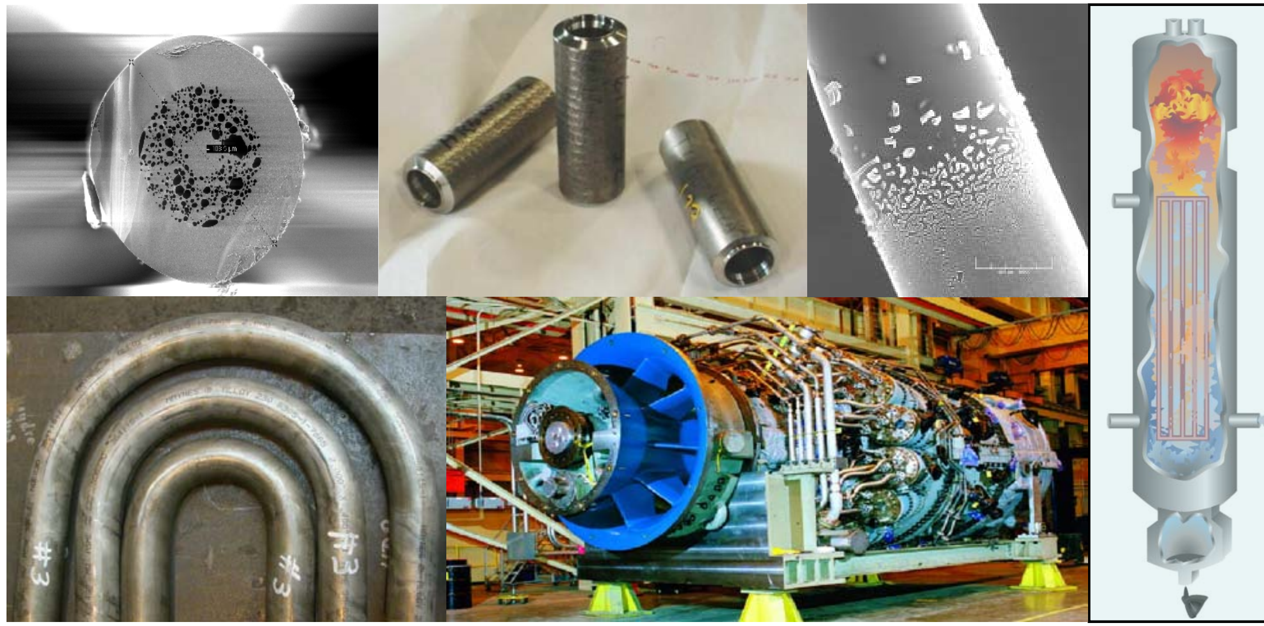
NATIONAL ENERGY TECHNOLOGY LABORATORY



24th Annual Fossil Energy Materials Conference

Robert R. Romanosky, Advanced Research Technology Manager

Pittsburgh, PA
May 25, 2010

DOE Office of Fossil Energy (FE) Advanced Power Systems Goals

- **2010:**
  - 45-50% Efficiency (HHV)
  - 99% SO_2 removal
  - NOx< 0.01 lb/MM Btu
  - 90% Hg removal
  - $1600 / kW ($2007)
- **2012: - Carbon Capture**
  - 90% CO_2 capture
  - <10% COE increase for IGCC
  - <30 % COE increase in PC
- **2015**
  - Multi-product capability
  - 60% efficiency (w/o CCS)

DOE FE programs:

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

FE Materials Program Goals

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

Advanced Research Materials Program

HIGH TEMPERATURE APPLICATIONS

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.

