FY20 CROSSCUTTING HIGH PERFORMANCE MATERIALS PEER REVIEW OVERVIEW REPORT

December 18, 2019

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

DISCLAIMER

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INTRODUCTION AND BACKGROUND

The Crosscutting High Performance Materials Program drives to characterize, produce, and certify cost-effective alloys and materials suitable for extreme environments that are found in fossil-based power-generation systems. The National Energy Technology Laboratory (NETL) supports and catalyzes a robust domestic materials supply chain that prepares materials for advanced ultra-supercritical (AUSC) steam cycles and spinoff applications. The work enables supercritical carbon dioxide (sCO_2) cycles, increases the efficiency of materials repair, and accelerates material discovery and qualification.

Transformational power technologies, like AUSC and sCO_2, have the potential to increase efficiencies and bolster clean coal efforts. However, these systems operate at higher temperatures and pressures, leading to more corrosive and harsher environments compared to traditional power plants. Additionally, the existing fleet is increasingly subjected to cycling conditions due to the penetration of renewable energy sources onto the electricity grid. Cycling adds stress to the materials of construction, because the plants were not designed for the extreme changes in temperature and pressure brought on by cycling conditions.

The Crosscutting High Performance Materials Program works to accelerate the development of improved steels, superalloys, and other advanced alloys to address challenges of both the existing fleet and future power systems. Materials of interest include those that enable components and equipment to perform in the high-temperature, high-pressure, corrosive environments of an advanced energy system with specific emphasis on durability, availability, and cost, both within and across each of the four primary research areas: Computational Materials Design, Advanced Structural Materials, Functional Materials for Process Performance, and Advanced Manufacturing.

Office of Management and Budget Requirements

In compliance with requirements from the Office of Management and Budget and in accordance with the U.S. Department of Energy (DOE) Strategic Plan, DOE and NETL are fully committed to improving the quality of research projects in their programs by conducting rigorous peer reviews. DOE and NETL conducted a Fiscal Year 2020 (FY20) Crosscutting High Performance Materials Peer Review Meeting with independent technical experts to offer each project prioritized recommendations and assess two projects' Technology Readiness Level (TRL) progression. KeyLogic (NETL site-support contractor) convened a panel of five academic and industry experts[*] on November 5-7, 2019, to conduct a peer review of four Crosscutting High Performance Materials Program research projects.

[*] Please see "Appendix D: Peer Review Panel Members" for detailed panel member biographies.

TABLE 1. CROSSCUTTING HIGH PERFORMANCE MATERIALS PEER REVIEW – PROJECTS REVIEWED

Project Number	Title	Lead Organization	Total Funding		Project Duration	
			DOE	Cost Share	From	To
FE0025064	Advanced Ultra-Supercritical Component Testing *	Energy Industries of Ohio, Inc.	$19,986,577	$6,764,245	11/01/2015	9/30/2021
FWP-FEAA128	Components Fabricated by Additive Manufacturing *	Oak Ridge National Laboratory	$900,000	$0	10/01/2018	09/30/2021
eXtremeMAT Task 2	Computational Modeling & Simulation **	Los Alamos National Laboratory	$20,350,000^	$0	10/01/2018	09/30/2023
eXtremeMAT Task 3	Data Science & Analytics **	Pacific Northwest National Laboratory				
FWP-1022406	Tasks 10-14 - sCO_2 **	National Energy Technology Laboratory	$893,000#	$0	10/01/2017	03/31/2022
	Task 6 - Fe-9Cr Steels Development (CPJ7) **		$433,000#			
	Tasks 5, 7, & 8 - Alloy Processing **		$846,000#			
			$43,408,577	$6,764,245		
			$50,172,822			

* TRL-Based Evaluation: During TRL-based evaluations, the independent panel offers recommendations and assesses the projects' technology readiness for work at the current TRL and the planned work to attain the next TRL.

** Recommendations-Based Evaluation: During recommendations-based evaluations, the independent panel provides recommendations to strengthen the performance of projects during the period of performance.

^ For entire eXtremeMAT Project; based on FY19, FY20, and budget levels.

Estimated FY Budget.

OVERVIEW OF THE PEER REVIEW PROCESS

Peer reviews are conducted to help ensure that the Office of Fossil Energy's (FE) research program, implemented by NETL, is in compliance with requirements from the Office of Management and Budget and in accordance with the DOE Strategic Plan and DOE guidance. Peer reviews improve the overall quality of the technical aspects of research and development (R&D) activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

KeyLogic convened a panel of five academic and industry experts to conduct a peer review of four research projects supported by the Crosscutting High Performance Materials Program. Throughout the peer review meeting, these recognized technical experts offered recommendations and provided feedback on two projects' technology readiness for work at the current TRL and the planned work to attain the next TRL. In consultation with NETL representatives, who chose the projects for review, KeyLogic selected an independent Peer Review Panel, facilitated the peer review meeting, and prepared this report to summarize the results.

