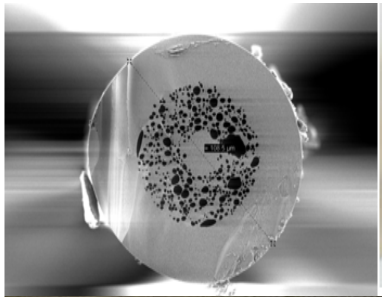
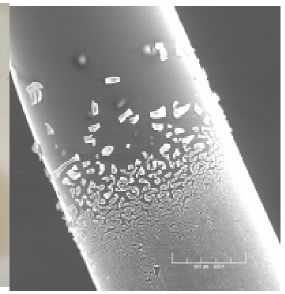
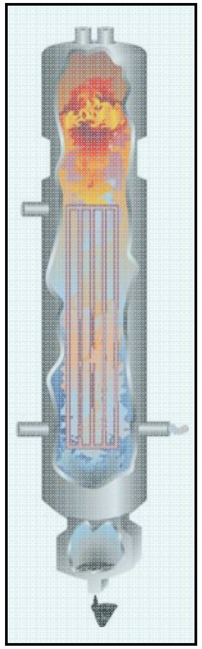
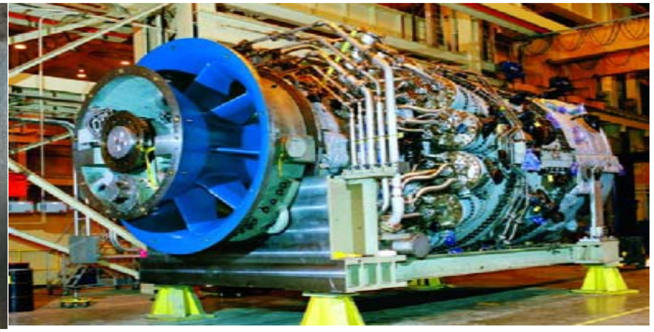
NATIONAL ENERGY TECHNOLOGY LABORATORY









DOE Perspective on Advanced Energy Materials

Robert Romanosky, Technology Manager

National Energy Technology Laboratory

October 9-10, 2008

Materials Program Goals

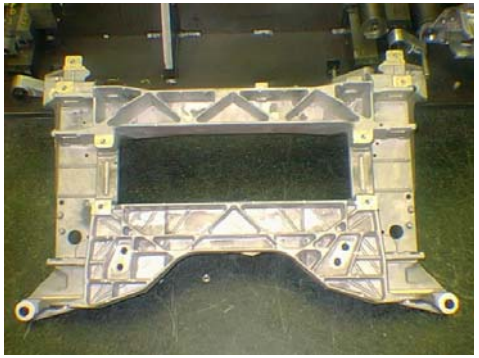
- **Development of a technology base in the synthesis, processing, life-cycle analysis, and performance characterization of advanced materials.**
- **Development of new materials that have the potential to improve the efficiency, performance and/or reduce the cost of existing technologies.**
- **Development of materials for new systems and capabilities.**

NETL Programs impacted by these goals:

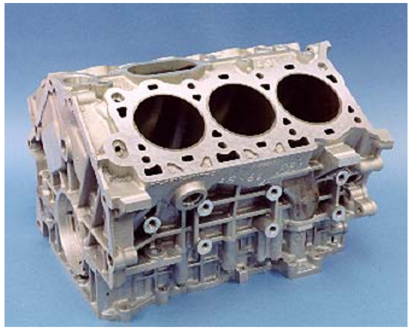
- ***Advanced Research***
- ***Advanced Turbines***
- ***Fuel Cells***
- ***Fuels from Coal***
- ***Gasification***
- ***Innovations for Existing Plants***
- ***Sequestration***

Advanced Vehicle Materials

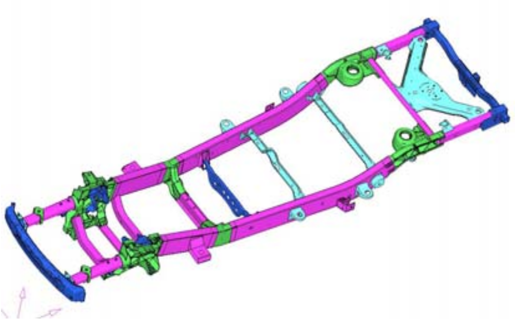
- The High-Strength Weight Reduction (HSWR) Materials Technology activity of the U.S. Department of Energy's (DOE's) Office of FreedomCAR and Vehicle Technologies (OFCVT) Program seeks to reduce the weight of vehicles components without reducing vehicle functionality, durability, reliability, or safety and to do so cost-effectively.



- Developing advanced materials and materials processing technologies that can be applied to heavy vehicle body, chassis, and suspension components to achieve weight reduction



- Priority materials include advanced high-strength steels, aluminum, magnesium, titanium, and composites such as metal matrix materials and glass- and carbon-fiber-reinforced thermosets and thermoplastics.