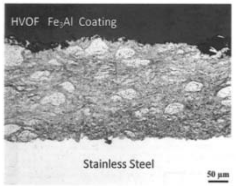
Breakthrough Materials

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

UltraSupercritical 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

Coatings and Protection of Materials



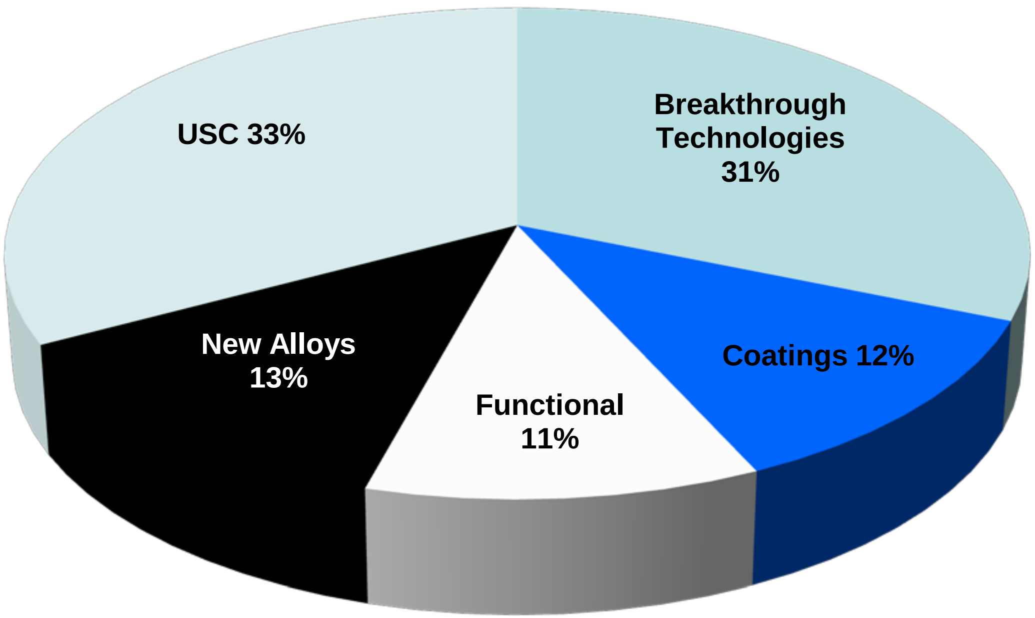
To develop the design, application, and performance criteria for coatings intended to protect materials from the high-temperature corrosive environments encountered in advanced fossil energy plants.

Functional Materials

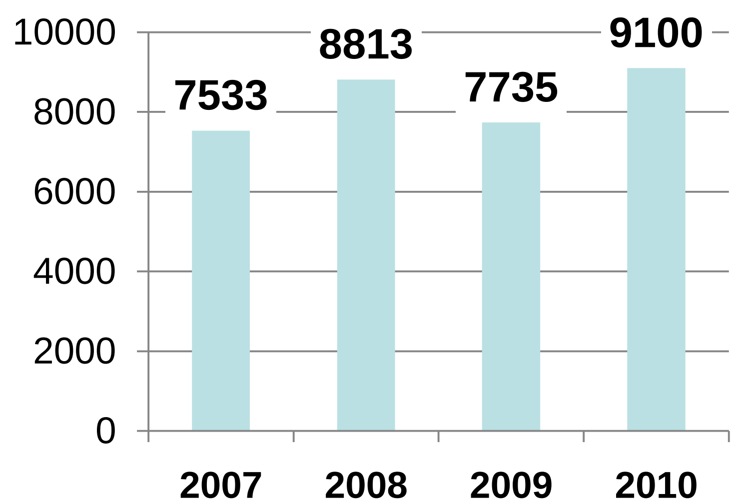
To understand the special requirements of materials intended to perform specific functions, such as energy storage systems.

Advanced Research Materials Program Funding Profile

FY10 Material Program



Annual Budget



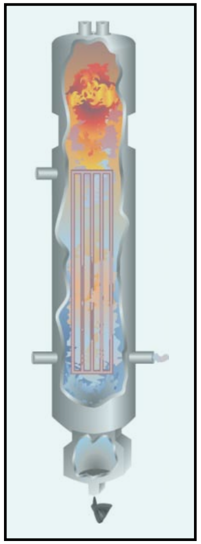
Projects by Organization

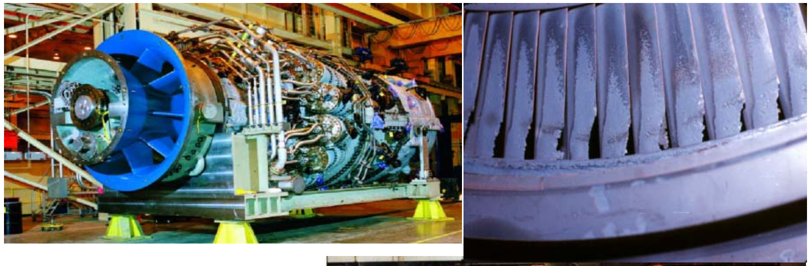
• Industry	*8*
• National Laboratories	*21*
Total Projects	*29*

