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CHANGING WHAT'S POSSIBLE

ULTIMATE—Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency

PROJECT DESCRIPTIONS

GE Research – Niskayuna, NY

ULTIMATE Refractory Alloy Innovations for Superior Efficiency (RAISE) - $1,600,000

GE Research has proposed transformational material solutions to potentially enable a gas turbine blade alloy-coating system capable of operating at a turbine inlet temperature of 1800 °C (3272 °F) for more than 30,000 hours. GE aims to develop a niobium (Nb)-based alloy that can operate at 1300 °C (2372 °F). The total proposed program effort includes development of a coating system consisting of a novel oxidation resistant bond coat compatible with the new Nb-based alloy and a thermal barrier coating for improved durability that can operate at 1700 °C (3092 °F) and a scalable manufacturing process for producing internally cooled gas turbine blades. Application of the new technologies to existing combined cycle gas turbines in the U.S. could increase the thermal efficiency by approximately 7%.

Oak Ridge National Laboratory – Oak Ridge, TN

Facility for Evaluating High Temperature Oxidation and Mechanical Properties - $1,500,000

Oak Ridge National Laboratory's (ORNL) will provide independent, accurate data on alloys and coatings developed by ULTIMATE teams. ORNL will supply technical performance target data, including room temperature and 1300°C (2372 °F) mechanical properties, post-exposure mechanical properties for coatings, and physical properties including thermal expansion and thermal conductivity. Additionally, ORNL will provide state-of-the-art characterization of as-received and post-test microstructure of alloys and coatings to assist in interpreting results. Facilities include high temperature furnaces for 1700°C (3092 °F) oxidation exposures and frames for mechanical properties testing of creep (deformation) and tensile properties using small- or full-scale specimens. ORNL aims to coordinate with ULTIMATE teams to deliver data within 4 weeks of receipt of specimens for most of the target experiments.

Raytheon Technologies Research Center – East Hartford, CT

Computationally Guided ODS Refractory HEAs via Additive Manufacturing - $800,000

To achieve higher efficiency turbine operation, Raytheon Technologies Research Center will use additive manufacturing (AM) to produce test coupons (specimens) and potentially a representative turbine blade using a high entropy alloy (HEA) enhanced with oxide dispersion strengthening (ODS) particles. HEAs, with multiple principal elements, offer a vast alloy design space and enhanced solid solution strengthening; a novel machine learning framework will be used to guide the HEA discovery process. ODS alloys, which consist of a metal matrix with nano-scale oxide particles dispersed within it, are some of the best performing materials for high temperature applications. Combining HEAs with ODS imparts high-temperature strength and creep (deformation) resistance to enable 1300°C (2372 °F) operation that significantly exceeds the capability of current single crystal nickel superalloys. Deploying this class of alloys for 1300°C turbine operation will allow airlines to save millions of gallons of fuel per year.

Raytheon Technologies Research Center – East Hartford, CT

Environmental Protection Coating System for Refractory Metal Alloys (EPCS for RMAs) – $700,000

The drive for higher fuel efficiency and higher core power of gas turbines used in electric power generation and aircraft propulsion requires higher peak operation temperatures in the hottest sections. Current state-of-the-art refractory metal alloys (RMAs), although highly resistant to heat and wear, tend to oxidize in the gas turbine environment. Raytheon Technologies Research Center aims to develop an environmental protection coating system (EPCS) for RMAs to radically improve long-term protection in the harsh gas turbine environment. If successful, the integrated EPCS could profoundly improve coating service life and meet long-term environmental protection requirements for RMAs over a wide temperature range required in future fuel efficient gas turbine applications.

University of Maryland – College Park, MD

New Environmental-Thermal Barrier Coatings for Ultrahigh Temperature Alloys –$600,000

The University of Maryland will leverage a newly invented, ultrafast high-temperature sintering (UHS) method to perform fast exploration of new environmental-thermal barrier coatings (ETBCs) for 1300°C (2372 °F)-capable refractory alloys for harsh turbine environments. UHS enables ultrafast synthesis of high-melting oxide coatings, including multilayers, in less than a minute, enabling rapid evaluation of novel coating compositions. By using UHS with fast-fail tests and modeling and analytics tools, the team will be able to explore hundreds of compositions and coating architectures to design and optimize 1700°C (3092 °F)-capable ETBCs with different layer sequences, thicknesses, porosity levels, and novel compositions.