Thin-Film Solar Cell

- A thin-film solar cell has been developed that can compete with the efficiency of the more common silicon-based multicrystalline solar cell, which can be as high as 20.3 percent.
- The copper indium gallium diselenide (CIGS) thin-film solar cell recently reached 19.9 percent efficiency, setting a world record for this type of cell.
- CIGS cells use extremely thin layers of semiconductor material applied to a low-cost backing such as glass, flexible metallic foils, high-temperature polymers or stainless steel sheets.

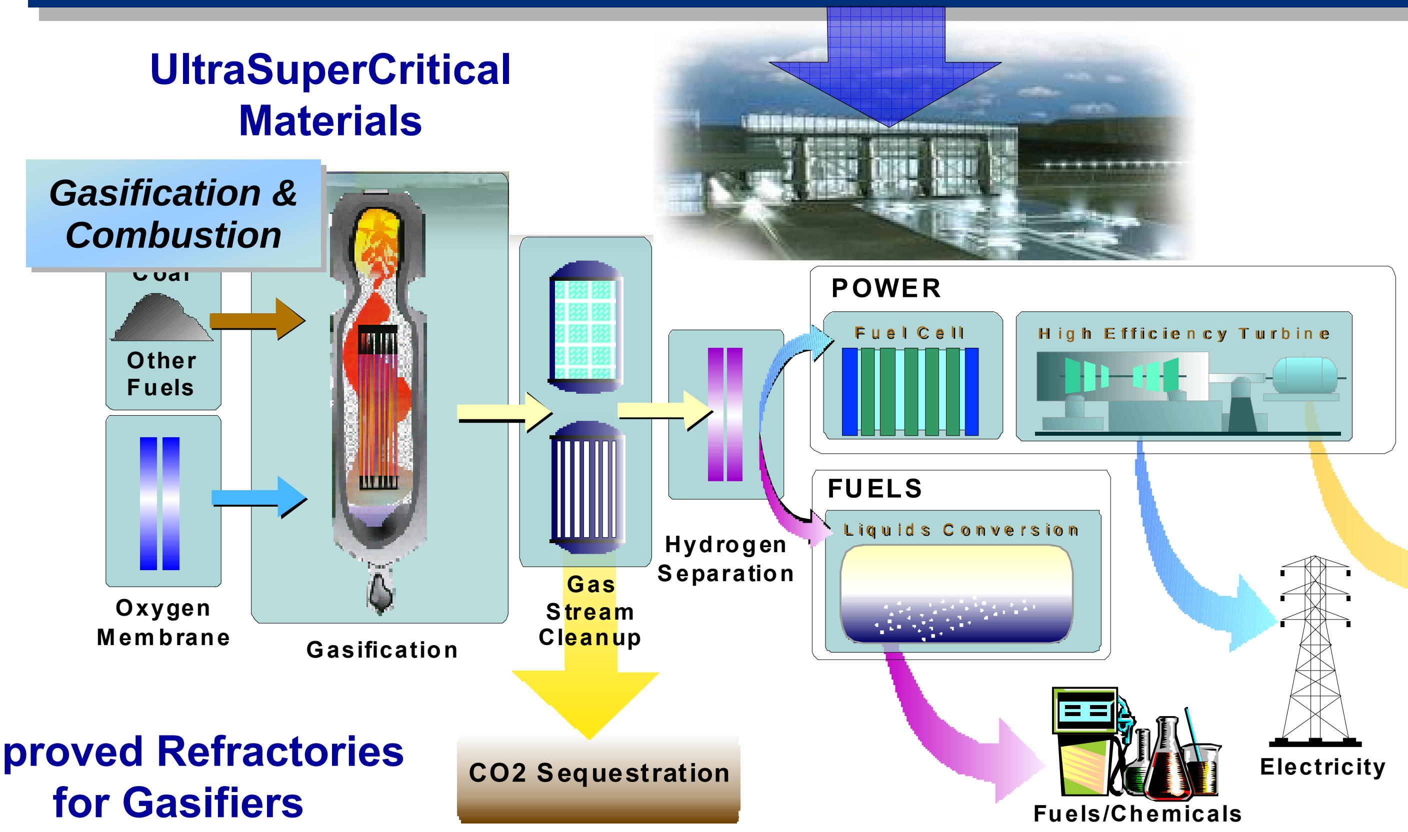
Ultra-Clean Energy Plant

Advanced Materials

Systems Integration
System modeling
Virtual Simulation

Instrumentation
Sensors & Controls

UltraSuperCritical Materials



Advanced Alloys

Seals & Electrodes for Fuel Cells

Thermal Barrier Coating for Turbines

Improved Refractories for Gasifiers

ODS Coatings

Gas Stream Cleanup Devices

Materials Evaluation for Biomass and Black Liquor Gasification

- Gasification of black liquor and biomass involves high-pressure, high-temperature, and sometimes caustic conditions.

- Critical materials issues such as fatigue, corrosion, stability, and longevity of materials are the primary focus of research.

- Corrosion and corrosion fatigue studies are being conducted to identify degradation mechanisms for metallic and refractory materials.

Advanced Research Materials Program Areas

- **New Alloys** - To increase the temperature capability of alloys for use in specific components required for advanced power plants by understanding the relationships among composition, microstructure, and properties.