Pre-Meeting Preparation

Before the peer review, each project team submitted a Project Technical Summary (PTS) and project presentation. The projects subject to a TRL-based evaluation also shared a Technology Maturation Plan (TMP) to facilitate TRL evaluation from the Peer Review Panel (reference Table 1). The Federal Project Manager (FPM) provided the Project Management Plan (PMP), the latest quarterly report, and supplemental technical papers as additional resources for the panel (as applicable). The panel received these materials prior to the peer review meeting, which enabled the panel members to fully prepare for the meeting with the necessary background information to thoroughly evaluate the projects.

To increase the efficiency of the peer review meeting, multiple pre-meeting orientation teleconference calls were held with NETL, the Peer Review Panel, and KeyLogic staff to review the peer review process and procedures, evaluation criteria, and project documentation, as well as to allow for the Technology Manager to provide an overview of the program goals and objectives.

Peer Review Meeting Proceedings

At the meeting, each project performer gave a presentation describing the project. The presentation was followed by a question-and-answer session with the panel and a closed panel discussion and evaluation. The time allotted for the presentation, the question-and-answer session, and the closed panel discussion was dependent on the project's complexity, duration, and breadth of scope.

During the closed sessions of the peer review meeting, the panel discussed each project to identify strengths, weaknesses, and recommendations in accordance with the Peer Review Evaluation Criteria[†]. For the first two projects reviewed (identified in Table 1), the panel offered prioritized recommendations and an evaluation of TRL progression. For the remaining two projects, the panel offered a series of prioritized recommendations by task to strengthen the projects during the remaining period of performance.

[†] Please see "Appendix A: Peer Review Evaluation Criteria" for more information.

SUMMARY OF KEY FINDINGS

This section summarizes the overall key findings of the projects evaluated at the FY20 Crosscutting High Performance Materials Peer Review Meeting. The panel concluded that the peer review provided an excellent opportunity to comment on the relative strengths and weaknesses of each project. The presentations and question-and-answer sessions provided additional clarity to complement the pre-meeting documentation. The peer review also provided an insight into the range of technology development and the relative progress that has been made by the project teams. The technical discussion enabled the panel to contribute to each project's development by identifying core issues and by making constructive recommendations to improve project outcomes. The panel generated 45 recommendations for NETL management to review and consider.

The panel offered several common strengths among the projects reviewed, including the projects' alignment with DOE goals and research priorities, dissemination of information on both successes and failures (e.g., publications, presentations, patents, and conference attendance), contributions to other efforts developing new alloys, and partnership(s) with industry and academic institutions. The panel also stated that all the projects reviewed are working to achieve greater efficiencies. Finally, the panel indicated that the quantity and fidelity of the data generated for the NETL Energy Data eXchange (EDX) will contribute to making it a world-class database.

The panel also noted several areas for improvement among the projects reviewed, such as the project teams needing to engage external organizations in non-traditional markets (e.g., pharmaceutical, medical products, botanicals) that use sCO_2 at a similar scale, as well as completing literature reviews earlier in the project schedule. The panel indicated that the teams would also benefit from attending National Association of Corrosion Engineers (NACE) conferences to gain additional perspectives; working with the Electric Power Research Institute (EPRI) to obtain perspective from utilities; and continuing involvement with the American Society of Mechanical Engineers (ASME) committees. The panel also advised the project teams to stay cognizant of the challenges of having regionally dispersed teams while working on a solution that requires high integration.

Evaluation of Technology Readiness Level Progression

At the meeting, the Peer Review Panel assessed two projects' readiness to start work towards the next TRL based on a project's strengths, weaknesses, recommendations, issues, and concerns. For the various projects subject to review, the panel found that all were on track to attaining their respective planned end-of-project TRL based on achievement of the project goals as planned and addressing the Review Panel recommendations.

- Project FE0025064 has attained TRL 4. Upon achievement of the legacy system-level demonstration in a relevant environment, Project FE0025064 will attain TRL 6. Upon building and demonstrating the system at design temperatures and pressures, Project FE0025064 will attain TRL 7.
- Project FWP-FEAA128 has attained TRL 3. Upon the development and validation of physics-based modeling tools for process, microstructure, and mechanical property control, Project FWP-FEAA128 will attain TRL 4.

