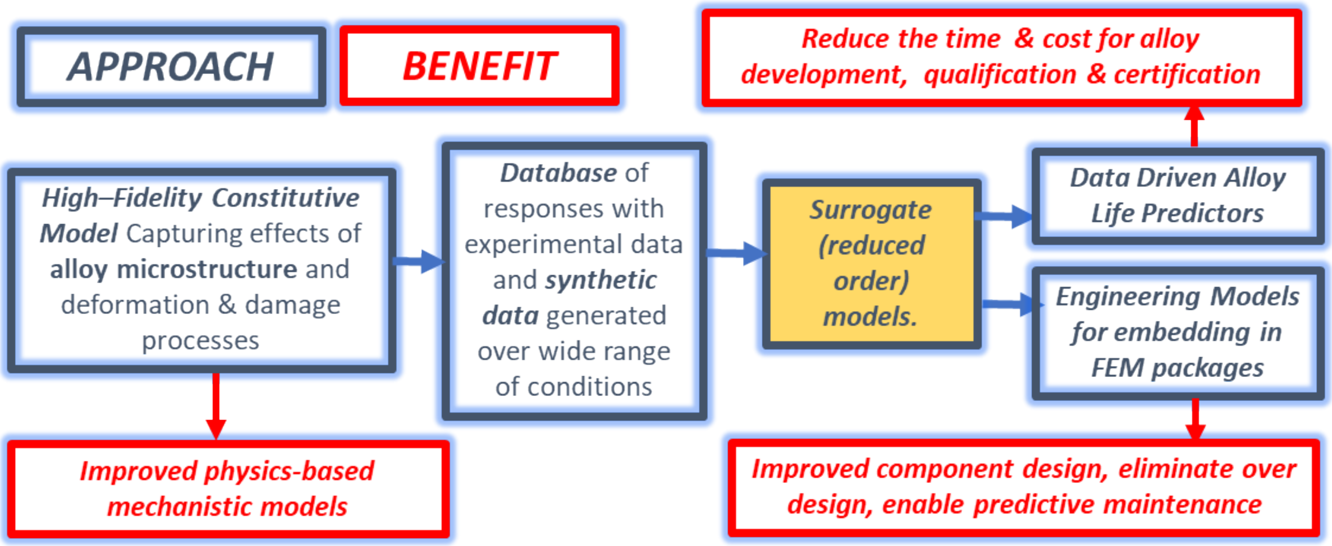
Creep behavior: NETL's CPJ-7 compared to other advanced Fe-9Cr streels, COST E, Cost CB3 and P92. W=Wrought, C=Cast.

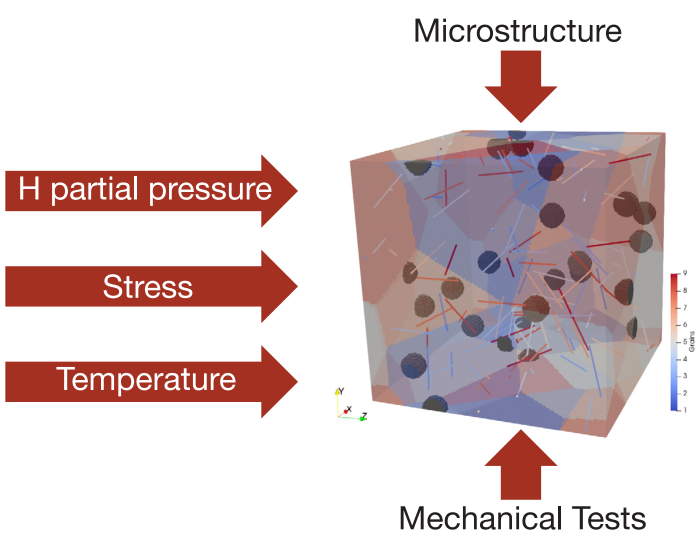
eXtremeMAT- Accelerated Design and Manufacture of Next Generation Extreme Environment Materials

Performer	**National Energy Technology Laboratory**
Award Number	FWP-1022433
Project Duration	10/01/2018 – 09/30/2023
Total Project Value	$ 3,189,921
Technology Area	Advanced Energy Materials