- **Functional Materials** - To understand the special requirements of materials intended to function in specific conditions such as those encountered in hot gas filtration, gas separation, and fuel cell systems.

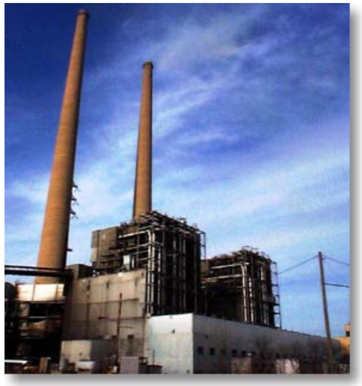
- **Breakthrough Materials** - To explore routes for the development of materials with temperature/strength capabilities beyond those currently available.

- **Coatings & Protection of Materials** - To develop the design, application, and performance criteria for coatings intended to protect materials from the high-temperature corrosive environments encountered in advanced fossil energy plants.

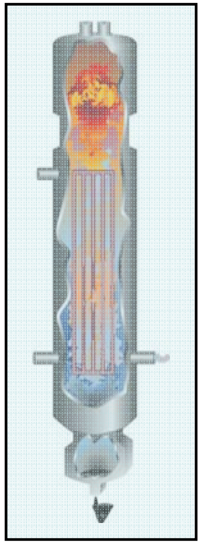
- **Ultra Supercritical Materials** – To evaluate and develop materials technologies that allow the use of advanced steam cycles in coal-based power plants to operate at steam conditions of up to 760°C (1400°F) and 5,000 psi

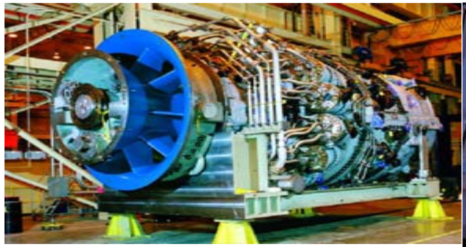
Fossil Energy Key Material Research Areas

USC Boilers/Turbines

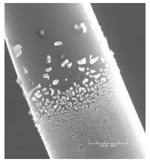
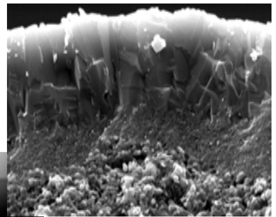
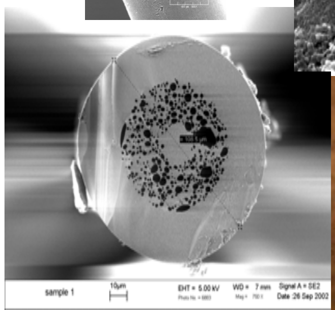