PROJECT SYNOPSES

For more information on the Crosscutting High Performance Materials Program and project portfolio, please visit the NETL website: https://netl.doe.gov/coal/high-performance-materials.

FE0025064

ADVANCED ULTRA-SUPERCRITICAL COMPONENT TESTING

Project Description: The National Energy Technology Laboratory (NETL) is partnering with Energy Industries of Ohio, Inc., to bring advanced ultra-supercritical (AUSC) technology to the commercial-scale demonstration level of technology readiness by designing a test facility that consists of prototype-scale (approximately 120,000 pounds/hour steam flowrate) equipment components that would operate at AUSC steam temperature up to 760°C and pressure of 70 bar (1,000 pounds per square inch absolute [psia]) or higher. The project will also complete the manufacturing research and development (R&D) of AUSC components by fabricating commercial-scale nickel superalloy components and sub-assemblies that would be needed in a coal-fired power plant with a generation capacity of approximately 800 megawatt-electric (MWe), operating at a steam temperature of 760°C and steam pressure of at least 238 bar (3,500 psia).

FWP-FEAA128

COMPONENTS FABRICATED BY ADDITIVE MANUFACTURING

Project Description: The goal of this project is to develop predictive tools to correlate additive manufacturing (AM) process parameters with bulk material properties of components using machine learning algorithms. There are several key challenges currently confronting AM processes for metal-based alloys. The internal microstructures, micro-, meso-, and macro- (part) level physical properties and performance under load, are all dependent on the manufacturing process. The large number of AM processing parameters available means that AM research and development (R&D) can be very long and expensive if done without the use of process and materials modeling tools. With modelling, the various interactions and parameter sensitivities can be investigated independently from each other. For AM, where the understanding of the effects of feedstock properties, deposition rates, thermal history, cooling rates, phase transformation, defect formation, and residual stress are still in an early phase, the framework to accurately predict the part properties is not well established. Various physics-based models will be developed to describe all steps of the AM process, allowing the determination of the alloy microstructure and mechanical properties based on the AM process parameters. A machine learning approach will also be investigated to enable rapid qualification of high-temperature structural alloys with increased additive manufacturing process reliability, which will enable design flexibility for full utilization of AM. Collaboration between Oak Ridge National Laboratory (ORNL) and Siemens will provide a unique opportunity of developing a simulation process that connects the process parameters through modeling to part microstructure and bulk mechanical properties and validate the process through test data on Alloy(CM)247 or Haynes 282 alloy.

EXTREMEMAT: EXTREME ENVIRONMENT MATERIALS TASK 2

COMPUTATIONAL MODELING & SIMULATION

Project Description: The objective of eXtremeMAT (XMAT) is to demonstrate how state-of-the-art computational materials modeling and cutting-edge experimental tools available across the national laboratories, in conjunction with industry partnership, can be used to predict the rupture life and mechanical performance of components (structural, heat exchangers) subjected to extreme environments (i.e., elevated temperatures, high stresses, complex cycling, oxidizing atmospheres, etc.). XMAT deliverables associated with the modeling and simulation component (i.e., Task 2.0) include developing models that can (1) accelerate the certification of the performance and lifetime of components made from existing austenitic stainless steels (347H) subjected to extreme environments, (2) accelerate screening of the mechanical performance of new metals, and (3) propose guidelines for metal design.

EXTREMEMAT: EXTREME ENVIRONMENT MATERIALS TASK 3

DATA SCIENCE & ANALYTICS

Project Description: The objective of eXtremeMAT (XMAT) is to demonstrate how state-of-the-art computational materials modeling and cutting-edge experimental tools available across the national laboratories, in conjunction with industry partnership, can be used to predict the rupture life and mechanical performance of components (structural, heat exchangers) subjected to extreme environments (i.e., elevated temperatures, high stresses, complex cycling, oxidizing atmospheres). The goal of the Data Science and Analytics Task of XMAT (Task 3.0) is to develop robust data-driven models to predict the creep failure time of alloys and demonstrate its applicability for an alumina-forming austenitic stainless-steel. Towards this goal, Task 3.0 has subtasks that collect and curate relevant alloy data; assess data quality and establish data quality metrics; develop a framework and the tools for collaborative data management; and apply data analytics and machine learning to accelerate the design, development, and lifetime assessment of novel heat resistant alloys in existing and future power cycles.