Fossil Energy Key Material Research Areas

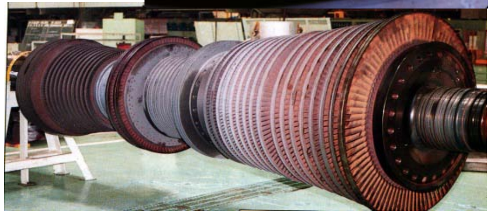
USC Boilers/Turbines

Gasifier

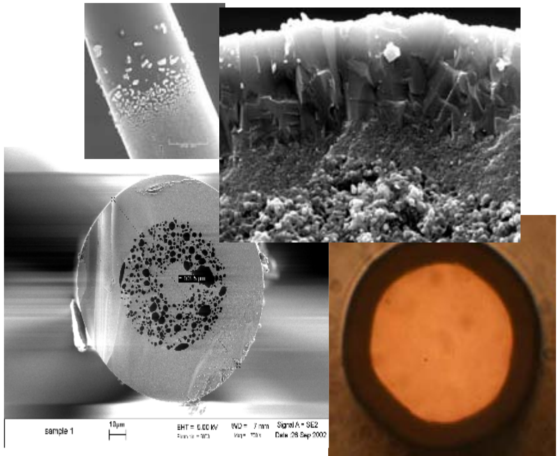




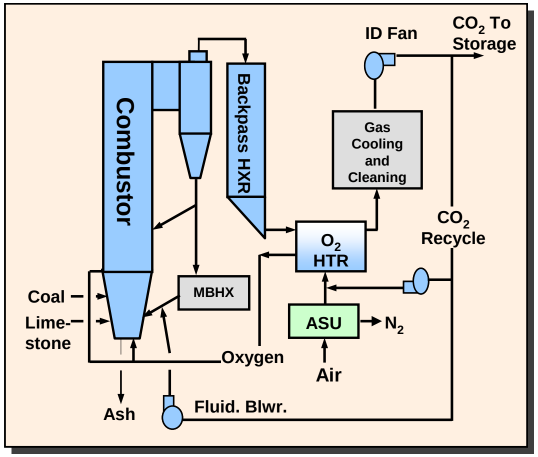
Advanced Turbines



Fuel Cells

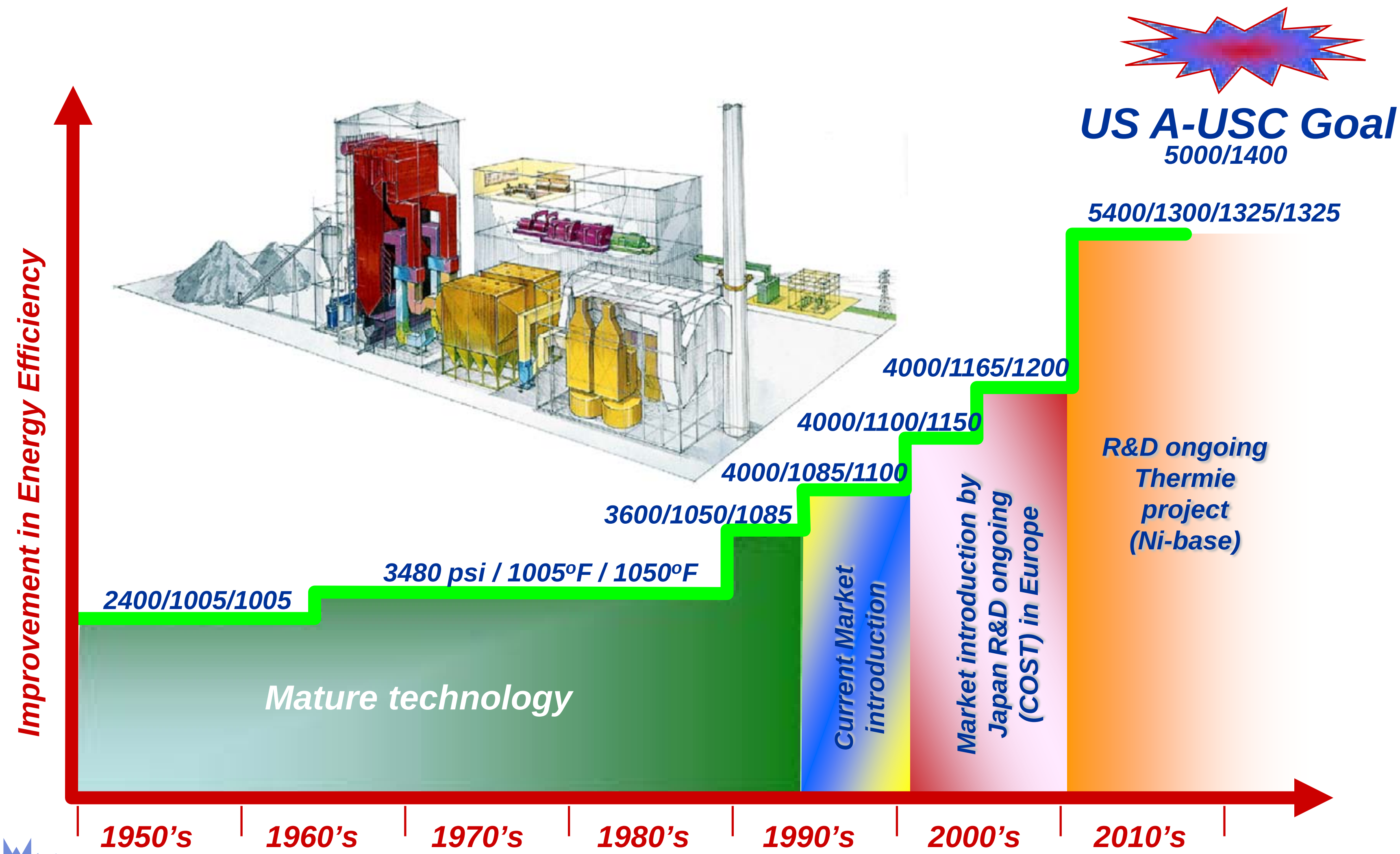


Sensors



Oxy-Firing

Evolution of Boiler Technology



Illustration/data: Alstom

US A-USC Materials Programs

- Identify and evaluate **advanced materials** that help achieve highly efficient, cost competitive, and environmentally acceptable pulverized coal combustion based electric power generation (A-USC)
  - Steam conditions of 760 C (1400 F) and 5000 psi
  - Plant efficiency increases to 45 -47%
- Primarily a Materials Technology Evaluation Program
  - Focus on **nickel-based alloys** including gamma prime (age-hardenable) strengthened alloys for highest temperature regions of the boiler and steam turbine
  - Develop fabrication and joining technology for new alloys
  - Continue research on stainless and ferritic steels for economy of new plant
- Unique Conditions for US Program
  - Higher-temperatures than European Program (760 C versus 700 C) means **different alloys** are being evaluated
  - High Cr Alloys and extensive testing of coatings and surface modification for **US coals**
  - Data for **ASME code** acceptance of new materials
  - Phase II Boiler work includes focus on **Oxycombustion**

Gasification Technology

Advanced Refractories for Gasifiers

Office of Research and Development

Enhancing reliability, performance, and on-line availability of gasification systems