University of Virginia – Charlottesville, VA

High Entropy Rare-earth Oxide (HERO) Coatings for Refractory Alloys- $600,000

A turbine engine's combustion environment can rapidly degrade high temperature alloys, which means they must be coated. This coating must be able to expand with the alloy so it adheres during temperature cycling, prevent combustion gases from permeating to the underlying alloy, and possess ultra-low thermal conductivity to protect the alloy from high surface temperatures. The University of Virginia will develop a novel coating for high temperature alloys that achieves these goals via a mixture of oxides of rare earth metals with different mass, ionic size, and charge. The coating will enable a dramatic increase in upper use temperature for turbine engine blades and increased engine efficiency. It will be manufactured using conventional air plasma spray or novel slurry-based processing to reduce cost and enable reparability.

University of Utah – Salt Lake City, UT

Designing Novel Multicomponent Niobium Alloys for High Temperature: Integrated Design, Rapid Processing & Validation Approach- $800,000

The University of Utah will use physical metallurgy principles and artificial intelligence to identify the chemistry of new niobium (Nb)-based refractory alloys to ensure they have excellent high-temperature properties without being brittle at low temperatures. The computational materials models will be used to predict the proper processing conditions for the material chemistries. This two-step process can down-select the alloy compositions and manufacturing conditions from millions of possibilities, greatly reducing the time and cost for the search of new materials. The team will perform laboratory-scale experiments to fabricate sample alloys with the selected compositions and processing conditions. If successful, the project will identify the alloy compositions and processing conditions to potentially produce turbine blades that can operate at the temperatures significantly higher than the current state of the art.

Texas A&M Engineering Experiment Station – College Station, TX

Batch-wise Improvement in Reduced Design Space using a Holistic Optimization Technique (BIRDSHOT) - $1,200,000

Increasing the efficiency of power generation and air transportation can only be achieved by increasing the temperature at which generation/propulsion turbines operate. The emerging Refractory High Entropy Alloys (RHEAS) can enable much higher operating temperatures than the state-of-the-art. Identifying the alloys' chemistry is difficult due to the vastness of the RHEA chemical space, however. BIRDSHOT proposes an interdisciplinary framework combining physics-based modeling, machine learning, and artificial intelligence as well as high-throughput synthesis and characterization platforms to explore the RHEA space in a parallel fashion. BIRDSHOT aims to discover alloys that can potentially withstand the extreme environments in a gas turbine, retain compatibility with protective coatings, and are amenable to additive manufacturing, resulting in significant energy savings in power generation and transportation.

West Virginia University – Morgantown, WV

High-Throughput Computational Guided Development of Refractory Complex Concentrated Alloys-based Composite- $700,000

West Virginia University (WVU) will develop a new class of ultra-high temperature Refractory Complex Concentrated Alloys-based Composites (RCCC) for high temperature applications such as combustion turbines used in the aerospace and energy industries. The RCCC will consist of Refractory Complex Concentrated Alloys (RCCA) mixed with nanosized particles of Refractory High Entropy Carbides, to increase RCCA strength to withstand extreme conditions. The goal is to optimize the balance among strength, creep (deformation), density, and stability at 1300 °C (2372 °F), while maintaining ductility (malleability) once the alloy cools to room temperature. The research team will develop a specialty 3-D metal printing process to produce test coupons and potentially components such as turbine blades.

The Boeing Company – Huntington Beach, CA

Ultra-High Performance Metallic Turbine Blades for Extreme Environments - $800,000

Boeing Research & Technology aims to develop a comprehensive solution for ultra-high performance turbine blades and other extreme environment aerospace applications. The team will develop a series of novel refractory complex concentrated alloys (RCCA) and their processing parameters for both laser powder bed fusion additive manufacturing and advanced powder metallurgy manufacturing, as well as intermediate layer materials optimized for coating solutions. This comprehensive solution will demonstrate a base alloy capability up to 1300 °C (2372 °F), and a coating capable of service in a turbine engine environment up to 1800 °C (3272 °F). The team will use advanced, high-throughput computational and experimental approaches to design and optimize the RCCAs to exploit the potential performance of such systems at significantly higher temperatures than current nickel- and cobalt- based superalloys.

National Energy Technology Laboratory – Albany, OR

Rapid Design and Manufacturing of High-Performance Materials for Turbine Blades Applications above 1300 Celsius- $1,500,000

The National Energy Technology Laboratory (NETL) will develop lightweight, cost-effective, precipitation-strengthened refractory high entropy alloys (RHEAs) for additive manufacturing. The alloys will comprise a ductile (malleable) high entropy solid solution matrix strengthened by fine precipitates of the high entropy carbides. NETL will use high throughput, multi-scale computer modeling, and machine learning (ML) to identify novel alloys within the large compositional space. The team will integrate computational and experimental additive manufacturing (AM) research into the alloy design effort with the aim of producing sound articles with stable and desirable microstructures and providing feedback to the alloy design. At completion, the project will demonstrate a disruptive alloy and technology for potentially manufacturing turbine blades for service at temperatures greater than 1300 °C (2372 °F).