FWP-1022406

ADVANCED ALLOY FWP TASKS 10-14 – SCO_2

Project Description: Efforts within this Field Work Proposal (FWP) focus on developing improved steels, superalloys, and other advanced alloys using an integrated materials engineering approach that incorporates computational alloy design with the best manufacturing practice (modified as needed) to achieve microstructure and performance objectives using focused mechanical testing and characterization. The goal of the project is to reduce technical risks to commercialization of the supercritical carbon dioxide (sCO_2) power cycle technology by generating alloy performance data and finding solutions to manufacturing challenges. The scope of the project is two-fold: demonstrate the long-term durability of commercial materials in a direct sCO_2 power cycle environment and improve manufacturing of compact heat exchangers needed for sCO_2 power systems. The project is focusing on generating materials property information on alloys in direct sCO_2 power cycle environments.

FWP-1022406

ADVANCED ALLOY FWP TASK 6 – FE-9CR STEELS DEVELOPMENT (CPJ7)

Project Description: Efforts within this Field Work Proposal (FWP) focus on developing improved steels, superalloys, and other advanced alloys using an integrated materials engineering approach that incorporates computational alloy design with the best manufacturing practice (modified as needed) to achieve microstructure and performance objectives using focused mechanical testing and characterization. Efforts within the FWP also focus on developing and validating computational algorithms for designing advanced alloys (of all types, not just the ferritic-martensitic steels) and for predicting alloy performance over multiple length scales and multiple time scales relevant to advanced fossil energy power system components. This review focuses on developing advanced heat-resistant 9 to 12% Chromium (Cr) ferritic-martensitic steels for existing and future power plants. In particular, the goal is to design and develop 9 to 12% Cr ferritic-martensitic steels that can be used in ultra-supercritical (USC), advanced ultra-supercritical (AUSC), and supercritical carbon dioxide (sCO_2) energy systems for component temperature up to 650°C. The approach within Task 6.0, and in conjunction with Tasks 5.0, 7.0, and 8.0, is to understand the basic high-temperature strengthening mechanisms in the steel, microstructure evolution due to time-temperature-stress, and alloy stability for component operational conditions.

FWP-1022406

ADVANCED ALLOY FWP TASKS 5, 7, & 8 – ALLOY PROCESSING

Project Description: Efforts within this Field Work Proposal (FWP) focus on developing improved steels, superalloys, and other advanced alloys using an integrated materials engineering approach that incorporates computational alloy design with the best manufacturing practice (modified as needed) to achieve microstructure and performance objectives using focused mechanical testing and characterization. Task 5.0 (Simulation and Manufacture of Large-Scale Ingots of Advanced Heat-Resistant Alloys for Fossil Energy Applications), Task 7.0 (High-Entropy Superalloys Development), and Task 8.0 (Grain Boundary Engineering and Design Techniques) are highly integrated, focusing on alloy design, alloy development activities, manufacturing process development activities, melt processing optimization, and structure-processing-performance relationships (e.g., the influence of a desired microstructure developed through design fundamentals and executed by manufacturing process control). The integrated approach combines computational thermodynamic and kinetic calculations to refine the alloy chemistry selection for the desired microstructure with computational fluid dynamics (CFD) analysis of the melt process for melt process control optimization, after which the materials are characterized by a number of means to see if the design targets were met.

APPENDIX A: PEER REVIEW EVALUATION CRITERIA

PEER REVIEW EVALUATION CRITERIA AND GUIDELINES

Peer reviews are conducted to ensure that the Office of Fossil Energy's (FE) research program, implemented by the National Energy Technology Laboratory (NETL), is compliant with the U.S. Department of Energy (DOE) Strategic Plan and DOE guidance. Peer reviews improve the overall quality of the technical aspects of research and development (R&D) activities, as well as overall project-related activities, such as utilization of resources, project and financial management, and commercialization.

In the upcoming NETL peer review, a significant amount of information about the projects within its portfolio will be covered in a short period. For that reason, NETL has established a set of rules for governing the meeting so that everyone has an equal chance to accurately present their project accomplishments, issues, recent progress, and expected results for the remainder of the performance period (if applicable).

The following pages contain the criteria used to evaluate each project. Each criterion is accompanied by multiple characteristics to further define the topic. Each reviewer is expected to independently assess all the provided material for each project prior to the meeting and engage in discussion to generate feedback for each project during the meeting.

Technology Readiness Level-Based Evaluation

At the meeting, the Facilitator and/or Panel Chairperson will lead the Peer Review Panel in assessing a project's readiness to start work towards the next Technology Readiness Level (TRL) based on a project's strengths[‡], weaknesses[§], recommendations, issues, and concerns. TRL definitions are included below.