Gasifier

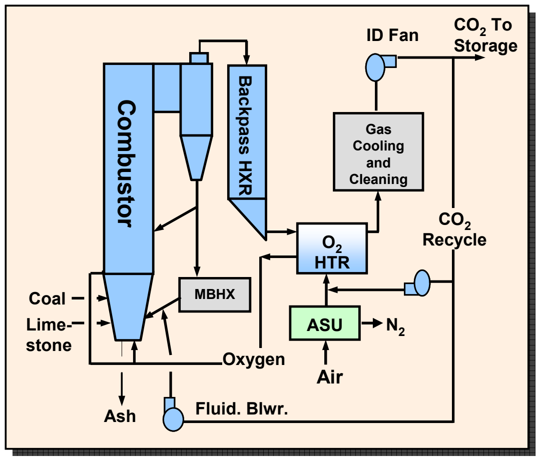





Advanced Turbines


Sensors

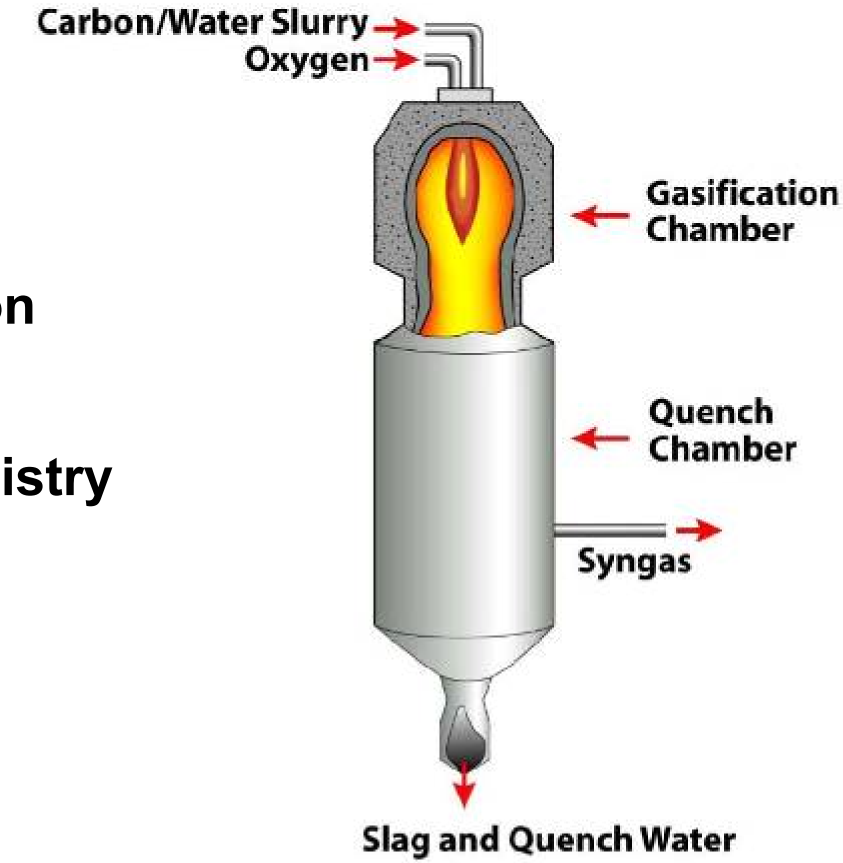


Oxy-Firing

Fuel Cells

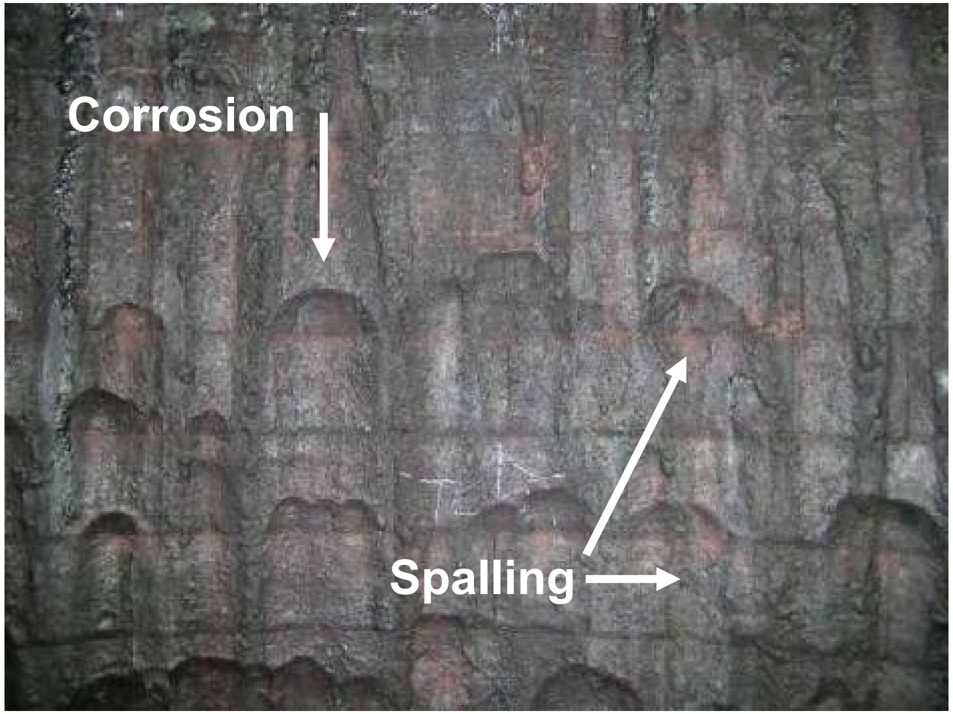
Refractory Materials Challenges in Gasifiers

- **Temperatures of 1325 to 1600 °C**
- **Thermal Cycling**
- **Variable Environment (oxidizing on start-up; reducing in service)**
- **Corrosive Slags of Variable Chemistry**
- **Corrosive Gases**
- **Pressures ≥ 400 psi**



The problem is frequent gasifier shutdowns for refractory replacement

Gasifier Refractory Failure Mechanisms: Corrosion and Spalling



Commercial Gasifier Side Wall Refractories are 90% Cr_2O_3

Brick from Side Wall

Spalling is the primary cause of material loss

Technology Transfer:
Now Commercially Available as *Aurex*® 95P

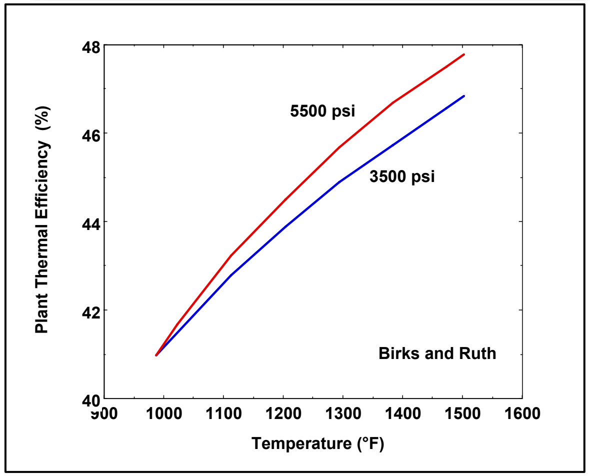
NETL Refractory is on the right, with hot face at the front

Field Trial in a Commercial Coal Gasifier; 237 days of actual service over ~14 months. Test panel is outlined in chalk. Note lack of spalling.

