the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

# Mechanisms Underpinning Degradation of Protective Oxides and Thermal Barrier Coatings in High Hydrogen Content-Fueled Turbines—University of California, Irvine

## Background

Thermal barrier coatings (TBCs) and components in the hot section of gas turbines are degraded by coal-derived high hydrogen content (HHC) synthesis gas (syngas). In this project the University of California, Irvine (UCI) will provide an improved mechanistic understanding of the degradation of critical turbine system materials in HHC-fueled systems and guide the development of more robust material sets.

This project is managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from HHC fuels derived from coal that is clean, efficient, and cost-effective; minimizes carbon dioxide ($CO_2$) emissions; and will help maintain the nation's leadership in the export of gas turbine equipment. This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers.

## Project Description

This project will evaluate the potential impacts of coal-derived syngas and HHC fuels on the degradation of turbine hot-section components through attack of protective oxides and TBCs. The primary focus is to explore mechanisms underpinning the observed degradation processes and connections to the combustion environments and characteristic non-combustible constituents.

This work addresses turbine materials stability concerns by conducting tests in simulated syngas and HHC environments to evaluate materials evolution and degradation mechanisms. Thermally grown oxide (TGO) development and TBC failure unique to HHC environmental exposures will be assessed. High-resolution imaging and microanalysis will be used to explain the evolution of surface deposits (molten phase, formation, and infiltration). Electron beam physical vapor deposition coating will be used to fabricate test coupons with idealized microstructures for comparison with thermal spray systems. Representative syngas and HHC fuels with realistic levels of impurities and contam-inants must be determined in order to explore differences in heat transfer, surface degradation, and deposit formation. Experiments will be executed to study the melting and infiltration of simulated ash deposits. Reaction products and evolving phases associated with molten phase corrosion mechanisms will be identified.

## CONTACTS


**Richard A. Dennis**
Technology Manager, Turbines
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4515
richard.dennis@netl.doe.gov

**Patcharin Burke**
Project Manager
National Energy Technology Laboratory
626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-7378
patcharin.burke@netl.doe.gov

**Daniel Mumm**
Principal Investigator
University of California, Irvine
916 Engineering Tower
Irvine, CA 92697
949-824-3858
mumm@uci.edu


## PARTNERS

None

## PROJECT DURATION

| Start Date | End Date |
|---|---|
| 09/01/2010 | 08/31/2013 |

## COST

**Total Project Value**
$625,000

**DOE/Non-DOE Share**
$500,000/$125,000

## AWARD NUMBER

FE0004727

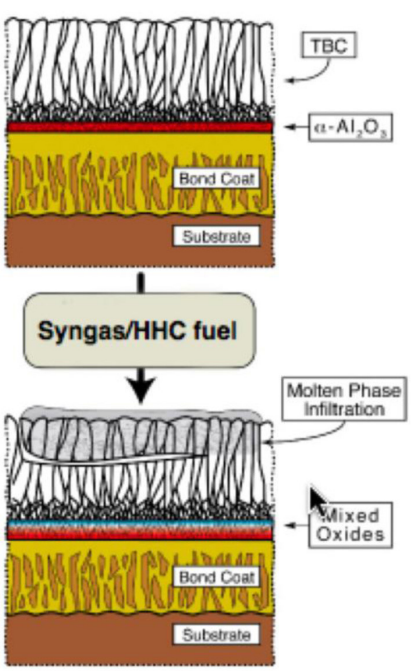
New material systems for laboratory testing will be developed and thermal gradient and combustion rig testing of material test coupons will be facilitated. Information on the resulting combustion environments will be correlated to properly assess materials exposure conditions and guide the development of lab-scale simulations of material exposures.

## Goals and Objectives

The goal of this project is to derive a mechanism-based understanding of protective TGO layer and TBC system degradation modes associated with turbine operation with syngas and HHC fuels, and develop a knowledge base upon which the design of coatings more resistant to the observed attack mechanisms may be based.

Specific objectives:

- Evaluate the unique impacts of utilizing coal-derived syngas and HHC fuels on the degradation of turbine hot-section components, and develop an improved mechanistic understanding of the observed degradation processes in relation to the fuel-dependent combustion environments.
- Develop material design protocols that maximize the lifetime of protective oxides and TBCs in syngas and/or HHC combustion turbine exposures.
- Procure baseline materials representative of overlay and bond coat materials, and begin assessing oxide growth and phase development (at 1,125 degrees Celsius [°C]) as a function of simulated combustion by-product stream composition and water vapor content.
- Explore the fundamental mechanisms by which water vapor affects non-ideal oxide growth and TBC system lifetime by (1) utilizing novel specimen exposure protocols, (2) carrying out selected experiments on a burner rig test system, and (3) applying advanced microscopy and spectroscopic methods to quantitatively evaluate oxide development in relation to varying exposure environments.




*Schematic of potential modifications to materials degradation with syngas/ HHC Fuels.*

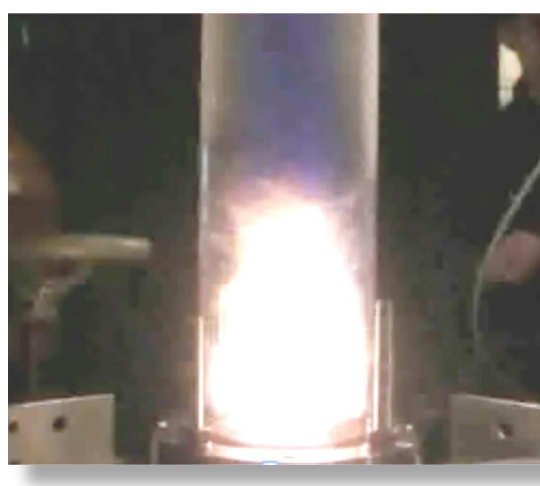
- Synthesize and/or procure representative fly ash compositions resulting from combustion of coal-derived syngas and HHC fuels and initiate evaluations of thermo-chemical interactions with baseline TBC systems.

## Accomplishments

- Completed modifications to furnace-based test rigs to facilitate extended oxidation experiments (up to 1,000 hours) in controlled water vapor content environments.
- Obtained bulk cast versions of (1) idealized nickel-aluminum (Ni-Al) alloy compositions, (2) two commercial M-chromium aluminum yttrium alloy (MCrAlY; where M is one of several different metals) bond-coat compositions including a cobalt (Co)-rich composition and a Ni-rich composition, and (3) several commercial bond-coat on Ni-based super-alloy substrate systems for studies of oxide growth in varying simulated combustion environments.
- Initiated characterization of oxide growth and phase development under 1,125 °C exposures in dry and elevated water vapor environments. The resulting oxide growth and phase development were assessed using (1) x ray diffraction, (2) high-resolution microscopy, (3) site-specific cross-sectional analysis by focused ion beam sectioning, and (4) energy dispersive spectroscopy analysis by focused ion beam sectioning.
- Demonstrated enhanced oxide formation (specifically, of Ni-based spinels) with increasing water vapor content, suggesting a direct role of water vapor pressure ($pH_2O$)-dependent species on the activities and transport of positive ions (Ni, etc.) through developing thermally grown oxides.
- Synthesized laboratory versions of syngas-derived fly ash and initiated studies of thermo-chemical interactions in yttria-stabilized zirconia (YSZ) TBC material reactions with baseline TBC systems.

## Benefits

This UTSR project supports DOE's Hydrogen Turbine Program that is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. This project will support an increase in the life of turbine hot-section components, which will increase maintenance intervals and ultimately the life of the power system.



*Tests of a combustor leveraged for materials exposure studies.*