The objective of eXtremeMAT is to demonstrate how state-of-the-art computational materials modeling and cutting-edge experimental tools across the National Laboratory (NL) Enterprise, in conjunction with industry partnership, can accelerate the deployment of conventional and additively manufactured alloys for application in extreme environments and are needed to enable technologies to achieve net-zero carbon emissions by mid-century. Hydrogen has become a focal point of attention, as its production and use pave a way towards eliminating carbon emissions. The production of hydrogen from carbonaceous sources with carbon capture via processes, such as gasification and steam methane reforming, will serve as a transition for the use of hydrogen in the power generation and industrial/ manufacturing sectors. These applications (hydrogen production from carbonaceous sources, hydrogen turbines [pre-combustion] for power generation) will impose a harsh constraint on alloys. To improve the reliability and enhance the safety, eXtremeMAT-H_2 aims to study the response of alloys subjected to creep and creep-fatigue under elevated temperatures and in contact with pressurized hydrogen gas. The overall intent is to be able to determine the expected creep-fatigue lifetime of alloys under combined stress, temperature, and hydrogen. This is important, as while the effect of hydrogen on the tensile response of metals has been extensively studied in the literature, little has been investigated on the impact on creep and creep-fatigue scenarios (conditions that are relevant to operating conditions from carbonaceous sources with carbon capture and power generation using hydrogen). In these conditions (elevated temperatures, complex loading states, and long service life), alloy microstructure and moderate changes in composition will have drastic effects on the overall performance of the system. eXtremeMAT developed a framework and a series of toolsets to predict the creep and creep-fatigue behavior of alloys that incorporate the effects of alloy chemistry and microstructural evolution during service. eXtremeMAT-H_2 will expand these tool sets to include materials' lifetime and failure under hydrogen environments. NETL-RIC efforts will focus on four tasks as follows: (i) atomic level calculations to simulate hydrogen-dislocation interactions, (ii) atomic level calculations to simulate hydrogen segregation at interfaces, (iii) quantify the epistemic or model form uncertainty; and (iv) perform as needed creep tests.

XMAT research provides the materials solutions needed to meet the challenges facing fossil energy power generation. Benefits include reducing the cost of alloy development and time-to-deployment; improved fossil energy plant operation performance through condition-based maintenance; eliminating overdesigned components; and enabling new fossil energy-based transformational power generation technologies.





- H effects on creep is poorly studied
- H effects on tensile response is well known (decrease in toughness, embrittlement)
- Creep/ creep fatigue is less studied (increase in creep rate, increase in power law exponent)... Although new studies are poring in

Digital Twin

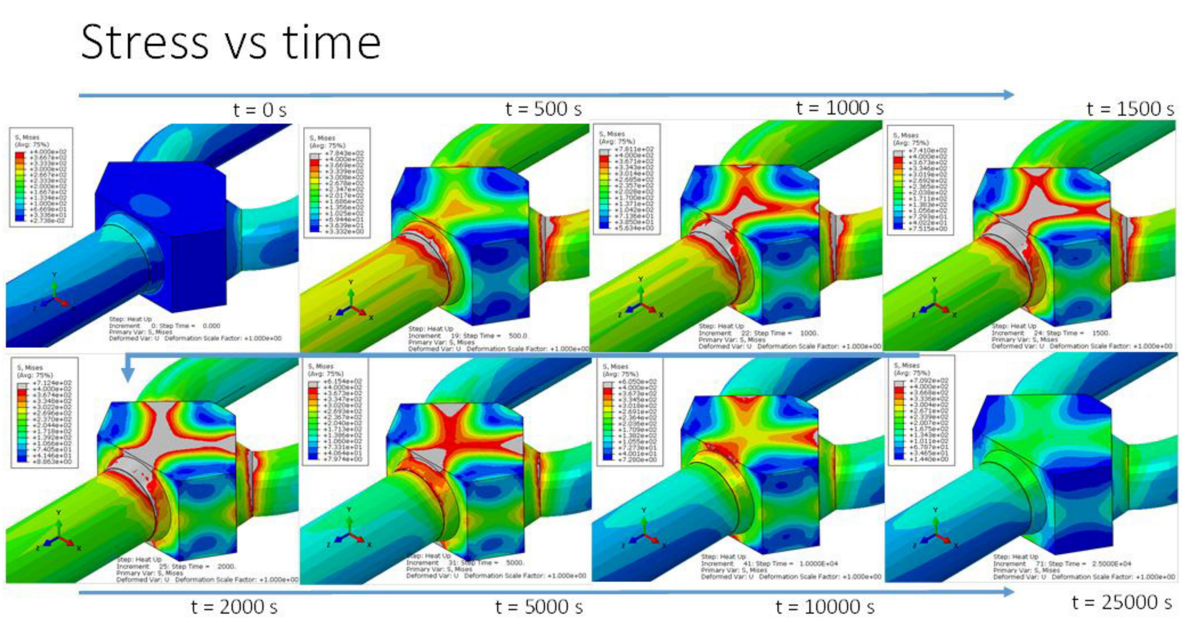
- Local H content at traps as a function of experimental conditions and microstructure?
- Does H increase the likelihood of crack nucleation, does it simply weakens preexisting cracks, does H affect precipitation kinetics?