Field Trials Confirm Superior Performance

UltraSupercritical Boilers and Turbines

- **Current technology for Boilers**
  - Typical subcritical = 540 °C
  - Typical supercritical = 593 °C
  - Most advanced supercritical = ~610 °C
- **Ultrasupercritical (USC) DOE goal for higher efficiency and much lower emissions, materials capable of:**
  - 760 °C (1400 °F)
  - 5,000 psi
  - Oxygen firing
- **USC Plant efficiency is improved to 45 to 47% HHV**
- **Meeting these targets requires:**
  - The use of new materials
  - Novel uses of existing materials



Ultrasupercritical Materials Program

Team was assembled:

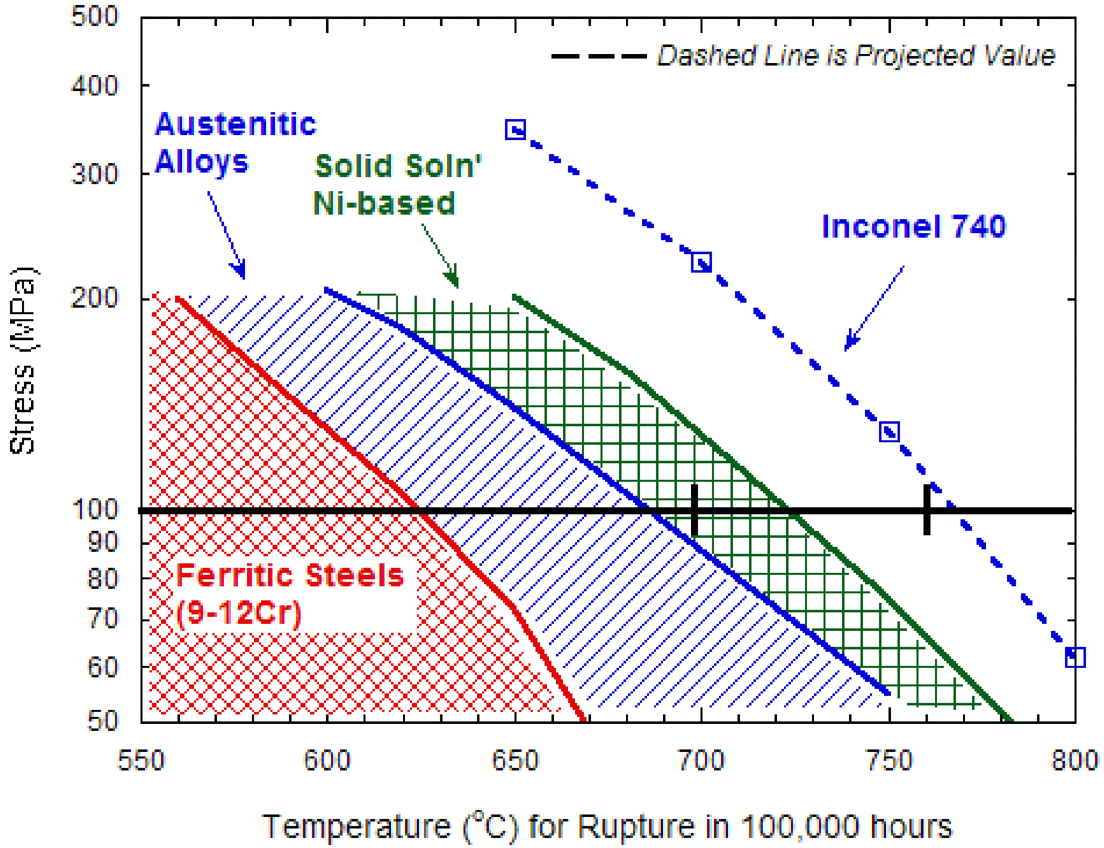
- National Energy Technology Lab (NETL)
- Electric Power Research Institute (EPRI)
- Energy Industries of Ohio (EIO)
- Oak Ridge National Lab (ORNL)
- Alstom Power, Inc.
- Riley Power
- Babcock and Wilcox Company
- Foster Wheeler Development Company
- General Electric
- Siemens

Tasks identified

1. Conceptual Design
2. Mechanical Properties
3. Steamside Oxidation
4. Fireside Corrosion
5. Welding Development
6. Fabricability
7. Coatings
8. Design Data and Codes

Material Performance Capability

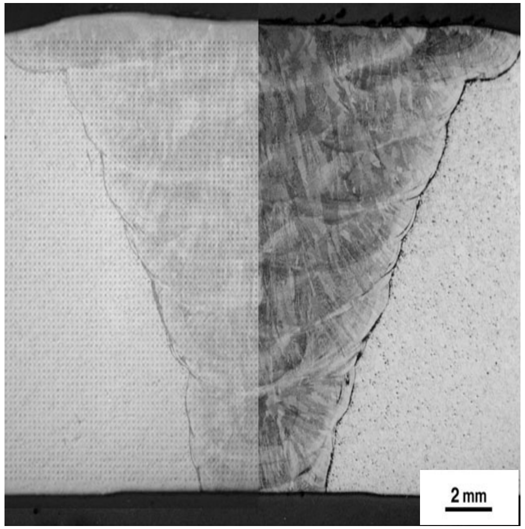
Currently, the temperature limit for steels is ~620 °C with the last 20+ years of alloy development only increasing temperature capability by ~20 °C!

