



# Low Thermal Conductivity, High Durability Thermal Barrier Coatings for IGCC Environments—University of Connecticut

## Background

Improved turbine materials are needed to withstand higher component surface temperatures and water vapor content for successful development and deployment of integrated gasification combined cycle (IGCC) power plants. Thermal barrier coatings (TBCs) in particular are required to have higher surface temperature capability, lower thermal conductivity, and resistance to attack at high temperature by contaminants such as calcium-magnesium-alumina-silicate (CMAS) and water vapor. There is also a concurrent need to address cost and availability issues associated with rare earth elements used in all low thermal conductivity TBCs.

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. Both are 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 high hydrogen content fuels derived from coal that is clean, efficient, and cost-effective; minimizes carbon dioxide (CO<sub>2</sub>) emissions; and will help maintain the nation's leadership in the export of gas turbine equipment.

## Project Description

The University of Connecticut, in cooperation with Pratt & Whitney and Siemens Energy, will use a novel solution precursor plasma spray (SPPS) process (Figure 1) to deposit low thermal conductivity, high durability yttria stabilized zirconia (YSZ) TBCs and to utilize surface protective layers (SPLs) to provide high temperature contaminant resistance and increased surface temperature capability, while minimizing the use of rare earth elements. The SPPS process provides a unique TBC microstructure that consists of through-thickness vertical cracks for strain tolerance, ultra-fine splats for spallation crack resistance, and the ability to produce very low thermal conductivities. The low thermal conductivities, or low-K (with K representing heat conductivity), will result from planar arrays of fine porosity called inter-pass boundaries (IPBs) and the ability to vary porosity content over wide ranges. The IPBs are generic conductivity lowering features that can be implemented for any TBC. Pratt & Whitney and Siemens Energy will contribute valuable specimens and will test the down-selected low-K TBCs.

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## the ENERGY lab PROJECT FACTS Hydrogen Turbines

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### PARTNERS

Pratt & Whitney  
Siemens Energy

### PROJECT DURATION

Start Date	End Date
10/01/2011	09/30/2014

### COST

**Total Project Value**  
\$657,212

**DOE/Non-DOE Share**  
\$498,886/\$158,326

### AWARD NUMBER

FE0007382



U.S. DEPARTMENT OF  
**ENERGY**

The low-K YSZ TBC structure will be created using the SPPS process. Taguchi methods for design of experiments will be used to systematically determine the deposition parameters to minimize the thermal conductivity. Cyclic durability tests of the low-K TBC will be conducted to verify that the excellent durability of the SPPS TBC is preserved. A protective surface layer of gadolinium-zirconium will be added to the low-K YSZ TBC to increase the maximum allowable surface temperature by at least 100 degrees Celsius (°C) and improve its CMAS resistance, while minimizing the heavy use of rare earth elements. This improved contaminant resistance will be verified by testing in CMAS and moisture. Contaminant resistance will be further enhanced by employing two novel approaches, one using aluminum-titanium additions to the YSZ, and the other by deliberately adding calcium sulfate, shown to block CMAS when deposited by natural processes in service engines. The spallation failure mechanisms of the low-K TBC will be defined to provide guidance for subsequent improvements and a sound basis for life prediction methodologies.

## Goals and Objectives

The goal of this project is to develop low-K, high durability TBCs for IGCC environments.

- Fabricate very low-K SPPS YSZ TBCs. The low thermal conductivities will result from planar arrays of fine porosity (also called IPBs) and the ability to vary the porosity content over wide ranges.
- Improve the maximum allowable surface temperature of the low-K TBC by at least 100 °C and dramatically improve its high-temperature contaminant resistance by adding an SPPS SPL.
- Improve the high contaminant resistance of the SPL coating by using two novel approaches to dope YSZ with minor elements.
- Define the spallation failure mechanisms of the low-K TBC to provide guidance for subsequent improvements and a sound basis for life prediction analyses.

## Accomplishments

- SPPS YSZ TBCs were deposited with a thermal conductivity of 0.6 watts per meter kelvin, a 50 percent reduction compared to air plasma spray (APS) YSZ. This breakthrough accomplishment achieved the prime goal of the program by introducing planar arrays of porosity, called inter-pass boundaries (IPBs). The IPBs are a unique microstructural feature of the SPPS process. Other low thermal conductivity TBCs rely on expensive rare-earth elements and exhibit poorer fracture toughness and erosion resistance (Figure 2).
- Preliminary thermal cycling tests were performed and showed that SPPS YSZ with IPBs had a cyclic life equal to that of standard SPPS YSZ TBCs and better than that of APS YSZ TBCs.
- A preliminary erosion test on low conductivity YSZ TBCs with IPBs showed erosion resistance as good as or better than standard YSZ TBCs (Figure 4).
- Successfully created a CMAS precursor solution suitable for use in subsequent CMAS testing.
- Successfully applied a protective surface layer consisting of a rare earth element based CMAS resistant higher temperature material (Figure 3).
- Purchased and installed a tube furnace for future high humidity testing.
- Successfully sprayed new YSZ-based TBCs with additional contents of Alumina and Titanium oxide, aiming to achieve advanced CMAS resistance as reported in Nitin Padture's work. The thermal conductivity of these new TBCs was measured using laser-flash (Figure 5).
- Demonstrated that calculated thermal conductivity based on micrographs are not reliable and replaced this method with laser flash measurements.

