Project No. 02-01-SR118 – Degradation of Thermal Barrier Coatings with Syngas Combustion: Testing by HADES and Characterization by Advanced Electron Microscopy

FACT SHEET

I. PROJECT PARTICIPANTS

University of Central Florida, Orlando, FL
Florida Turbines Technologies, Inc., Jupiter, FL

II. PROJECT DESCRIPTION

A. Objective(s) – To provide performance data and fundamental understanding of degradation for thermal barrier coatings (TBCs) in natural gas (NG) and syngas (SG) combustion environment by

- Identify degradation (e.g., hot corrosion) mechanisms (e.g., YSZ destabilization, deposit penetration and reaction, etc.).
- Generate critical materials data (e.g., solubility, eutectic compositions and degradation kinetics for realistic NG and SG combustion turbine environment).
- Provide feasible approaches to improve resistance against TBC degradation in fuel-flexible combustion environment.

To achieve the above objectives, the following task-based goals have been set forth.

- Testing of various ▪ types of TBCs in NG and SG combustion environments:
  - Air plasma spray (APS), electron beam physical vapor deposition (EB-PVD) and dense vertically cracked (DVC) TBCs.
  - Hyperbaric advanced development environmental simulator (HADES) with TBC surface temperature of 1150°C (2100°F) and 1050°C (1920°F) for 10, 100 and 400 hours
  - Comparison of NG and SG combustion with 1650°C (3000°F) exit temperature and 350 psi gas pressure.
- Identification and characterization of the degradation using advanced characterization techniques such as FESEM, FIB-INLO, TEM and STEM:
  - Deposits identification.
  - Penetration/reaction/degradation characterization.
  - Generate critical materials data (e.g., solubility, eutectic compositions and degradation kinetics for realistic turbine environment).
- Transfer to industrial partners, the attained knowledge on TBC degradation in NG and SG combustion environments.
- Provide two doctoral and two undergraduate students with interactive team-based research activities in collaboration with industrial partners.

B. Background/Relevancy – The development of technology that will allow turbine power plant fuel flexibility, and increase the efficiency as well as reliability, availability, and maintainability, with low emissions and life cycle costs is the primary objective of The Turbine Program (TTP) at National Energy Technology Laboratory (NETL). One of the most critical tasks for this goal is to enable low-cost and environmentally acceptable use of large coal reserves in the U.S. Integrated Gasification Combined Cycle (IGCC) plants, compared to the conventional coal-burning steam turbine plants, operate at higher turbine inlet temperature and provide a more efficient energy source with reduced emissions. These IGCC plants need advanced combustion turbines (CTs) that operate at higher firing temperature while being significantly more tolerant of the contaminations that erode, corrode, and deposits onto hot section components of the turbine. This is an advance from today's CTs that operate at reduced firing temperatures to maintain availability but suffer from reduced thermal efficiency and higher emissions of CO_2. Synthetic gas (syngas) fueled CTs with advanced thermal barrier coatings (TBCs) must be developed, which can tolerate the more aggressive combustion byproducts while still maintaining high turbine inlet temperatures, increased power output, and power plant efficiency, which all improve the economics of power generation. To that end, there is an important need for a detailed understanding of TBC degradation in syngas combustion environment.

The evaluation of TBCs in syngas combustion environment using HADES proposed in this program will help develop IGCC power generation technologies; leading to less expensive and more reliable energy sources, and reduce U.S. dependence on foreign resources. Specifically, development of reliable and durable TBCs for IGCC based on decrease fuel cost can increase the performance efficiency of turbines by 2.2%, equivalent to CO_2 emission reduction by 300 million tons per year per unit and operational savings of 6.3% (assuming 40/60 split in fuel/capital cost).

C. Period of Performance – August 1, 2005 ~ July 31, 2007

D. Project Summary – Under the University Turbine Systems Research (UTSR) program, this program will provide, for the first time, a study on the degradation mechanisms of TBCs in a realistic syngas combustion environment using advanced microstructural analysis techniques. The findings of the program will provide degradation modes and mechanisms of TBCs that lead to failure in realistic syngas turbine conditions that includes high pressure, high temperature, temperature gradient, syngas combustion contaminants, and high velocity flow erosion using Hyperbaric Advanced Development Environmental Simulator (HADES) designed and built by Florida Turbine Technologies (FTT), Inc. Materials characterization will be carried out using state-of-the-art electron microscopy that includes field-emission scanning electron microscope (FESEM), x-ray diffraction (XRD), focused ion beam (FIB) with in-situ lift-out (INLO), transmission electron microscope (TEM), and scanning TEM (STEM). Emphasis will be given to the phase identification (i.e., crystallography and compositions) of deposits and their penetration/reaction products as well as reaction products from gaseous contaminations, related to TBC degradation. Critical materials information, such as deposit solubility, eutectic composition, and reaction/hot corrosion rates in the light of TBC constituents will be provided from the selected in-laboratory thermodynamic/kinetics experiment/modeling in addition to HADES testing. In order to achieve this objective, following goals have been set forth and will be pursued in partnership with Florida Turbine Technologies (FTT), and with technical assistance from Siemens-Westinghouse Power Corporation, Solar Turbines, General Electric Power Systems, and Howmet Research Corporation.