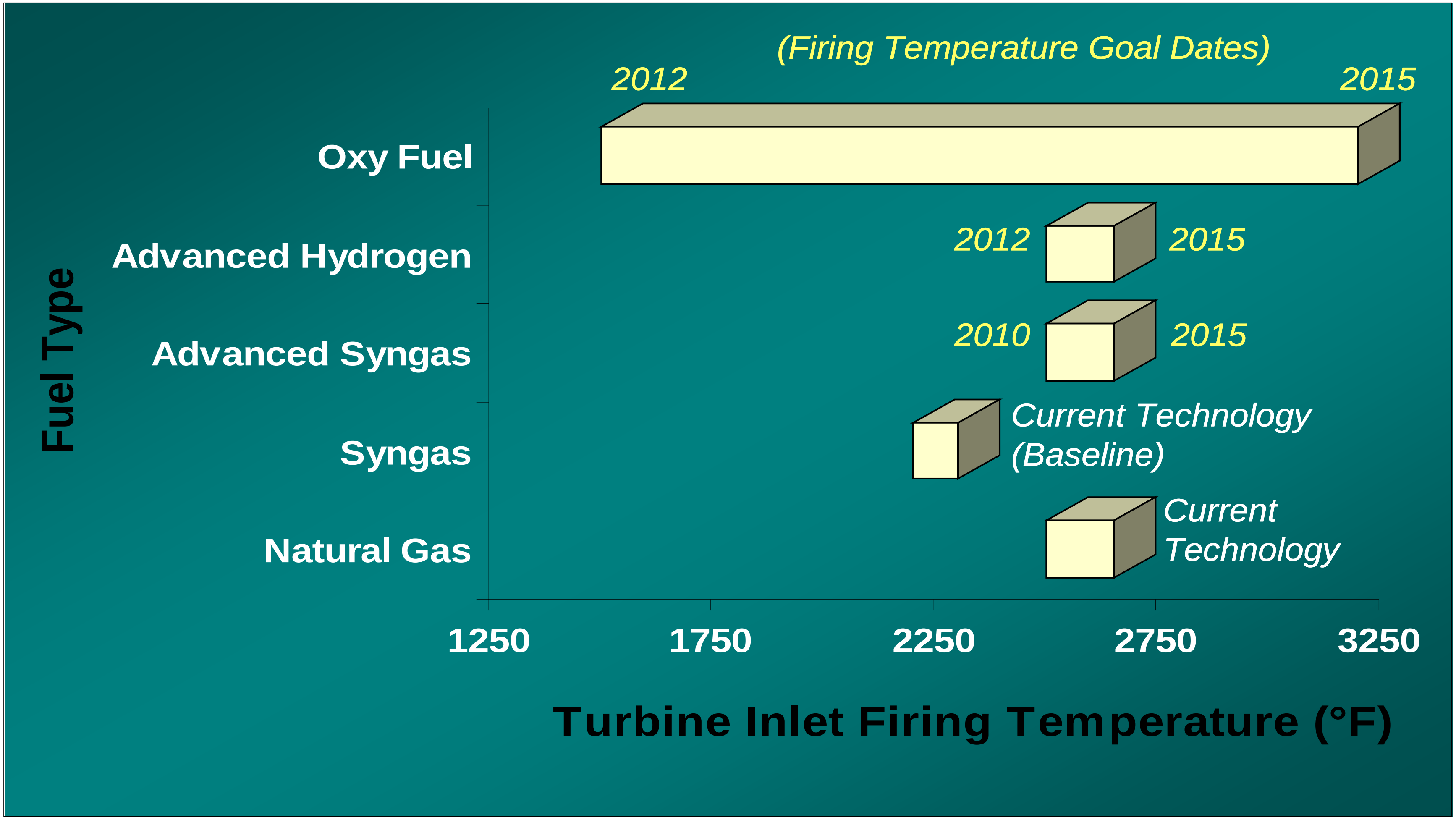
Project Objectives:

- Develop refractories with improved performance longer and predictable service life
- Develop refractories that are environmentally friendly and cost effective low/no chrome, minimize Cr+6 formation
- Develop refractories with carbon feedstock flexibility
  - model gasifier slag predict chemistry, viscosity, and phases formed
  - control slag/refractory interactions and slag viscosity
  - design slag to increase refractory service life
- Develop reliable sensors to accurately monitor gasification temperature