Recommendations-Based Evaluation

At the meeting, the Facilitator and/or Panel Chairperson will lead the Peer Review Panel in identifying strengths, weaknesses, overall score, and prioritized recommendations for each project. The strengths and weaknesses shall serve as a basis for the determination of the overall project score in accordance with the Rating Definitions and Scoring Plan (see below). Under a recommendation-based evaluation, strengths and weaknesses shall be characterized as either "major" or "minor" during the Review Panel's discussion at the meeting. For example, a weakness that presents a significant threat to the likelihood of achieving the project's stated technical goal(s) and supporting

‡ A strength is an aspect of the project that, when compared to the evaluation criterion, reflects positively on the probability of successful accomplishment of the project's goal(s) and objectives.

§ A weakness is an aspect of the project that, when compared to the evaluation criterion, reflects negatively on the probability of successful accomplishment of the project's goal(s) and objectives.

objectives should be considered “major,” whereas relatively less significant opportunities for improvement are considered “minor.”

A recommendation shall emphasize an action that will be considered by the project team and/or DOE to correct or mitigate the impact of weaknesses, expand upon a project’s strengths, or progress along the technology maturation path (TRL-based evaluation). A recommendation should have as its basis one or more strengths or weaknesses. Recommendations shall be ranked from most important to least, based on the major/minor strengths/weaknesses.

NETL Peer Review Evaluation Criteria

1. **Degree to which the project, if successful, supports the U.S. Department of Energy (DOE) Program's near- and/or long-term goals.**
   - Program goals are clearly and accurately stated.
   - Performance requirements[1] support the program goals.
2. **Degree to which the project demonstrates alignment with a commercially relevant challenge or opportunity.**
   - The intended commercial application is clearly defined.
   - The technology value proposition has been validated by potential end-users.
   - The technology development plan and associated metrics and milestones meaningfully reduce the risk of market adoption.
   - The technology is ultimately technically and economically viable for the intended commercial application.
3. **Degree to which there are sufficient resources to successfully complete the project.**
   - There is adequate funding, facilities, and equipment.
   - Project team includes personnel with the needed technical and project management expertise.
   - The project team is engaged in effective teaming and collaborative efforts, as appropriate.
4. **Degree of project plan technical feasibility.**
   - Technical gaps, barriers, and risks to achieving the performance requirements are clearly identified.
   - Scientific/engineering approaches have been designed to overcome the identified technical gaps, barriers, and risks to achieve the performance requirements.
   - Remaining technical work planned is appropriate considering progress to date and remaining schedule and budget.
   - Appropriate risk mitigation plans exist, including Decision Points when applicable.
5. **Degree to which progress has been made towards achieving the stated performance requirements.**
   - The project has tested (or is testing) those attributes appropriate for the next Technology Readiness Level (TRL). The level of technology integration and nature of the test environment are consistent with the aforementioned TRL definition.
   - Project progress, with emphasis on experimental results, shows that the technology has, or is likely to, achieve the stated performance requirements for the next TRL (including those pertaining to capital cost, if applicable).
   - Milestones and reports effectively enable progress to be tracked.
   - Reasonable progress has been made relative to the established project schedule and budget.
6. **Degree to which an appropriate basis exists for the technology's performance attributes and requirements.**
   - The TRL to be achieved by the end of the project is clearly stated[2].
   - Performance attributes for the technology are defined[2].
   - Performance requirements for each performance attribute are, to the maximum extent practical, quantitative, clearly defined, and appropriate for and consistent with the DOE goals as well as technical and economic viability in the intended commercial application.
7. **The project Technology Maturation Plan (TMP) represents a viable path for technology development beyond the end of the current project (with respect to scope, timeline, and cost) and includes a plan for the commercialization of the technology.**
   (This criterion is not applicable to a recommendations-based evaluation)

[1] If it is appropriate for a project to not have cost/economic-related performance requirements, then the project will be evaluated on technical performance requirements only.
[2] Supported by systems analyses appropriate to the targeted TRL.

Rating Definitions and Scoring Plan (not applicable to TRL-based evaluation)

The Review Panel will be required to assign a score to the project, after strengths and weaknesses have been agreed upon. Intermediate whole number scores are acceptable if the Review Panel feels it is appropriate. The overall project score must be justified by, and consistent with, the identified strengths and weaknesses.

