Regis K. Conrad
Director, Division of Cross-cutting Research
Office of Clean Coal
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Many energy & environmental challenges face the world

- Increasing energy demand (2-3x increase)
- Water scarcity
- Pollution reduction
- Greenhouse gas emission reduction
- Climate change and arctic impacts
We live in a time of energy abundance

We’re #1!
- In Oil and Gas production
- In Innovation

We’re #2!
- In Coal production & use
- In GHG emissions

We’re top 10
- In renewable loading
- In uranium production

*Once in a generation opportunity to build*
Outline

• Cross-cutting Research Program
  o Sensors and Controls
  o Materials
  o Computational Modeling
  o University Training
  o Water Management

• Advanced Energy Systems Program
  o Gasification & Fuels
  o Solid Oxide Fuel Cells
  o Hydrogen Turbines
  o Advanced Combustion
Crosscutting Research
Crosscutting Research Program

Is an applied research effort with a multidisciplinary approach aimed at addressing barriers to clean fossil energy-based power generation and fosters breakthrough concepts that offer the potential to result in a step-change improvement over current technology.

Bridging the gap between fundamental research and applied development

Our mission space is bound by investments in innovative sensor and control technology, advanced materials, revolutionary modeling and simulation tools, university training and research and other novel concepts.
Crosscutting Research
Sensors & Controls

Transformational Development
For Online Monitoring
and Process Control

Advanced Sensing
Harsh environment sensing concepts and approaches for low cost dense distribution of sensors

Distributed Intelligence
Computationally driven approaches for novel control architectures and logic, information generation, sensor networking & placement
Crosscutting Research

Materials

- New materials are essential for advanced power generation systems with carbon capture and storage capability to achieve performance, efficiency, and cost goals.

- Materials of interest are those that enable components and equipment to perform in the harsh environments of an advanced power system.
Additive manufacturing has arrived

50% less time; up to 90% less material; small supply chains

Projection Microstereolithography

Direct Ink Writing

Electrophoretic Deposition

Laser sintering and net shaping
Crosscutting Research

Computational Energy Sciences

The development of science-based models of the physical phenomenon occurring in fossil fuel conversion processes and multiscale, multiphysics simulation capabilities that couple fluid flow, heat and mass transfer, and complex chemical reactions for optimizing the design and operation of critical unit processes.

**Carbon Capture Simulation Initiative (CCSI)** is charged with developing integrated multiscale physics-based simulations of post-combustion capture processes.
Crosscutting Research

*Computational System Dynamics*

The development of dynamic computation, simulation, and modeling tools aimed at the optimization of plant design and shortening of developmental timelines.

**National Risk Assessment Partnership** (NRAP) is charged with developing a defensible, science-based quantitative methodology for determining risk profiles (and, hence, residual risk) at CO₂ storage sites.
Crosscutting Research

University Training & Research

Supports science and engineering education at major universities (University Coal Research) and in minority colleges (Historically Black Colleges and Universities and Other Minority Institutions) to improve the understanding of chemical and physical processes involved in the conversion and utilization of coal in an environmentally acceptable manner; maintain and upgrade the coal research capabilities and facilities.
Crosscutting Research
Water Management

Advanced Materials
- Nano-enhanced Fluids
- Temp. and Pressure Tolerance
- Scaling/Fouling Resistance
- Boundary Layer Minimization
- Membranes

Waste Heat Recovery
- Thermoelectric Materials
- Supercritical CO₂ RCBC
- Advanced Heat Exchangers

Powerplant Cooling
- Hybrid Wet/Dry Systems
- Air Cooling Cost Reductions
- Recirculating Non-traditional waters
- Nanofiltration of Blowdown

Process Efficiency
- Advanced Carbon Capture
- Bioenergy Feedstocks
- Industrial Water Usage
- Appliances
- Biorefineries
Advanced Energy Systems
Integrated Fossil Energy Solutions

Advanced Combustion
- Pressurized
- O₂ membrane
- Chemical looping
- USC Materials

Advanced Energy Systems
- Gasification
- Turbines
- Supercritical CO₂
- Direct Power Extraction

Efficiencies > 45%
↓ Capital Cost by 50%
$40/tonne CO₂ Captured
Near-zero GHGs
Near-zero criteria pollutants
Near-zero water usage

Advanced CO₂ Capture and Compression
- Solvents
- Sorbents
- Membranes
- Hybrid
- Process Intensification
- Cryogenic Capture

