U.S. DEPARTMENT OF ENERGY

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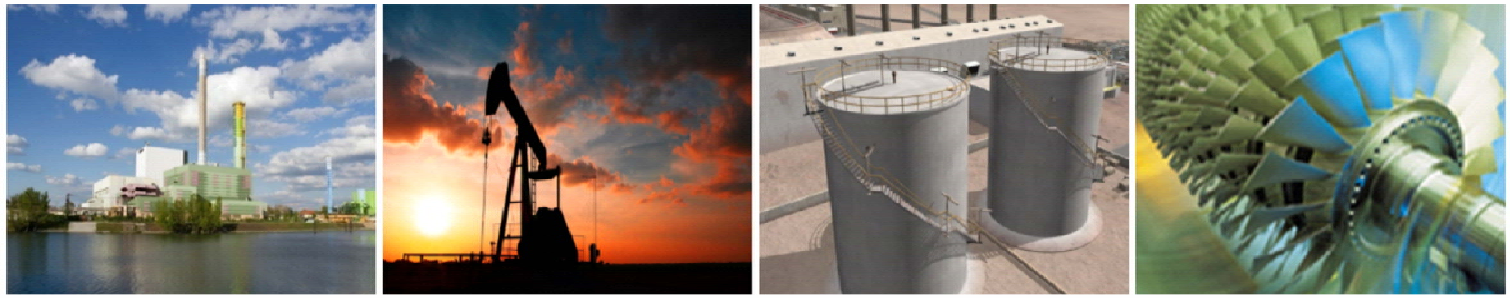


Advanced Energy Systems Program Overview

Regis Conrad

Division Director Advanced Energy Systems

Office of Coal and Carbon Management

March 2017

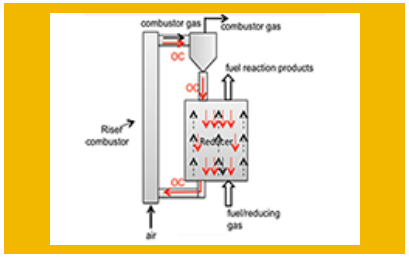
Crosscutting Review Meeting

Advanced Energy Systems

Fossil Energy | National Energy Technology Laboratory

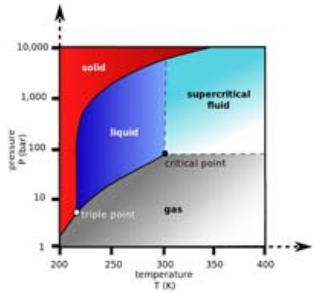
Program Research Areas

Gasification Systems

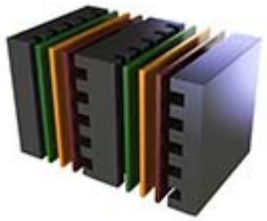


Advanced Combustion

Advanced Turbines



Supercritical CO_2



Solid Oxide Fuel Cells

Cross-cutting Research Program

- Sensors and Controls
- Computational Modeling
- Extreme Environment Materials
- Water Management
- Rare Earth Elements

Modularity

Modularity

The definition of “Modularity” is an integrated power system that uses coal or natural gas and capable of generating anywhere from kW’s up to 20 MW of power but also integrated to produce products such as heat and value added products. The program provides integrated technologies that can work off-grid and provide power, heat, other products, and employment for remote communities utilizing coal and natural gas at the source.

Modularity

Benefits

- Modular power plants can be created from **“building blocks”**
- **Pre-constructed** systems only need to be connected to other systems
- Smaller component size **simplifies transportation**

Challenges

- Limited size and operating conditions of products made via **Additive Manufacturing**; lack of designs using AM products
- **Modeling tools** are still in early development
- **Advanced technologies** need development (heat management, microwaves, biomass co-feeding, biological creation of hydrogen may be ideal for modular systems)

Advanced Turbines

Objectives

- Lower the cost of electricity from coal-based IGCC power generation with CCS
- Scale up technology from components to entire systems to improve efficiency and affordability

Strategies

- Improve technologies for higher gas turbine firing temperatures (combustion, materials, aero-heat transfer)
- New technologies using non-traditional working fluids (indirect and direct-fired supercritical CO_2)

Future Directions

- Pressure gain combustion
- 10 MW Supercritical CO_2 Transformational Electric Power (STEP) Facility