NETL Peer Review Rating Definitions and Scoring Plan	
10	**Excellent -** Several major strengths; no major weaknesses; few, if any, minor weaknesses. Strengths are apparent and documented.
8	**Highly Successful -** Some major strengths; few (if any) major weaknesses; few minor weaknesses. Strengths are apparent and documented, and outweigh identified weaknesses.
5	**Adequate -** Strengths and weaknesses are about equal in significance.
2	**Weak -** Some major weaknesses; many minor weaknesses; few (if any) major strengths; few minor strengths. Weaknesses are apparent and documented, and outweigh strengths identified.
0	**Unacceptable -** No major strengths; many major weaknesses. Significant weaknesses/deficiencies exist that are largely insurmountable.

APPENDIX B: DOE TECHNOLOGY READINESS LEVELS

The following is a description of U.S. Department of Energy (DOE) Technology Readiness Levels (TRLs).

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected mission conditions	The technology is in its final form and operated under the full range of operating mission conditions. Examples include using the actual system with the full range of wastes in hot operations.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration	The technology has been proven to work in its final form and under expected conditions. In almost all cases, this Technology Readiness Level (TRL) represents the end of true system development. Examples include developmental testing and evaluation of the system with actual waste in hot commissioning. Supporting information includes operational procedures that are virtually complete. An Operational Readiness Review (ORR) has been successfully completed prior to the start of hot testing.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in relevant environment	This represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing full-scale prototype in the field with a range of simulants in cold commissioning (1). Supporting information includes results from the full-scale testing and analysis of the differences between the test environment, and analysis of what the experimental results mean for the eventual operating system/environment. Final design is virtually complete.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in relevant environment	Engineering-scale models or prototypes are tested in a relevant environment. This represents a major step up in a technology's demonstrated readiness. Examples include testing an engineering-scale prototypical system with a range of simulants (1). Supporting information includes results from the engineering-scale testing and analysis of the differences between the engineering-scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins true engineering development of the technology as an operational system. The major difference between TRL 5 and 6 is the step-up from laboratory scale to engineering scale and the determination of scaling factors that will enable design of the operating system. The prototype should be capable of performing all the functions that will be required of the operational system. The operating environment for the testing should closely represent the actual operating environment.

Technology Development	**TRL 5**	Laboratory-scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity, laboratory scale system in a simulated environment with a range of simulants (1) and actual waste (2). Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	The basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing with a range of simulants and small-scale tests on actual waste (2). Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4–6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function.

Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative tested with simulants (1). Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3 the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected on simulants. Components of the technology are validated, but there is no attempt to integrate the components into a complete system. Modeling and simulation may be used to complement physical experiments.
	TRL 2	Technology concept and/or application formulated	Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or other references that outline the application being considered and that provide analysis to support the concept. The step up from TRL 1 to TRL 2 moves the ideas from pure to applied research. Most of the work is analytical or paper studies with the emphasis on understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	This is the lowest level of technology readiness. Scientific research begins to be translated into applied R&D. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or other references that identify the principles that underlie the technology.

[1] Simulants should match relevant chemical and physical properties.

[2] Testing with as wide a range of actual waste as practicable and consistent with waste availability, safety, ALARA, cost and project risk is highly desirable.

APPENDIX C: MEETING AGENDA

Crosscutting High Performance Materials Peer Review
November 5-7, 2019
NETL-Pittsburgh Building 922 Room 106A

Tuesday, November 5, 2019

8:00 a.m. (no earlier)	*Panel Members Arrive at NETL-Pittsburgh for Security Check*
8:30 a.m. (no earlier)	*Morning Presenters Arrive, Visitors Escorted to NETL-Pittsburgh Building 922 Room 106A*
8:30 – 9:00 a.m.	Peer Review Panel Kickoff Session *DOE HQ/NETL, KeyLogic Peer Review Support Staff, and Panel Members Attend* - Facilitator Opening, Review Panel Introductions, Technology Manager Welcome, Peer Review Process and Meeting Logistics
9:00 – 9:45 a.m.	Project FE0025064 – Advanced Ultra-Supercritical Component Testing *Robert Purgert* – Energy Industries of Ohio, Inc.
9:45 – 10:30 a.m.	Question-and-Answer Session
10:30 – 10:45 a.m.	BREAK
10:45 – 12:00 p.m.	Closed Discussion (TRL-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
12:00 – 1:00 p.m.	Lunch
12:45 p.m. (no earlier)	*Afternoon Presenters Arrive at NETL-Pittsburgh for Security Check*
1:00 – 1:45 p.m.	Project FWP-FEAA128 – Components Fabricated by Additive Manufacturing *Sebastien Dryepondt* – Oak Ridge National Laboratory
1:45 – 2:30 p.m.	Question-and-Answer Session
2:30 – 2:45 p.m.	BREAK
2:45 – 4:00 p.m.	Closed Discussion (TRL-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
4:00 p.m.	Adjourn

