This work was funded by the Department of Energy's Kansas City National Security Campus which is operated and managed by Honeywell Federal Manufacturing Technologies, LLC under contract number DE-NA0002839.

I/UCRC Executive Summary - Project Synopsis	**Date**: April 2022
Center/Site: CANFSA/Colorado School of Mines	
Tracking No.: 45: Additive Manufacturing Feasibility of Refractory Alloys	**E-mail :** amiklas@mines.edu **Phone :** (617) – 320 – 4389
Center/Site Director: CANFSA/M. Kaufman/P. Collins/A. Clarke	**Type:** Master's
Project Leader: Abby Miklas	**Proposed Budget:** $160,000 CANFSA and Leveraged

Project Description: Refractory alloys have the potential to perform in extreme environments, such as at ultrahigh temperatures. Opportunity exists to develop production methods, such as additive manufacturing, for these alloys. By understanding the solidification behavior and microstructure development in refractory alloys under additive manufacturing conditions, strategies for alloying and microstructure development by additive manufacturing can be developed to achieve tailored microstructures.

Experimental plan: Four refractory alloys including two refractory binaries (Mo30Nb and Nb7.5Ta) and two RHEAs (C103 and NbMoTaTi) are each subjected to single-track laser melts. The melts are evaluated metallographically via scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and x-ray diffraction (XRD) to understand the solidification and microstructure development. Thermal gradient modeling will be completed for the laser track melts with SYSWELD and columnar to equiaxed transition (CET) modeling will be completed using literature data and data generated with thermodynamic modeling. These models will be compared to the microstructure characterization results to evaluate their accuracy and determine if adjustment is needed.

Related work elsewhere: Other work is largely focused on refractory alloy powder production and testing the ability of current systems to create a full part or coupon. The resultant material has been characterized based on solidification segregation, microstructure, and mechanical properties.

How this project is different: This study will evaluate the effect of a single laser track on conventional, model, and refractory multi-principle element alloys (RMPEAs) so the solidification behavior and microstructural changes can be isolated and studied. Other work has proven that laser additive manufacturing is feasible.

Milestones for the current proposed year: Perform thermal gradient modeling of melt tracks; complete microstructure characterization of melt tracks; perform CET/solidification modeling; complete journal publications and defend MS thesis.

Deliverables for the current proposed year: Compare the CET/solidification modeling to the thermal gradient modeling and microstructure characterization to evaluate the accuracy of the modeling for refractory alloys and the microstructural control possible with laser additive manufacturing.

How the project may be transformative and/or benefit society: If additive manufacturing of refractory alloys can be effectively controlled, these alloys will enable engines to burn hotter. This will ultimately make them run more efficiently and use less fuel and reduce emissions.

Research areas of expertise needed for project success: Access to commercially available thermal gradient and property modeling software; EDAX's EBSD post-processing software NPAR to aid in data analysis of grain size and grain boundary misorientation.

Potential Member Company Benefits: Introducing refractory alloys to high temperature applications where superalloys are typically used has the potential of expanding the temperature capabilities of engines, making them more fuel and cost efficient. Developing a method to produce refractory alloys by additive manufacturing that does not require thermomechanical processing to achieve desired microstructures would decrease production costs.

Progress to Date: Refractory alloy samples have been subjected to five single-track laser melts. Each melt was completed at a different laser speed and power combination to evaluate various melt pool morphologies. Top-down imaging and EBSD of the melt tracks has been initiated. Thermodynamic modeling has been completed. Solidification and thermal gradient modeling is underway.

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Estimated Start Date: Fall 2020	**Estimated Knowledge Transfer Date**: August 2022

The Executive Summary is used by corporate stakeholders in evaluating the value of their leveraged investment in the center and its projects. It also enables stakeholders to discuss and decide on the projects that provide value to their respective organizations. **Ideally, the tool is completed and shared in advance of IAB meetings to help enable rational decision making.**