Supercritical CO_2 Program Objectives

Objectives

- Construct 10 MW Supercritical Transformational Electric Power (STEP) **pilot facility** to address technical issues, reduce risk, and mature the technology
- Develop **next-generation materials** and technologies and mature through STEP facility

1 meter sCO_2 (300 MWe)
(Brayton Cycle)

Strategies

- Develop necessary technologies via robust R&D program
- Leverage knowledge and expertise of the national labs, universities, and industry
- Demonstrate direct-fire with 50MW demonstration, with initial deployment on natural gas with CO_2 storage

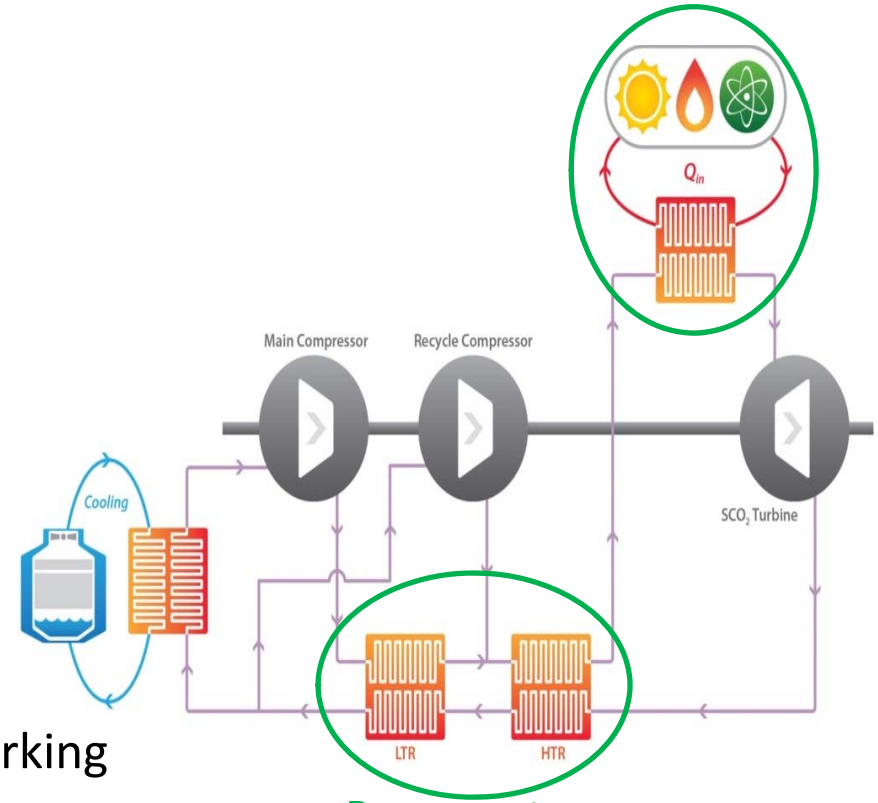
Benefits SCO2 Power Cycles

SCO2 Advantages:

- **Higher plant efficiency**
- **Synergistic with a wide spectrum of heat sources**
- **Single-phase working fluid**
- **Compact turbomachinery**
- **Low water consumption**
- **CO_2 is safe, available, and less corrosive**
- **Lower COE**
- **Current Status: TRL 3 – 4**

Advanced Combustion Systems Areas of R&D

Heat extraction – heat exchangers, boiler tubes



Recuperators

DOE FE Turbine program is working the R&D for turbines and compressors for this cycle

Solid Oxide Fuel Cells

Objectives

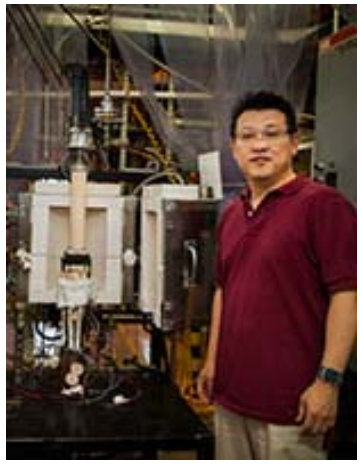
- Integrate coal gasification with efficient power production from coal to facilitate carbon capture
- Sponsor demonstration projects to accelerate the commercial readiness of components

Strategies

- Focus RD&D on supporting components to ensure reliability, long-term operation, and cost effectiveness.
- Develop innovative stack designs in the 5-10kWe scale.
- Develop specific targets to meet goals, such as:
  - System Performance Degradation: 0.2%/1,000 hours
  - System Cost: $900/kWe (Nth-of-a-Kind)