Wednesday, November 6, 2019

8:00 a.m. (no earlier)	*Panel Members, Morning Presenters Arrive at NETL-Pittsburgh for Security Check*
8:30 – 8:45 a.m.	eXtremeMAT – Extreme Environment Materials Overview *Jeffrey Hawk* – NETL
8:45 – 9:30 a.m.	eXtremeMAT Task 2: Computational Modeling & Simulation *Laurent Capolungo* – Los Alamos National Laboratory
9:30 – 10:15 a.m.	Question-and-Answer Session
10:15 – 10:30 a.m.	BREAK
10:30 – 11:45 a.m.	Closed Discussion (Recommendations-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
11:45 – 12:45 p.m.	Review Panel Working Lunch
12:30 p.m. (no earlier)	*Afternoon Presenters Arrive at NETL-Pittsburgh for Security Check*
12:45 – 1:30 p.m.	eXtremeMAT Task 3: Data Science & Analytics *Ram Devanathan* – Pacific Northwest National Laboratory
1:30 – 2:15 p.m.	Question-and-Answer Session
2:15 – 2:30 p.m.	BREAK
2:30 – 3:45 p.m.	Closed Discussion (Recommendations-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
3:45 p.m.	Adjourn

Thursday, November 7, 2019

8:00 a.m. (no earlier)	*Panel Members, Morning Presenters Arrive at NETL-Pittsburgh for Security Check*
8:30 – 9:30 a.m.	Advanced Alloy FWP Tasks 10-14 – sCO_2 *Omer Dogan* – NETL
9:30 – 10:15 a.m.	Question-and-Answer Session
10:15 – 10:30 a.m.	BREAK
10:30 – 11:45 a.m.	Closed Discussion (Recommendations-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
11:45 – 12:15 p.m.	Lunch
12:15 – 12:45 p.m.	Advanced Alloy FWP Task 6 – Fe-9Cr Steels Development (CPJ7) *Jeffrey Hawk* – NETL
12:45 – 1:15 p.m.	Question-and-Answer Session
1:15 – 2:15 p.m.	Closed Discussion (Recommendations-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
2:15 – 2:30 p.m.	BREAK
2:30 – 3:00 p.m.	Advanced Alloy FWP Tasks 5, 7, & 8 – Alloy Processing *Paul Jablonski* – NETL
3:00 – 3:30 p.m.	Question-and-Answer Session
3:30 – 4:30 p.m.	Closed Discussion (Recommendations-Based Evaluation; Review Panel) *DOE HQ/NETL and KeyLogic Peer Review Support Staff Attend as Observers*
4:30 – 5:00 p.m.	Peer Review Panel Wrap-Up Session *DOE HQ/NETL, KeyLogic Peer Review Support Staff, and Panel Members Attend*
5:00 p.m.	Adjourn

APPENDIX D: PEER REVIEW PANEL MEMBERS

Crosscutting High Performance Materials Peer Review
November 5-7, 2019
NETL-Pittsburgh Building 922 Room 106A

Nathan Ames

Nathan Ames is the associate director and engineering manager for the Center for Design and Manufacturing Excellence (CDME), where he oversees growth and daily operations. Prior to joining CDME, his work experiences included various industry positions where he has been involved in the design and implementation of engineering solutions into commercial markets. His positions included serving as co-founder and director of engineering at Apeks Supercritical, founder of the Nuclear Fabrication Consortium (NFC) with the Edison Welding Institute (EWI), co-founder of Meetacular LTD, president of Zoar Industries, and research engineer at Swagelock.

As a founder of multiple small businesses, Mr. Ames has a firm understanding of the challenges of small business growth. His experience at EWI, where he founded NFC, brought on the responsibility of managing an international business development team where he implemented new strategic account plans for clients in order to grow sales. In 2008, he established NFC, which in less than four years went from a concept to an organization with more than 25 paying members, conducting more than $4 million in precompetitive research. As president of Zoar Industries, Mr. Ames provided manufacturing entities with smart solutions for some of the most common hurdles encountered in typical early-stage manufacturing companies. He has a B.S. and M.S. in welding engineering from Ohio State University.

Timothy Gabb, Ph.D.

Timothy P. Gabb is a research metallurgist employed at the National Aeronautics and Space Administration (NASA) Glenn Research Center. He received a B.S. and M.S., both in mechanical engineering, from Louisiana State University, and a Ph.D. in materials science from Case Western Reserve University. His research interests have principally concerned processing-microstructure-mechanical property relationships for nickel-base alloys used at high temperatures.