Life Modelling of Critical Steam Cycle Components in Coal- Fueled Power Plants

Performer	Kratos Defense & Security Solutions, Inc.
Award Number	FE0031811
Project Duration	10/01/2019 – 03/31/2023
Total Project Value	$ 862,345
Technology Area	Coal Utilization Science

Kratos Defense & Security Solutions will calibrate an existing damage accumulation and component life model to a high-pressure turbine disk/rotor alloy (used in a steam-cycle turbine of a coal-fueled plant) and a steam-cycle Y-block alloy. The component life model that will be calibrated accounts for coupled thermomechanical damage accumulation, material microstructural evolution, and material or component erosion or corrosion damage to determine component life predictions. The damage accumulation model, complete with lifetime prediction capabilities, will be implemented in Microsoft Excel or MATLAB format, and will only require particular input data such as inelastic strain, hydrostatic stress, temperature-time waveforms, initial microstructure, etc., from a component-specific finite element analysis, to predict component lifetime. The work will be performed in conjunction with Southern Company, an industry partner and owner of a coal-fueled power plant. The project will include four primary tasks: (1) project management and planning, (2) materials characterization, (3) damage model calibration, and (4) component life model calibration and verification. The primary goal is to provide calibrated life estimation models for a DR22 steel Y-block and a Jethete stainless steel turbine blade.

The tool developed will enable lifetime prediction as a function of historical plant steam-cycle operational data as well as any potential proposed future operational cycling. Consequently, existing coal-fueled power plants will be able to operate safely for longer periods of time and at higher efficiencies, thereby reducing the economic and environmental impact of the existing coal power plant fleet.



Design, Modeling, and Experimental Validation for Life-Optimization of Hydrogen Turbine CMC Components

Performer	**Free Form Fibers, LLC**
Award Number	SC0022704
Project Duration	06/27/2022 – 06/26/2023
Total Project Value	$ 250,000
Technology Area	Plant Optimization Technologies

In preparation for the widespread implementation of ceramic matrix composites (CMCs) for hot gas path applications within hydrogen turbines, the Department of Energy, Office of Fossil Energy and Carbon Management seeks to encourage the development of process intelligence for CMCs operating at surface temperatures in excess of 1500°C, for extended periods of time in hydrogen-rich environments. CMCs are a new class of composite materials, but their application in hydrogen turbines is sure to raise new technical challenges that have, so far, not been of concern to other domains where CMCs are considered. To address anticipated shortcomings with hydrogen powered gas turbines, research is needed to design, model and test alternative interphase coatings and Environmental Barrier Coatings for the intended conditions. To this end, Free Form Fibers (FFF) and Materials Research and Design (MR&D) will implement a combined CIME-experimental approach leading to a CMC engineered for hydrogen turbines. FFF has unique capabilities to produce micro- composite samples with custom made interphase coatings while MR&D has a proven history of modeling material behavior.