Failed refractory material

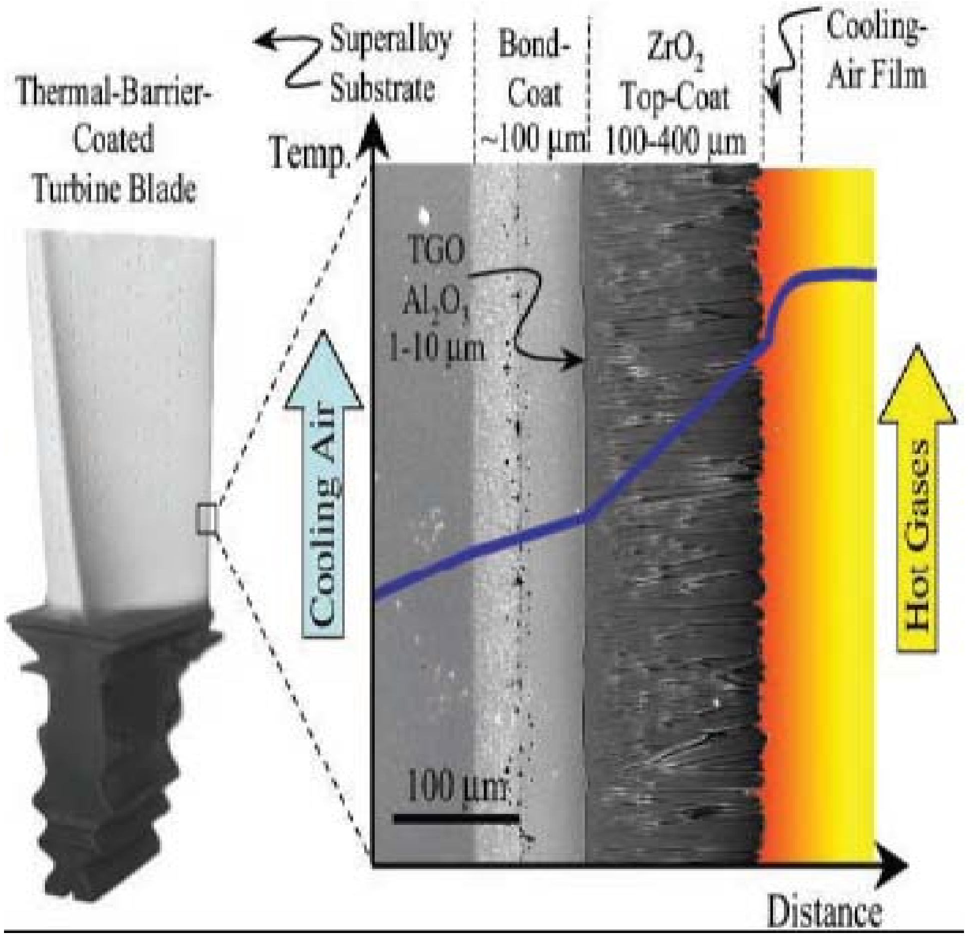
Failed thermocouple

Advanced Turbines Technology



Advanced Turbines Technology
Advanced Turbine Materials

- **Investigating the role of super alloy dopants on performance - ORNL**
- **Materials issues for innovative spare and shell turbine blade designs - ORNL**
- **Bond Coat Development (UPitt)**
- **Advanced APS TBC Development (UPitt)**
- **Diffusion Barrier Coating Development (UPitt)**
- **TBC Overlay Development (UPitt)**



Innovations for Existing Plants Technology
Advanced Flue Gas CO_2 Membranes

Membrane Advantages

- *Simple operation; no chemical reactions, no moving parts*
- *Tolerance to contaminants*
- *Compact, modular → small footprint*

Challenges

- *Low flue gas CO_2 partial pressure*
- *Particulate matter*
- *Cost reduction and device scale-up*
- *Power plant integration*

Current State: Small Pilot-scale

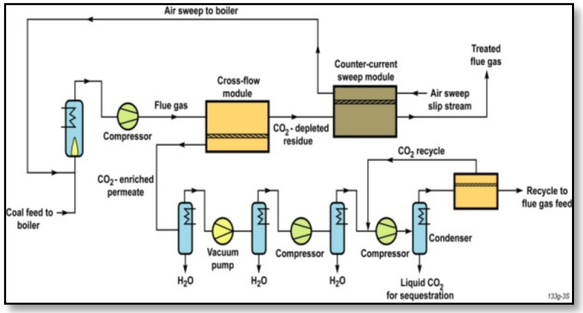
2011: Large Pilot Scale 1 – 5 Mwe

2015: Demonstration Scale

Advanced Membrane R&D Focus

- *High CO_2/N_2 selectivity & permeability*
- *Durability*
  - *- Chemically (SO_2), thermally*
  - *- Physically*
- *Membrane systems*
  - *- Process design critical*
- *Low cost*
  - *- Capital and energy penalty*