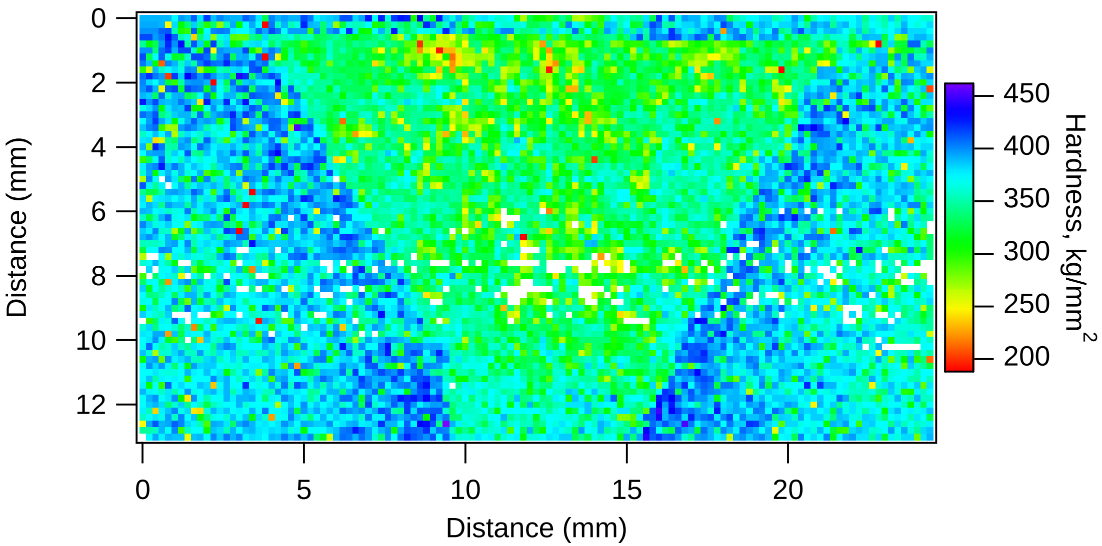


- **For USC Steam at 760 °C, weldable age-hardenable alloys are required – few candidate alloys and no properties and processes are developed for this type of alloy class**
- **Solid solution Ni-based alloys are typically easier to weld and fabricate but do not meet the requisite strength requirement**

Technical Barriers

- Long-term degradation of materials (100-300,000 hours) are not well understood or characterized for this alloy class
- Combination of creep strength, weldability (necessary component for boiler fabrication), oxidation, and corrosion resistance
- Effects of heat-treatment, fabrication variables, welding is critical
- Need new welding processes, fabrication processes, etc.
- Ability to produce material is also an issue





Microhardness map of Thick Section USC weld showing "soft" weld metal – long-term testing is needed to understand the implication of this type of weld on material performance

What and Why Oxy-fuel Combustion

- **Energy production (in particular, electricity) is expected to increase due to population increase and per capita increase in energy consumption**
  - Oxy-fuel combustion is one option for providing increased capacity to satisfy the future energy consumption demand
  - Can be used for retrofitting or new plants

- **Global climate change - one of the sources for CO_2 increase in the atmosphere is exhaust from fossil fuel combustion plants**
  - Oxy-fuel combustion readily supports the capture and sequestration of CO_2 from power plants

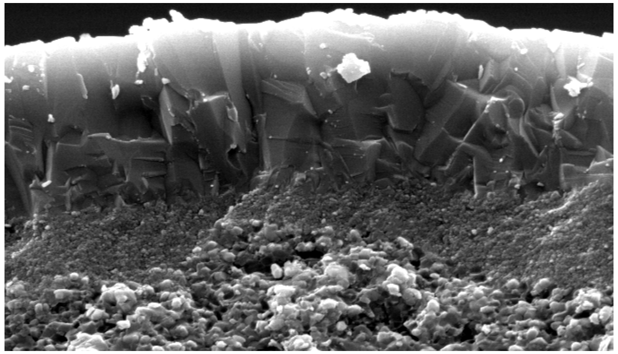
Technological Barriers – Materials Needs

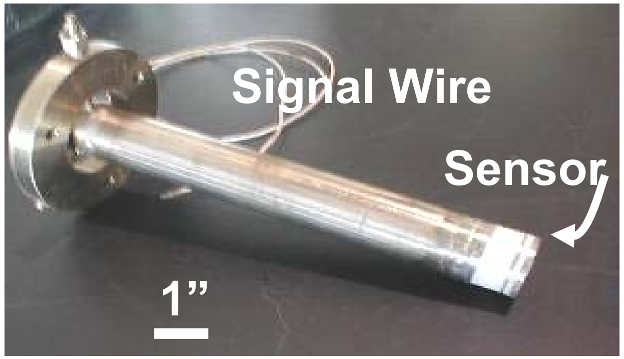
- **Better understanding of material performance in oxyfuel environments**
  - Evaluate ash assisted hot-corrosion of boiler alloys
  - Develop computational models to predict fireside corrosion - will aid in the development of all advanced combustion systems
  - Evaluate other plant components   e.g., coal pulverizers (wear-corrosion interactions)