Spencer Luke

Spencer Luke serves as a welding and materials specialist in the Black and Veatch (B&V) Materials Application Section. As the welding and materials engineer lead, he supports various construction projects, including energy, electrical transmission, gas, oil and chemical, federal, nuclear, and water. Mr. Luke's responsibilities include review of vendor welding, inspection, and quality procedures to ensure conformance to contract requirements; development and revision of various welding standards and specifications (e.g., welding and heat treatment requirements P91 for B31.1 applications, welding requirements for stainless, duplex and super duplex stainless steels for water and FGD service); resolving non-conformances of critical high-temperature creep resistant materials, such as alloy P91 and P92; assisting project engineers in failure analysis investigations (Reliance Project [weld HAZ cracking] and Passaic Valley [corrosion evaluations]), Mariveles (2205 pump shaft), Kandahar (transmission tower weld cracking), Plum Point (boiler tube weld failures and coal pipe failures); performing surveillances related to welding and fabrication at vendor's shops, American Society of Mechanical Engineers (ASME) VIII Pressure Vessels, and B31 Piping. Mr.

Luke has been a welding/metallurgical engineer for more than 39 years and received his B.Sc. in metallurgical engineering from the University of Missouri at Rolla.

Onome Scott-Emuakpor, Ph.D.

Dr. Onome Scott-Emuakpor is an Air Force Research Laboratory (AFRL) researcher who leads basic research focused on the development of new life prediction models and the improvement of fatigue and fracture understanding in gas turbine engine components. His work helps ensure advanced engine designs meet program structural integrity requirements for safe testing. He also supports the existing Air Force engine fleet, investigating real-word issues and helping to define solutions to enable return-to-flight. As the Turbine Engine Integrity Branch technical lead, he developed an energy-based critical fatigue life prediction method that led to a greater understanding of fatigue problems in gas turbine engines. He also works on small-scale propulsion and supersonic turbine engine long-range programs.

Dr. Scott-Emuakpor is also an active member of a number of professional societies and has recently been sought out to co-author a book on the fatigue of structures. Dr. Scott-Emuakpor received a Ph.D. and M.S. in mechanical engineering from Ohio State University.

David Shifler, Ph.D., PE

Dr. David Shifler is currently a Science & Technology (S&T) program officer at the Office of Naval Research (ONR), supporting research of high-temperature propulsion materials for aircraft and shipboard gas turbine engines and cellular structural materials for light-weighting, thermal management applications, and armor applications. High-temperature materials include thermal barrier coatings, environmental barrier coatings, diffusion and overlay coatings, ceramic matrix composites, metallized and diffusional coatings, refractory multiple principal element alloys (or high-entropy alloys), innovative intermetallic Mo-Si-B alloys, and advanced nickel-base superalloys, which can withstand a combination of corrosion and oxidation resistance, creep, and fatigue. He supports research in the creation, development, and characterization of materials by involving the use of integrated computational materials science and engineering (ICME) with experimental validation to develop models describing material mechanisms and phenomena that guide understanding of materials performance and drive further materials innovations. Dr. Shifler has recently started to explore and support basic research within the Navy on high-entropy alloys, particularly refractory high-entropy alloys (or multiple principal element alloys).

Dr. Shifler has also managed Small Business Technology Transfer (STTR) and Small Business Innovation Research (SBIR) programs on low-temperature solid oxide fuel cells; Fischer-Tropsch (F-T) catalysis; propulsion materials; ballistic resistance; and methods for predicting crack initiation of gas turbine components, processing Mo-Si-B intermetallic alloys, hot corrosion-resistant coatings, ceramic fib light-weight armor, predictive modelling for determine coatings to resist variable sand chemistries, additive manufacturing, and data analytics and machine learning. He participates in collaborative endeavors involving ONR Global, Navy Program Offices, Office of the Secretary of the Defense (OSD), Air Force (AFRL and Air Force Office of Scientific Research [AFOSR]), Army, U.S. governmental agencies through Versatile, Affordable, Advanced Turbine Engines (VAATE) and Advanced Turbine Technology for Affordable Mission Capability (ATTAM) national aeronautical programs, foreign defense ministries, industry, academia, and various Naval Sea Systems Command (NAVSEA) and Naval Air Systems Command (NAVAIR) personnel. Dr. Shifler received his B.A. in chemistry from Western Maryland College and M.S.E. and Ph.D. in materials science and engineering from Johns Hopkins University.