Future Directions

- kWe Power Prototype System Field Test
- 1 MWe-class Power System at customer site



DOE Fuel Cell Test Stack

Source: NETL

Supporting Technologies

- Sensors & controls
- Heat exchangers
- Blowers
- Power conditioning

Cross-cutting Research
Fuel Cell Program Mission

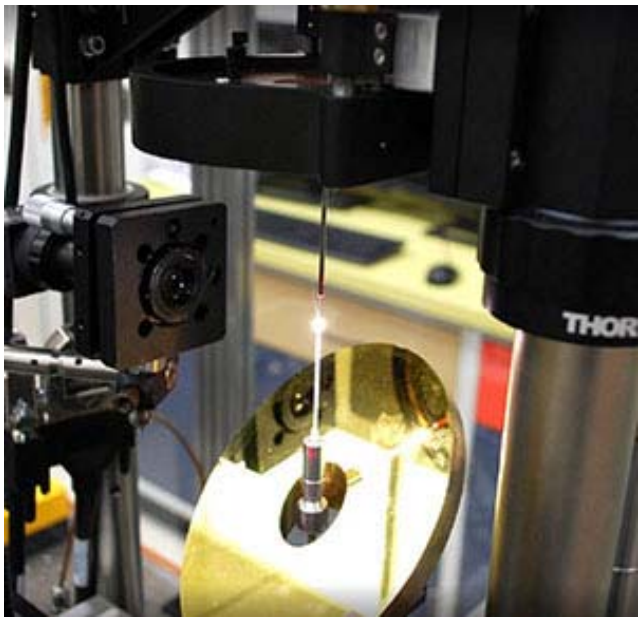
- To enable the generation of efficient, low-cost electricity with intrinsic carbon capture capabilities for:
  - Near term: Natural gas-based distributed generation
    - 100 kWe – 1 MWe
  - Long term: Coal and natural gas utility-scale applications with Carbon Capture and Sequestration (CCS)
    - 10 MWe – 50 MWe

Based on progressively larger natural gas-fueled validation tests, MWe-class DG SOFC Power Systems that are cost-competitive with existing DG technologies are envisioned circa 2020

Sensors & Controls Program

Objectives

- Develop sensors capable of taking measurements in high-temperature, high-pressure, and/or corrosive environments in a power system or underground injection system
- Enable distributed intelligence for decision making and optimization of plants



To monitor operations in the harsh environments of advanced power systems, NETL researchers fabricate sensors using single-crystal optical fibers that offer broader functional temperature ranges, increased durability, and reduced cost.

Plant Optimization

- Using sensors and controls to shift from the current preventive maintenance model to models based on the monitoring of the condition of the plant and scheduling maintenance around a more realistic need for shutdowns and repairs, would save millions of dollars in yearly unplanned shutdowns. This can only be accomplished with advanced sensing able to monitor the health of the power facility and control systems capable of discerning actionable information and utilizing this within novel control strategies.

Computational Modeling Program

Objectives

- Transform computationally intensive models into reduced-order, fast, user-enabled models for study, development, and validation
- Optimize data handling and exploit information technology to design advanced energy systems with carbon capture

IDAES

- Building on the capabilities developed under the CCSI, IDAES focuses on the use of advanced Process Systems Engineering (PSE) tools and approaches to support innovative conceptual design and process intensification while supporting technology maturation.

Cross-cutting Research: Materials

Materials R&D encompasses the spectrum of fundamental materials design for advanced ultra-supercritical steam and supercritical CO_2 (sCO_2) environments through qualification of functional materials that support the next generation of advanced power generation. New computational techniques will continue to be developed to design materials that are needed for advanced combustion, fuel cells, turbines and gasification systems. This computational work decreases the time and cost to develop the new materials and is projected to lead to classes of improved high performance materials.