- **Future Capability: Combine Oxyfuel with USC.**
  - Potential cleaner coal combustion technology
    - Oxyfuel: ease of flue gas clean-up and CO_2 sequestration
    - USC: maximize efficiency
  - Need cost effective advanced alloys that can withstand the oxyfuel/USC environment
    - higher temperatures and higher pressures than current systems

Advanced Sensor Materials

- Harsh Environmental Conditions
- Sensor Material Development
- Rugged Sensor Designs





Driver for New Sensing Technology

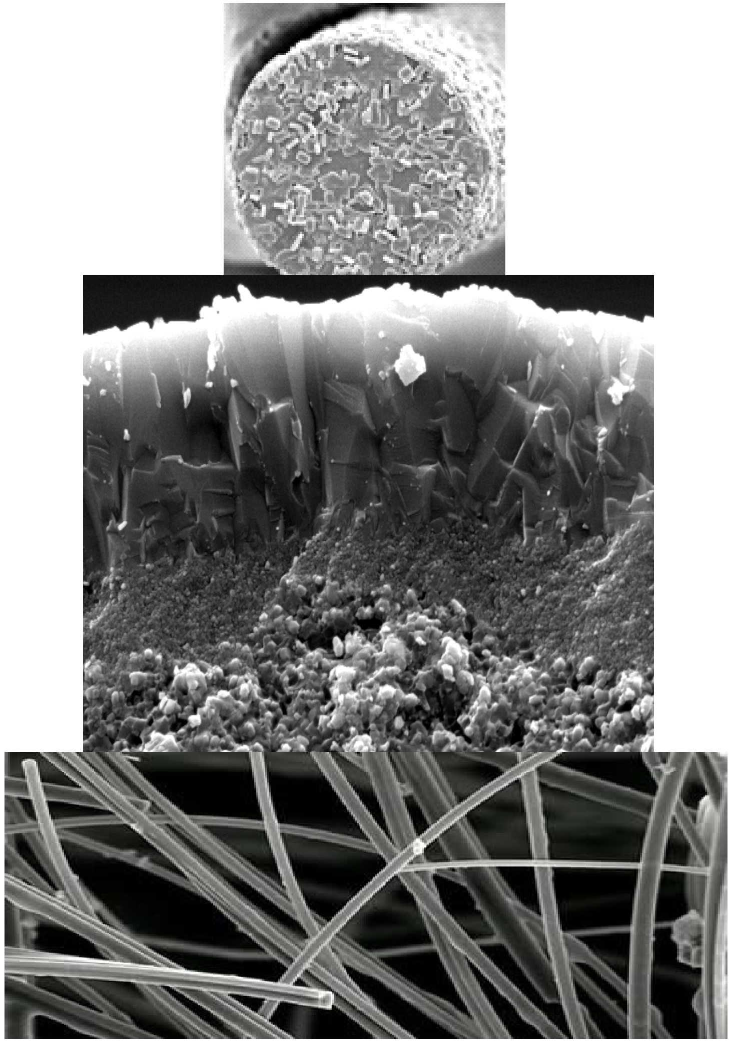
- **Advanced Power Generation:**
  - Harsh sensing conditions throughout plant
  - Monitoring needed with advanced instrumentation and sensor technology.
  - Existing instrumentation and sensing technology are inadequate

- **Coal Gasifiers and Combustions Turbines:**
  - have the most extreme conditions
    - Gasifier temperatures may extend to 1600 °C and pressures above 800 psi. Slagging coal gasifiers are highly reducing, highly erosive and corrosive.
    - Combustion turbines have a highly oxidizing combustion atmosphere.

- **Targeting development of critical on line measurements**
  - Sensor materials and designs are aimed at up to 1600 °C for temperature measurement and near 500 °C for micro gas sensors.
  - Goal is to enable the coordinated control of advanced power plants followed by improvement of a system's reliability and availability and on line optimization of plant performance.

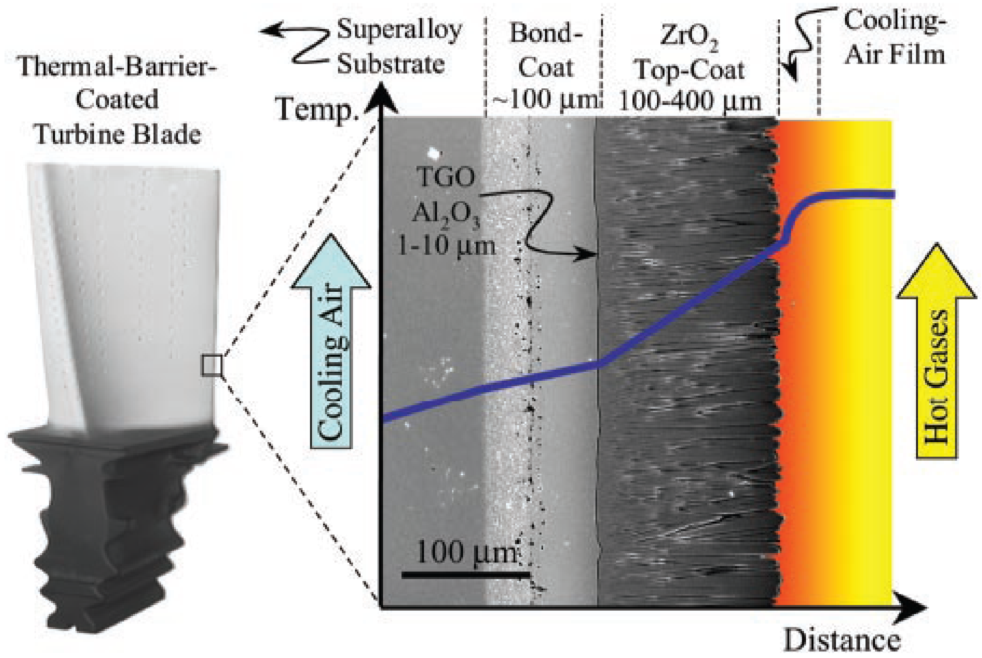
Materials for Sensing in Harsh Environments (Optical and Micro Sensors)