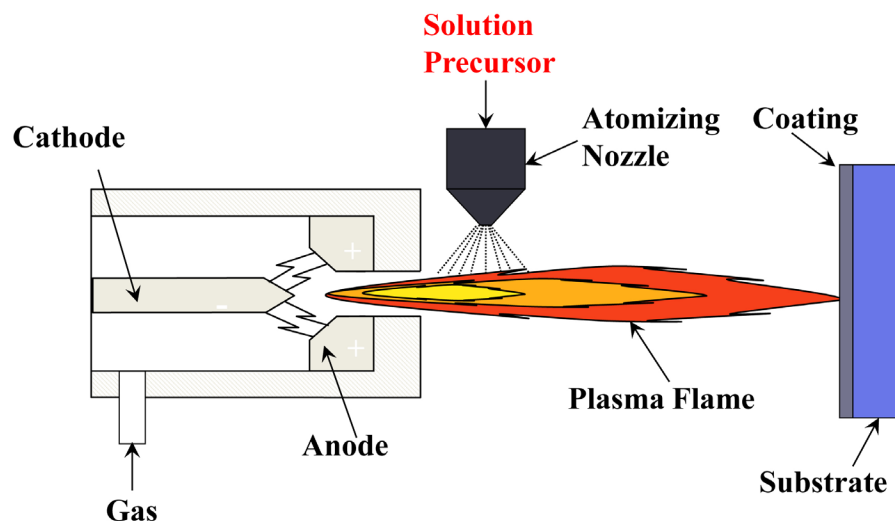


Figure 1. Solution Precursor Plasma Spray Process.

## Benefits

This USTR 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 work will support the development and deployment of IGCC power plants through the development of improved turbine materials capable of withstanding higher component surface temperatures.

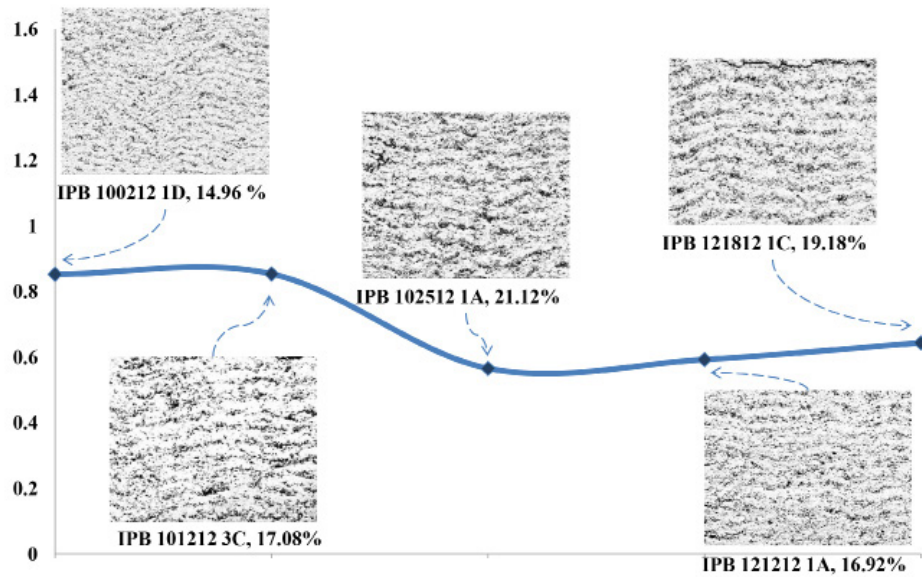


Figure 2. Thermal conductivity of SPPS YSZ reduced 50% compared to APS YSZ using planar arrays of porosity (IPBs). The more prominent the IPB structure, the lower the thermal conductivity.