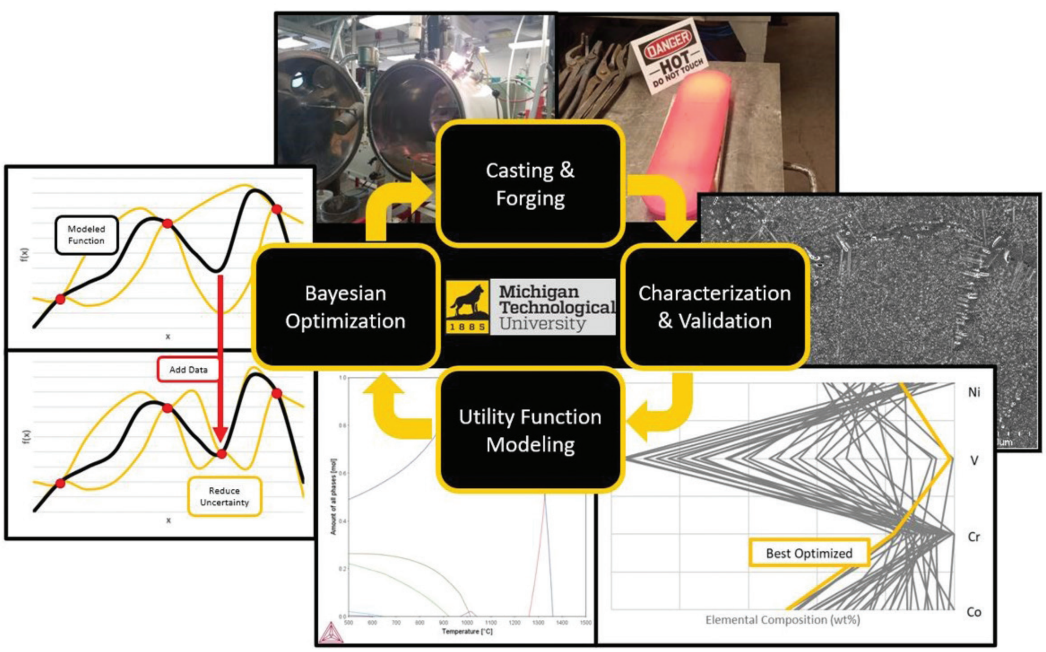
CMCs represent a new class of engineered materials for extreme environments that hold the promise of significant increases in energy efficiency and greenhouse gas reductions. This project will focus on micro-composite samples with custom coatings as well as sophisticated modeling to understand the material behavior and develop predictive models that can then be more broadly applied. The combined effort is expected to advance the state of the art for CMCs and build a predictive modeling capability to elicit the long-term behavior of such structures.

Hybrid Structured Nickel Superalloys to Address Price Volatility and Weld/Weld Repair Based Supply Chain Issues

Performer	**Michigan Technological University**
Award Number	FE0032071
Project Duration	09/03/2021 – 09/02/2024
Total Project Value	$ 400,000
Technology Area	University Training and Research

Two key factors affecting the fossil power high-temperature material supply chain are the volatility of nickel-based alloy prices and the challenges in welding precipitation-strengthened alloys. This project seeks to use integrated computational materials engineering (ICME) design strategies to solve these challenges by designing, casting, forging, welding, and validating the properties of hybrid eta-gamma prime-strengthened nickel superalloys optimized for cost and weldability. Specifically, significant reduction in cobalt to less than 5 wt.% versus 10–20% in candidate alloys for advanced energy systems is sought. Performance in high-temperature strength and creep will be maintained within 10% compared against existing candidate alloys designed for extreme environments. Weldability criteria will be evaluated through use of various susceptibility indices (solidification cracking, liquation, stress relief cracking) with the goal of broadening the welding and post-weld heat treat processing windows to be more forgiving.

Benefits are focused on providing alternatives to existing alloys with significant weldability issues which will enhance fabrication of new components, on-site assembly, and in-service repairs. Additional impacts include training graduate students in "hybrid" real-world/theoretical design methodologies to better prepare for advanced materials development.



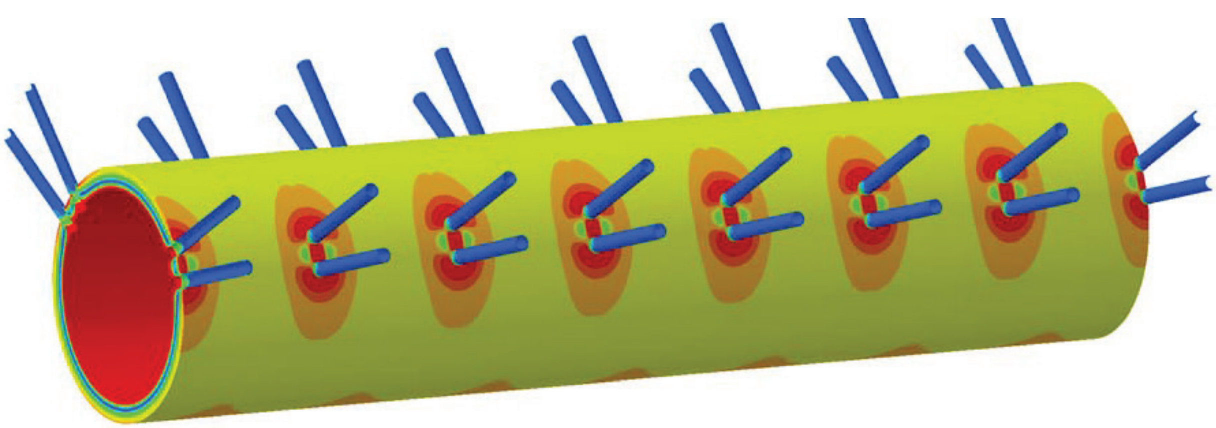
Michigan Technological University's Experimental Process.