- **Extreme Environment Materials (EEM)**
- **High Performance Computing for Materials (HPC4-materials)**

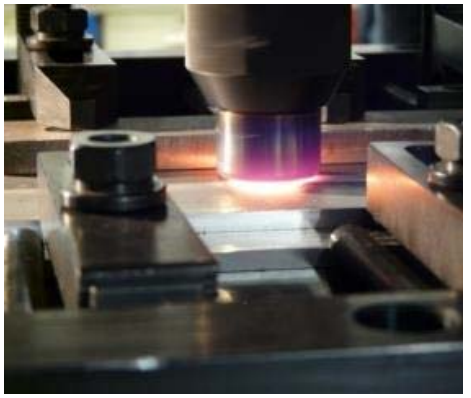
Extreme Environment Materials (EEM)

- Emerging extreme environment materials (EEMs) are new classes of alloys and ceramics that are not yet commercially available and will require significant research and discovery in terms of their potential, and which by their very nature may impact applications in many transformational power generation technologies

Extreme Environment Materials Program

Objectives

- Develop high-performance structural and functional materials that are lower cost, endure extreme environments, offer long service (>100,000 h), and can adapt to large components
- Reduce the cycle time, cost, and failure rate of advanced materials development by a factor of ≥2



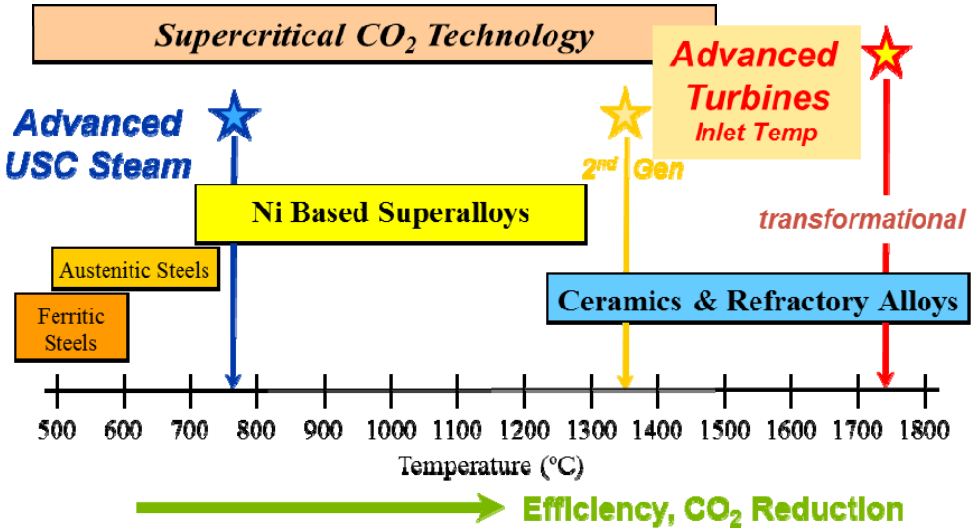
Strategies

- Develop multi-scale computational models to link atomic-scale phenomena with microstructural evolution, manufacturing, and materials performance.
- Use integrated High Performance Computing in materials design
- Integrate long-term predictive behavior tools with smarter, more efficient experimental techniques; run targeted validation experiments
- Develop data analytics to leverage data and knowledge

Extreme Environment Materials Program (cont'd)

Opportunities

- New-phase stable alloys
- Manufacturing of alloys, materials systems, and components
- Build on successes in integrated computational materials engineering (ICME) environments



Challenges

- New high-temp structural alloy development and commercialization is time consuming and expensive: >10 years and multi-million $ for a single alloy:
  - Long-term mechanical properties are sensitive to tiny variations in composition
  - Long life requirements can only be evaluated via long-duration creep tests
  - Early experimental indicators of long-term creep behavior not yet demonstrated
  - Computational materials design/experimental methods do not yet assess service life

Cross-cutting Research: Materials

The Emerging EEMs Program consists of five major focus areas:

- High Entropy Alloys
- Ni_2AlTi Strengthened Iron Based Alloys
- Next-Generation High-Strength Ductile Superalloys
- Gamma Prime Strengthened Cobalt Alloys
- High Yield Strength Austenitic Stainless Steels for High Temperature Power Plant Service

Cross-cutting Research: Materials

High Performance Computing for Materials (HPC4-materials)

Objective – Accelerate the pace of deployment of new materials by giving industry better access to National Lab technology and expertise.

Scope – Focus will be on materials for the energy space including severe environment structural materials, cladding materials, environmental barrier materials, process materials such as sorbents and catalysts, other.

Cross-cutting Research: Materials

HPC 4 Materials - Provide industry access to:

- Computational techniques for highly dissimilar mixed materials at high temperatures
- Computational Methods to Design Improved materials for severe environments (new alloys, improve existing, MGI approaches)
  - >750°C, pressure >200 bar
  - Oxidation and other chemical attack
  - Neutron and other bombardment
- Improved DFT and CALPHAD predictions
- Big data analysis and high speed data management with real time interpretation
- Multi scale, multi-physics, prediction model to allow rapid assessment of scale dependent material properties
- Linkage with HPC4Mfg for integration of new materials into a manufacturing process.