University of Wisconsin-Madison – Madison, WI

Additive Manufacturing of Ultrahigh Temperature Refractory Metal Alloys- $650,000

Current alloys used in gas turbines operate at about 90% of their melting temperature, which sets a limit on achieving higher temperatures. Refractory metal alloys (RMA) have the capability to enable continuous operation at 1300°C (2372 °F) and with compatible coatings along with cooling systems to allow for gas inlet temperatures to reach 1800°C (3272 °F). The high RMA melting temperatures present challenges for traditional manufacturing methods, however. The University of Wisconsin will use a novel additive manufacturing approach based upon a thermodynamically guided alloy selection, high-throughput materials synthesis and characterization using reactive synthesis of powders, and an innovative processing scheme for the fabrication of test coupons and potentially turbine components.

Oak Ridge National Laboratory – Oak Ridge, TN

Development of Niobium-Based Alloys for Turbine Applications - $700,000

Current nickel (Ni)-based alloys used in turbine blade applications are operating at 1100°C (2012 °F), which is approximately 90% of their melting temperatures. Refractory alloys, such as niobium (Nb) alloys, can withstand higher temperatures. Oak Ridge National Laboratory (ORNL) will use computational modeling tools and advanced characterization to develop two classes of Nb alloys for use in a tri-layered turbine blade that can continuously operate at 1300°C (2372 °F) with coatings. This capability will enable gas turbine inlets of 1800°C (3272 °F) or higher.

Pacific Northwest National Laboratory – Richland, WA

Selective Thermal Emission Coatings for Improved Turbine Performance – $600,000

Pacific Northwest National Laboratory aims to develop a new type of thermal barrier coating that performs dual functions. The coating will act as a barrier to conventional heat transfer and have ability to alter the wavelength of light radiated from the hot turbine blade surface. This normally wasted energy will be absorbed in the turbine exhaust where it can produce additional electrical power or thrust. Simulations show this new coating could increase turbine output by as much 6%. The project team will design, synthesize, and measure the optical and thermal properties of candidate coatings for operation at up to 1800°C (3272 °F). Coatings passing performance tests will be implemented on gas turbine blades that will be tested in a mini-turbine to measure coating impact on turbine output.

Massachusetts Institute of Technology – Cambridge, MA

Additive Manufacturing of Oxidation-Resistant Gradient Refractory Composites - $600,000

Massachusetts Institute of Technology will develop a new additive manufacturing (AM) process, capable of producing refractory composite materials for use in high-temperature, oxidation-resistant turbine blades and other demanding energy-conversion applications. The AM process will incorporate hardware and software to establish uniform, high-quality refractory materials that are traditionally prone to micro-cracking and oxidation during AM, and thereby establish the required mechanical properties and oxidation resistance of a target alloy. In synergy with materials development and evaluation, the team will build two generations of a new AM system, ultimately enabling digital production of representative turbine blade geometries with low surface roughness and high-precision, complex internal cooling channels.

Pennsylvania State University – University Park, PA

Design and Manufacturing of Ultrahigh Temperature Refractory Alloys- $1,200,000

Pennsylvania State University (PSU) will develop an integrated computational and experimental framework for the design and manufacturing of ULtrahigh TEmperature Refractory Alloys (ULTERA). Penn State will generate alloy property data through high-throughput computational and machine learning models; design ultrahigh temperature refractory alloys through a neural network inverse design approach (where one first articulates the needed functionality/property, and then looks for the materials that haves the property); manufacture the designed alloys utilizing field assisted sintering technology and/or additive manufacturing; and demonstrate the performance through systematic characterization in collaboration with industry. The proposed platform with a sustainable data ecosystem could create fundamentally new approaches to understand and design a new generation of materials and provide pathways to improve existing materials to meet performance requirements.

QuesTek Innovations LLC – Evanston, IL

Concurrent Design of a Multimaterial Niobium Alloy System for Next-generation Turbine Applications- $1,200,000

QuesTek Innovations will apply computational materials design, additive manufacturing, coating technology, and turbine design/manufacturing to develop a comprehensive solution for a next-generation turbine blade alloy and coating system capable of sustained operation at 1300°C (2372 °F). QuesTek will design a niobium (Nb)-based multi-material alloy system consisting of a ductile, precipitation-strengthened, creep (deformation)-resistant alloy for the turbine "core" combined with an oxidation-resistant, bond coat-compatible Nb alloy for the "case." The proposed multi-material Nb alloy and coating system will achieve a combination of properties suitable for a variety of gas or industrial turbine components such as blade, vane, and panel structures. Concurrent design of both alloy and component will enable next-generation technologies within an accelerated timeline.