III. PROJECT COSTS

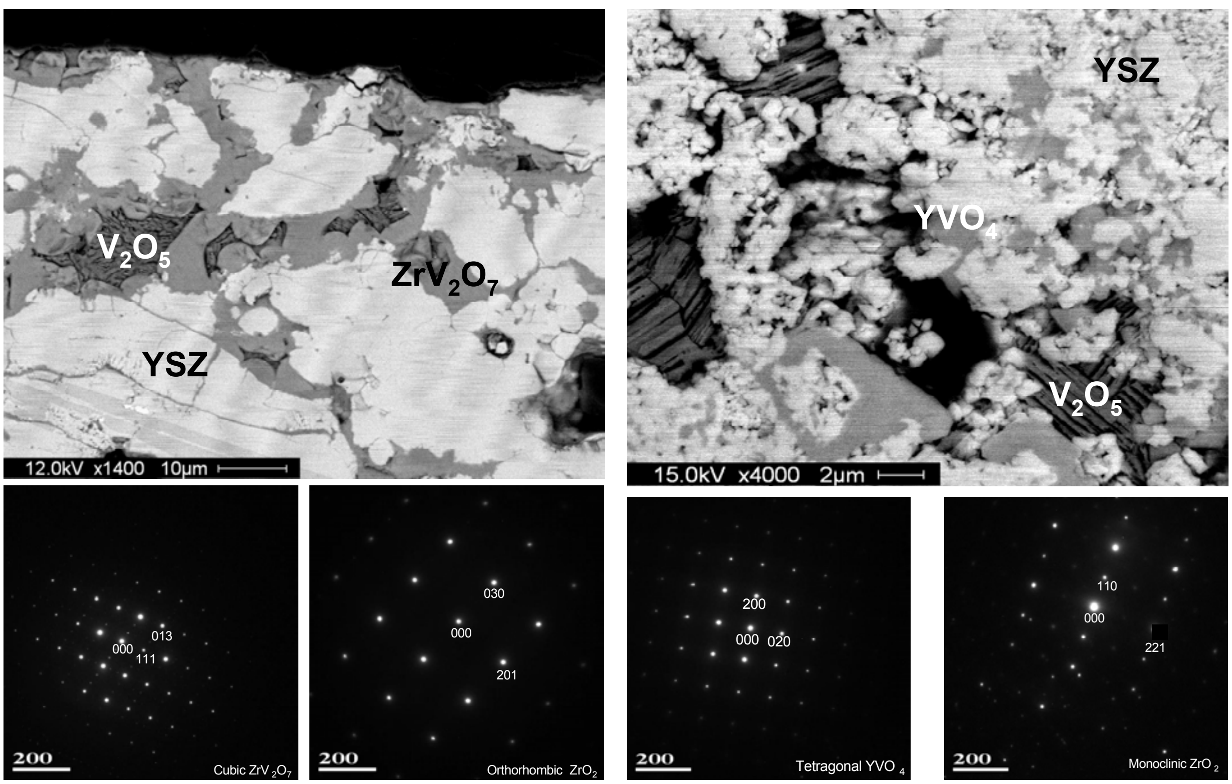
A. DOE Costs $ 246,599
B. Prime Cost Sharing $ 38,892
C. Partner Cost Sharing None

IV. MAJOR ACCOMPLISHMENTS SINCE THE BEGINNING OF THE PROJECT

- Characterization of syngas tested NiCoCrAlY coatings and TBCs
    - Deposits consisting of cubic Fe_3O_4 with a large solubility and monoclinic Fe_2O_3 with minimal solubility.
    - TGO scale consisting of α-Al_2O_3 and tetragonal spinel-(Ni,Co)$(Al,Cr)_2O_4$.
    - Internal oxidation in NiCoCrAlY bond coats consisting of α-Al_2O_3 and cubic NiO.
- Successful production of free-standing APS YSZ coatings (t' phase) at UCF's Thermal Spray Facility (UCF-TSF).
- Degradation of free-standing APS YSZ coatings by V_2O_5:
    - Formation of YVO_4 and ZrV_2O_7 above and below 750°C, respectively.
    - YSZ destabilization with the formation of YVO_4 via incongruent melting of ZrV_2O_7.

Degradation up to 747°C
ZrO_2 (in YSZ) + $V_2O_5 \rightarrow$
ZrV_2O_7 + ZrO_2 (Orthorhombic)

Degradation above 747°C
ZrO_2 (in YSZ) + $V_2O_5 \rightarrow$
$2YVO_4$ + ZrO_2 (Monoclinic)



V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS

- Specification and design of TBC specimens for HADES rigs.
- Manufacturing of TBC specimens in collaboration with industrial partners.
- Baseline TBC testing in natural gas combustion environment using HADES.

VI. MAJOR ACTIVITIES PLANNED IN OUTYEARS (6 – 18 MONTHS)

- TBC testing in syngas combustion environment using HADES.
- Advanced microstructural analysis.

VII. ISSUES

- Delay in HADES operation.

VIII. ATTACHMENTS