Alloy for Enhancement of Operational Flexibilty of Power Plants

Performer	North Carolina Agricultural and Technical State University
Award Number	FE0031747
Project Duration	08/15/2019 – 08/14/2023
Total Project Value	$ 400,000
Collaborator	University of North Carolina Charlotte
Technology Area	University Training and Research

North Carolina Agricultural and Technical State University will employ advanced computational techniques to address the challenge of higher material deterioration facing existing coal-fired power plants due to a shift in their operational mode from baseline steady state to cycling. The cycling operation of coal-fired power plants promotes thermo-mechanical fatigue damage in boiler headers. As a result, materials deteriorate at a higher rate and ligament cracking occurs in headers in a shorter time. The main objective of this project is to employ computational fluid dynamics and finite element analysis to conduct a comprehensive and advanced study of the applicability of Inconel (IN) 740H superalloy in steam headers to improve the operating flexibility of power plants. The project team will use the results of the analysis to optimize the geometry of headers to minimize the quantity of material used.

A cost-benefit analysis of headers designed with IN740H (employing both traditional and optimized shapes) in comparison with creep-strength-enhanced ferritic (CSEF) steels such as Grade 91 will be conducted. This analysis will consider the higher cost of IN740H with respect to CSEF steels and the lower maintenance cost of IN740H during operation of the power plant.



Stress contour plot of a steam header.

High-Speed and High-Quality Field Welding Repair Based on Advanced Non-Destructive Evaluation and Numerical Modeling

Performer	**Ohio State University**
Award Number	FE0032067
Project Duration	09/24/2021 – 09/23/2024
Total Project Value	$ 400,000
Technology Area	University Training and Research

The goal of the project is to establish the experimental and computational foundations that are crucial to implement high-speed and high-quality field welding repair based on advanced non-destructive evaluation (NDE) and numerical modeling. The scope of work of the project is focused on developing two enabling techniques for repair of CSEF Grade 91 and 92 steel components: (1) microstructure detection using ultrasonic NDE, and (2) hardness prediction using a computational model for multi-pass, multi-layer welding.

Weld coupons will be fabricated using a high-deposition-rate process based on hot wire gas tungsten arc welding (GTAW). These weld coupons will be characterized for microstructure and hardness, which provides the baseline data for Gleeble® physical simulation to produce a bulk weld microstructure. Through the control of peak temperature and time, individual microstructures (especially martensite) with different levels of tempering will be produced. This simulated microstructure is needed since the actual weld comprises a highly inhomogeneous microstructure that is difficult for analysis by raw ultrasonics. Samples containing different microstructures will be scanned using ultrasonic testing and advanced data processing algorithms such as machine learning will be used to find ultrasound parameters that are unique to the susceptible microstructures. The physics-based models will consider the heat transfer and molten pool fluid flow in a multi-pass, multi-layer dissimilar metal welding repair. The Gleeble testing results will also be used to develop a tempering kinetic model to predict the as-welded hardness distribution as well as that after post-weld heat treatment (PWHT).

High-quality field welding repairs on CSEF steel components are critical to the reliable and efficient operation of the current fleet of power plants in the United States. Development of a reliable field-usable NDE technique will ensure that the required microstructure is achieved after onsite welding. Additionally, establishing knowledge of weld reparability for newer CSEF steels such as Grade 92 based on advanced numerical models of welding processes will facilitate their adoption. The tools and knowledge to be generated in the project will establish experimental and computational foundations to achieve the overall goal of detecting and controlling microstructure and properties for welding repair onto CSEF steel components.

HYDROGEN PRODUCTION

Electromagnetic Energy-Assisted Thermal Conversion of Fossil-Based Hydrocarbons to Low-Cost Hydrogen

Performer	University of North Dakota
Award Number	FE0032061
Project Duration	08/01/2021 – 07/31/2023
Total Project Value	$ 398,969
Collaborator	Envergex, LLC
Technology Area	University Training and Research

Hydrogen can be produced from the decomposition of hydrocarbons such as methane, without the production of carbon oxides. This represents a highly favorable route for hydrogen production compared to industrial production methods based predominantly on steam-methane reforming (SMR). Breaking hydrogen-oxygen bonds in water requires about seven times the energy compared to breaking carbon-hydrogen bonds in methane. SMR and methane decomposition processes both require indirect heating to provide the overall endothermic heat of reaction for hydrogen formation, but the heat of reaction for the SMR is more than double that for methane decomposition. In contrast to the SMR process, the methane decomposition process offers a promising path for economical and environmentally sound production of hydrogen without production of carbon dioxide.