1 TPD CO_2 , 6 month test



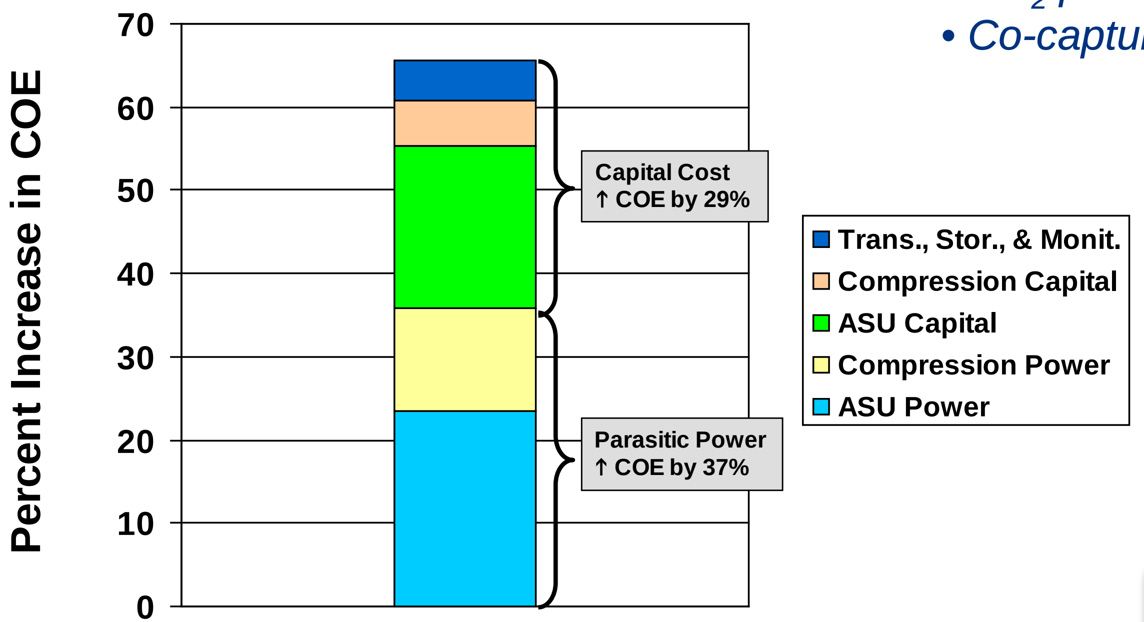
Innovations for Existing Plants
Pulverized Coal Oxy-combustion

Challenges

- *Cryogenic ASUs are capital and energy intensive*
- *Existing boiler air infiltration*
- *Corrosion and process control*
- *Excess O_2 and inerts (N_2, Ar) ↑ CO_2 purification cost*

Advanced Oxy-combustion R&D Focus

- *New oxyfuel boilers*
  - *Advanced materials and burners*
  - *Corrosion*
- *Retrofit existing air boilers*
  - *Air leakage, heat transfer, corrosion*
  - *Process control*
- *Low-cost oxygen*
- *CO_2 purification*
- *Co-capture (CO_2 + SOx, NOx, O_2)*



No-capture base = 6.4 cents/kWh

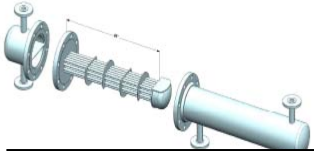
Laboratory to 5 MWe Pilot-scale

Partners (11 projects): Praxair, Air Products, Jupiter, Alstom, B&W, Foster Wheeler, REI, SRI