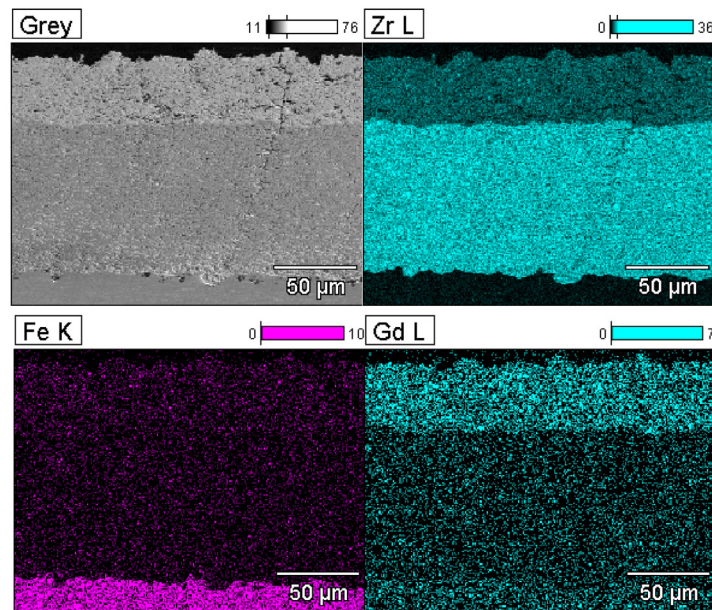


Figure 3. Gadolinium Zirconate (GdZr) protective surface layer (PSL) successfully applied. Top left image is an electron microscope image of a multi-layer coating with the bottom layer being the substrate, the middle layer is YSZ, and the top layer is GdZr. The other images are chemical maps created with Electron Dispersion Spectroscopy. The GdZr PSL can clearly be seen at the top and there is minimal chemical interaction between the layers.



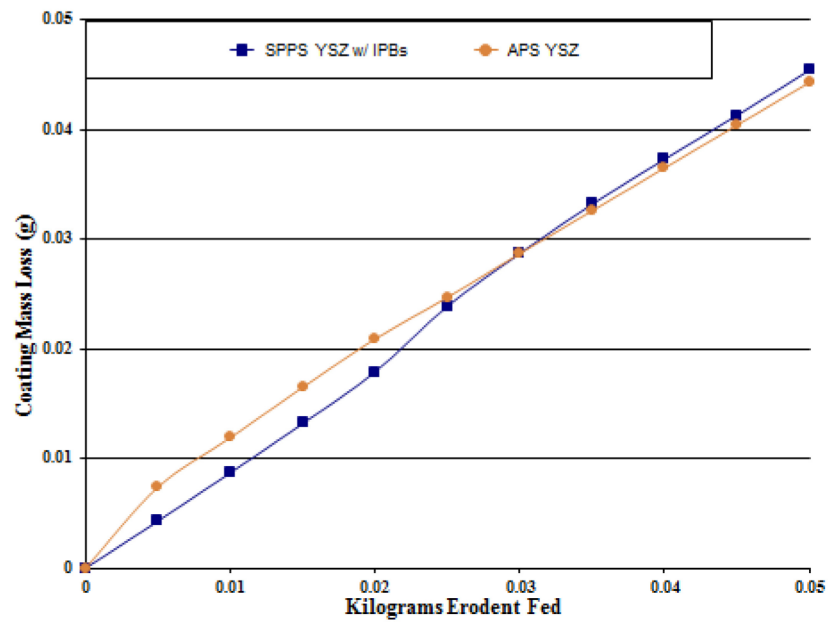


Figure 4. Erosion performance of SPPS YSZ TBCs with IPBs comparable to APS YSZ coatings. The lower the coating mass loss rate, the better the erosion resistance.

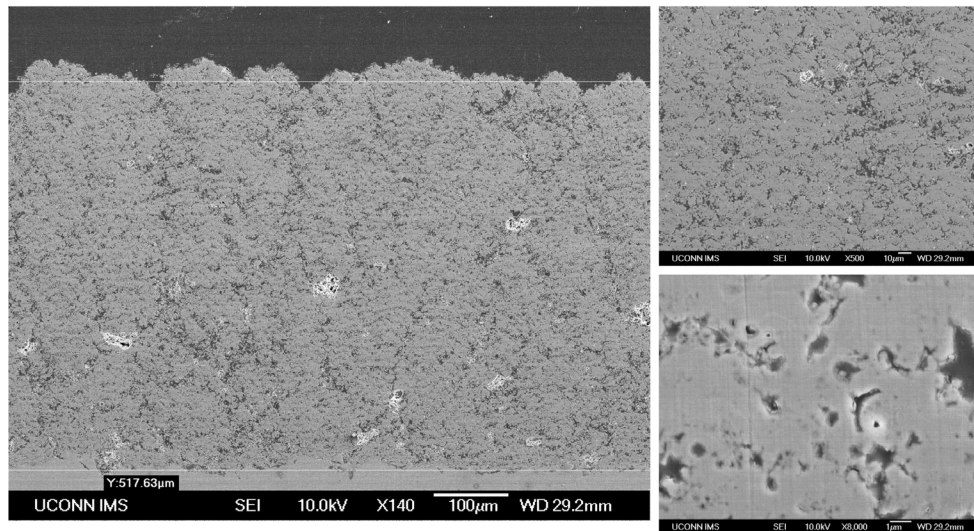


Figure 5. CMAS resistance coating successfully applied using SPPS process for new YSZ-based TBCs with additional contents of Alumina and Titanium oxide.