The goal of this project is to make targeted improvements to the conventional thermo-catalytic hydrocarbon conversion process using an electromagnetic energy assisted mechanism; resulting in the reduction of downtime associated with catalyst reactivation or replacement due to poisoning. State-of-the-art solid catalysts exhibit short process lifetimes that are not suitable for commercial application. This project uses both experimental and computational tools to understand the fundamental interactions between fossil fuels and their interactions with an electromagnetic energy source. This technology can utilize natural gas or volatiles obtained from coal decomposition to provide carbon dioxide-free hydrogen. The first objective of this project is to identify catalyst supports that enhance the electromagnetic energy-assisted mechanism to ensure in-situ catalyst reactivation to near-initial fresh conditions. The performance of these prepared catalysts will be tested in laboratory units and the results will be used to validate computational fluid dynamics (CFD) and chemical kinetics models. Finally, CFD will be used to investigate the electromagnetic energy-assisted conversion mechanism as a function of catalyst structure and operating conditions for hydrogen production.

This study will provide future researchers with a cost-effective tool to explore a multitude of yet-to-be-conceived electromagnetic systems to ensure long-term catalytic activity. The technology has the potential to extend the longevity of catalyst materials, thereby reducing overall catalyst replenishment costs. With these improvements to the conventional thermo-catalytic hydrocarbon conversion process, it is hoped to enable a wider adoption of hydrogen-related technologies from fossil resources. This project will also support two graduate students focused on fossil energy research.

ABBREVIATIONS

°C....................degrees Celsius

°F....................degrees Fahrenheit

AEM....................Advanced Energy Materials

AM....................additive manufacturing

AM-GCTJ....................additively manufactured graded composite transition joint

ASME....................American Society of Mechanical Engineers

ALD....................atomic layer deposition

AUSC....................advanced ultrasupercritical

CCS....................carbon capture and storage

CFD....................computational fluid dynamics

CMC....................ceramic matrix composites

CO_2....................carbon dioxide

Cr....................chromium

CSEF....................creep strength enhanced ferritic

DMW....................dissimilar metal weldments

DOE....................Department of Energy

Er_2O_3....................erbium oxide

$Er_2Ti_2O_7$....................erbium titanate

FAST....................field assisted sintering technology

Fe....................iron

FE....................Fossil Energy

FECM....................Fossil Energy and Carbon Management

FFF....................Free Form Fibers

FSW/P....................friction stir welding and processing

FWP....................Field Work Proposal

GE....................General Electric

GTAW....................gas tungsten arc welding

H_2O....................water

HCM....................Hydrogen with Carbon Management

HP....................high-pressure

HRSG....................heat recovery steam generator

ICME....................integrated computational materials engineering

ICWE....................integrated computational welding engineering

IN....................Inconel

IN740H....................Inconel 740H

INL....................Idaho National Laboratory

LP....................laser processing

ML....................machine learning

MPa....................megapascals

MR&D....................Materials Research and Design

NDE....................non-destructive evaluation

NETL....................National Energy Technology Laboratory

NFA....................nanostructured ferritic alloy

Ni....................nickel

NPV....................net present value

O_2....................oxygen (molecular)

ORNL....................Oak Ridge National Laboratory

Pitt....................University of Pittsburgh

psi....................pounds per square inch

psig....................pounds per square inch gauge

PSU....................Pennsylvania State University

PWHT....................post-weld heat treatment

R&D....................research and development

R-SOFCs....................Reversible Solid Oxide Fuel Cells

SBE....................Simulation-Based Engineering

sCO_2....................supercritical carbon dioxide

SE&A....................Systems Engineering & Analysis

SiC....................silicon carbide

SMR....................steam-methane reforming

SNS....................Spallation Neutron Source

TiO....................titanium oxide

UMA....................University of Massachusetts at Amherst

WAAM....................wire-arc additive manufacturing

YSZ....................yttria stabilized zirconia

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WEBSITES:

https://netl.doe.gov/carbon-management/high-performance-materials

https://netl.doe.gov/onsite-research/materials

https://netl.doe.gov/sites/default/files/2022-11/Program-124.pdf

https://energy.gov/fe/plant-optimization-technologies

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NATIONAL
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