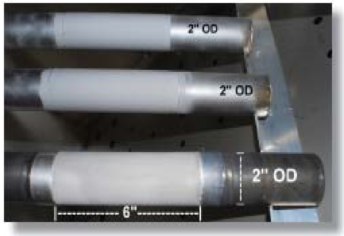
Fuels Technology

Membrane Development Status

- **Developers Achieving Targets**
- **Eltron tests under water-gas shift feed streams initiated; best alloy membrane has demonstrated a H_2 flux rate of 411 scfh/ft^2**
  - Lifetime testing reactor operated several tests to 600 hours; initial baseline membrane testing in H_2/N_2 feed streams show stable performance at 200 scfh/ft^2.
  - down-selected catalyst tested in streams with 20 ppm H_2S. Stable H_2 flux observed for 160 hours.
- **WPI achieved 359 scfh/ft^2 H_2 flux with 3-5 µm Pd/Inconel membrane at 442^{o}C and 100 psi ΔP.**
  - Built engineering-scale prototype membrane (2"OD, 6"length, 8.8 µm).
  - Total test 63 days at 450^{o}C, 15 psi ΔP, 80 scfh/ft^2 H_2 flux, 99.99% purity (calculates to 340 scfh/ft^2 H_2 flux)
- **UTRC tested five separators using PdCuTM alloy which showed increased surface stability in bench-scale tests**
  - Colloidal Pd/Nano Oxide membrane to show H_2 flux 400 scfh/ft^2
- **Unbiased verification testing (NETL)**



Prototype PDU Membrane Module Configuration

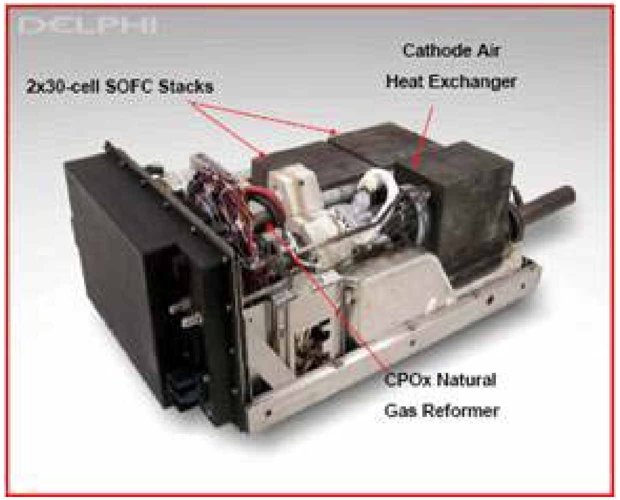


WPI Pd/Inconel H_2 Separation Membranes

United Technologies Research Center

Fuel Cells

- Extreme System Conditions
- Material Improvement Process
- Research Underway



a solid oxide fuel cell

a SOFC stack

Fuel Cell Materials

Extreme System Conditions

- **For SOFC cathodes extreme conditions are:**
  - high temperatures
  - large oxygen activity gradients
  - heterogeneous interfaces
  - complex dopant distributions
  - high electrical conductivity requirements
  - high transport current densities

- **Oxidant chamber operates:**
  - in the 650 to 850°C temperature range
  - requires a mechanically stable electrical path between the membrane walls that separate oxidant and fuel in the repeating cell units of the SOFC stack.

- **Material improvements process**
  - Faster kinetics for oxygen reduction to lower the irreversible losses for electrochemical charge transfer.
  - Stable surface chemistries are sought with active sites for dissociative adsorption of oxygen

- **Technical barriers**
  - Cathode performance correlated with oxide surface chemistry in high partial pressures of oxygen

What Does the Future Look Like?

- **The USA and the world will face great energy challenges with ever increasing environmental constraints**
- **Advanced fossil energy power systems will be needed**
- **The Advanced Research Materials Program is poised to have even greater impacts on future energy systems**
  - Novel materials for high temperature applications
  - Next generation ferritic steels with higher strength and better oxidation resistance
  - Advanced coatings
  - Computational materials design and lifetime prediction for extreme environments

Contact Information

Robert R. Romanosky

304-285-4721

robert.romanosky@netl.doe.gov

NETL

www.netl.doe.gov

Office of Fossil Energy

www.fe.doe.gov

Patricia Rawls

412-386-5882

patricia.rawls@netl.doe.gov