- **Sapphire**
- **Alumina**
- **Silicon Carbide**
- **Doped Silicon Carbide Nitride**
- **Yttria stabilized zirconia**
- **Fused/doped silica for certain conditions**
- **Interest in**
  - Active / doped coatings
  - 3D porous or “mesh” nano-derived ceramics / metal oxides



Turbines

- Environmental Conditions
- Research Underway



Gas Phase Conditions for Advanced Turbines

IGCC Based Syngas and H2 Fueled Turbines

Parameter	ST 2010	HT 2015
Combustor exhaust temp	2700 °F	2700 °F
Turbine inlet temp	2500 °F	2600 °F
Turbine exhaust temp	1100 °F	1100 °F
Turbine inlet pressure	250 psig	300 psig
Combustor exhaust composition	CO_2 (9.27), H_2O (8.5), N_2 (72.8), Ar (0.8), O_2(8.6)	CO_2 (1.4), H_2O (17.3), N_2 (72.2), Ar (0.9), O_2(8.2)

IGCC Oxy-Fuel Turbine Cycle

Turbine Parameters	OFT 2010	OFT 2015
Intermediate Pressure		
Turbine inlet	1150 °F	3200 °F
Pressure	450 psig	625 psig
High Pressure		
Turbine inlet	-	1400 °F
Pressure	-	1500 psig
Working Fluid Composition (%)	H2O (82), CO_2 (17), O2 (0.1), N_2 (1.1), Ar (1)	H2O (75-90), CO_2 (25-10), balance (17) O2, N_2, Ar

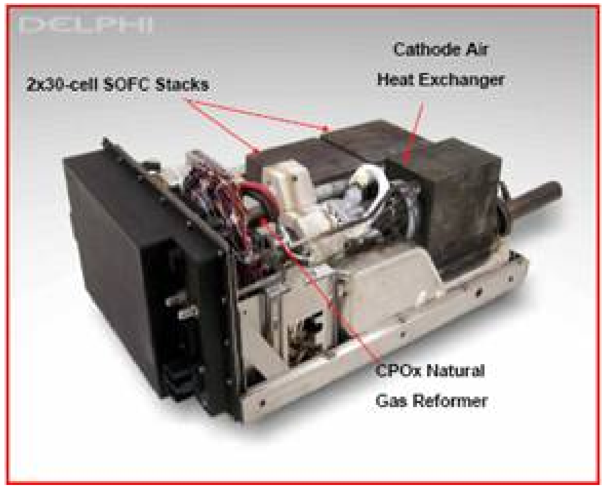
Evolution and Revolution of Technology

- **Evolution**
  - Material development
  - Air foil design
  - Optimization of conventional CO_2 compression technology
  - Approach to system studies
- **Revolution**
  - Hydrogen combustion
  - Oxy-fuel turbines
  - Ramgen shock wave compressor
  - Spar and shell air foil design

MATERIALS !
MATERIALS !
MATERIALS !

Courtesy of Siemens Energy

Fuel Cells



a solid oxide
fuel cell

a SOFC stack

Fuel Cell Materials

R&D Underway

- Work to fully understand the surface chemistry of established cathode oxides
- Epitaxial growth through pulsed laser deposition to prepare thin film model surfaces
- Identify key correlations between surface structure, chemistry, and performance parameters
- Theoretical modeling to interpret the underlying chemistry and guide modifications to the cathode surfaces.

Technology Future

- Improve Cathode performance to extend functional operating temperature from the current lower range of 750 °C down to 650 °C.

Technology Benefit

- Reduce SOFC cost through more efficient operational performance.
- Increase efficiency in advanced power generation systems

What Does the Future Look Like?

- **The USA and the world will face great energy challenges with ever increasing environmental constraints**
- **Advanced fossil energy, zero or near zero emissions, power systems will be needed**
- **The Advanced Research Materials Program is poised to have even greater impacts on future energy systems**
  - Prescriptive materials design and lifetime prediction for extreme environments
  - High temperature sensor material
  - Next generation stainless steels with higher strength and better oxidation resistance
  - Advanced coatings
  - Novel materials for gas separation
  - Advanced fuel cell materials