Water Management Program

Objective

- Support sustainability and improved water efficiency by focusing on:
  - Treatment and use of non-traditional water
  - Water-efficient cooling
  - Data modeling and analysis

Strategies

- Field test technologies and processes for treating water produced by injection of CO_2 in deep saline aquifers
- Explore water-limited cooling and innovative multi-stage filtration technologies
- Use data modeling and analysis to compile existing water availability data for regional analysis

Source: LBNL

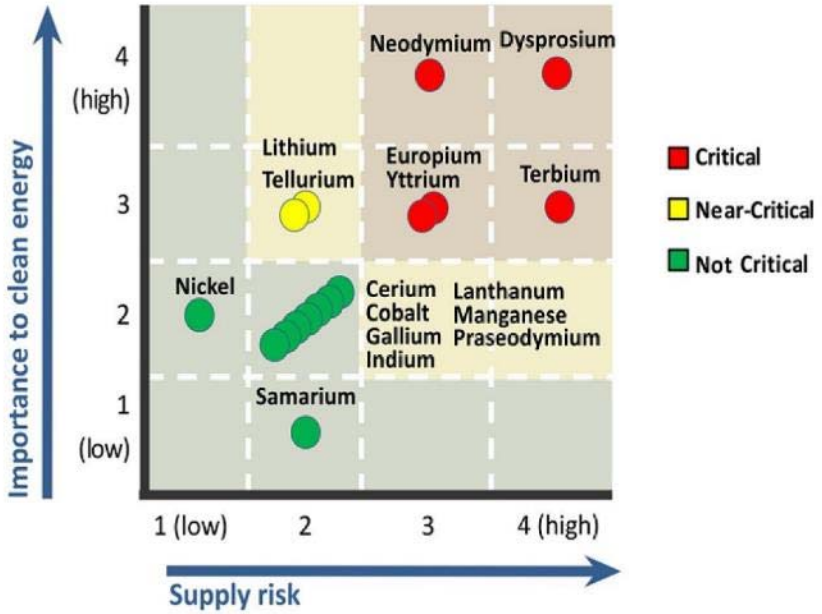
Water Research Opportunities

- **Water Treatment and Reuse**
  - Economic pathways to zero liquid discharge
  - Treatment of high TDS waters (for greater water reuse)
- **Advanced / Novel Heat Transfer and Cooling Systems**
  - Wet, dry, hybrid
  - Incremental and step change improvements
  - Advanced manufacturing of recuperators for combustion turbines
- **Process Efficiency and Heat Utilization:**
  - Pathways to produce more power per unit of water withdrawn, consumed, and treated
  - Utilization of low-grade heat
  - Bottoming cycles
- **Data, Modeling, and Analysis**
  - Develop a *National Water Atlas*
  - Tools to enable regional and plant decision making
- **Breakthrough or Out of the Box**
  - Low / No water FE-based systems, distributed generation, grid upgrades

Rare Earth Elements Program

Objective

- Support economic production of rare earth elements from coal and coal byproducts from U.S. coal fields



Strategies

- Identify highest rare earth content materials in the U.S. coal value chain
- Develop ore-specific plant designs for these materials
- Project business case for rare earth production from these materials
- Engage U.S. technical resources, including industry and academia

Future Directions

- Expand search via high rare earth assays
- Scope pilot-scale operations

Advanced Energy Systems

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Program Research Areas

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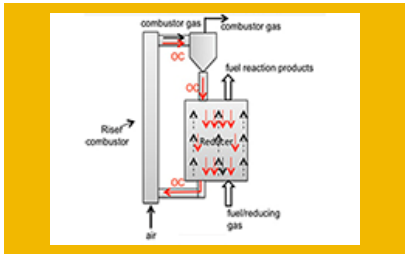

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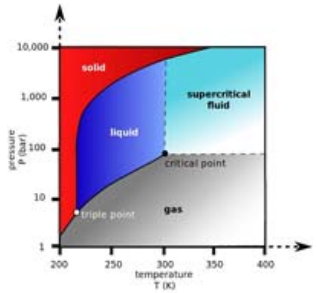

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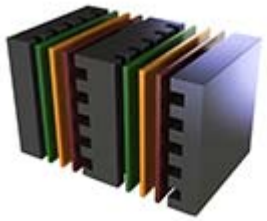

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Thank You