CO₂ Storage
- Carbon Utilization (EOR)
- Infrastructure (RCSPs)
- Geological Storage
- Monitoring, Verification and Accounting
The AES program consists of four Technology Areas. Each of these Technology Areas is further subdivided into key technologies:

- Research focused on the continued development of oxy-combustion technologies.
- Research focused on developing low-cost, highly efficient, solid oxide fuel cell (SOFC) power systems that are capable of simultaneously producing electric power from coal with carbon capture when integrated with coal gasification.
- Research to convert coal to make fuels, chemicals, and power with significantly reduced plant capital costs and increased plant availability, while maintaining environmental excellence.
- Research focused on developing advanced technology for the integral electricity-generating component for clean energy plants fueled with coal by providing advanced turbines, supercritical carbon dioxide (CO₂)-based power cycles, and advanced steam turbines.
Gasification Technology Roadmap

R&D Timelines

**GASIFICATION SYSTEMS RESEARCH TIMELINE**

<table>
<thead>
<tr>
<th>KEY TECHNOLOGIES</th>
<th>PROGRAM TARGETS</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Systems</td>
<td>$15/tonne Contribution of 2nd-Generation Technologies to the Cost Target for CO₂ Removal in CCS Systems (&lt;$40/tonne)</td>
<td>Advanced Oxygen Production</td>
<td>Low-Rank Coal Feed Systems</td>
<td>Advanced O₂ - H₂ Turbine Integration</td>
<td>Fuel System Optimization</td>
</tr>
<tr>
<td>Gasifier Optimization and Plant Supporting Systems</td>
<td>$15/tonne Additional Contribution (Beyond 2nd Gen.) of Transformational Technologies to the Cost Target for CO₂ Removal in CCS Systems (&lt;$10/tonne)</td>
<td>Advanced Syngas Cooler Technology</td>
<td>RAM Improvements</td>
<td>RAM Improvements</td>
<td>Novel Syngas Production Technologies</td>
</tr>
<tr>
<td>Syngas Processing Systems</td>
<td></td>
<td>Near-Zero Emission Syngas Cleaning</td>
<td>H₂ Membranes</td>
<td>Novel Syngas H₂ Enrichment</td>
<td>Advanced Syngas Conversion Technology</td>
</tr>
</tbody>
</table>

**Notes:**
- TRL: Technical Readiness Level
- TRL 2-4: Applied Research
- TRL 5-6: Development
- TRL 7-9: Large-Scale Testing

**Source:** U.S. Department of Energy, Fossil Energy
Coal & Fuels

Program Objective

- Enable cost competitive U.S. production of ultra-clean liquid transportation fuels from domestic coal or coal-biomass blends
  - At or below life-cycle GHG emissions from conventional petroleum
  - Zero-sulfur diesel (neat or as blendstock)

- Consider hybrid configurations
  - Liquid fuels and power/chemicals co-production
  - DCL and Gasification - FT fuel and/or power and/or hydrogen production
SOFC power systems, which have the potential to achieve greater than 60 percent efficiency, will produce less CO₂ per unit of electricity, reducing the amount of CO₂ that has to be captured. Carbon capture is easily facilitated as the anode (fuel) and cathode (air) streams are separated by the electrolyte; all carbon enters the SOFC with the fuel on the anode side and exits in the anode off-gas as CO₂.
SOFC Program Timeline

- Improved electrochemical performance
- Increased power density
- Reduced long-term degradation rates
- Improved mechanical integrity
- Reduced material cost
- Cell-stack integration and scale-up

R & D

- Technologies critical to commercialization

Demonstrations

- Stack Building Block >20 kW
- System Module ~60 kW
- POC >125 kWe
- 250 kW to MWe-Class
- NGFC/IGFC Commercial Scale
SOFC Program Technology Progress

- **Core R&D 1st Industry Teams**
  - Natural Gas 5 kWe modules
  - TRL 2 - 4

- **Successful Prototype Test**
  - Coal-based Industry Teams
  - TRL 5 - 7

- **10 kWe Stack Test**
  - $\eta = 35 - 41\%$
  - <2%/1000 hr degradation
  - Cost target at high volume achieved (extrapolated)

- **60 kWe Stack Test**
  - $\eta = 64\%$
  - <1%/1000 hr degradation

- **>125 kWe Proof of Concept Module (Planned)**
  - TRL 7 - 9

- **MWe-Class (Planned)**
Hydrogen Turbines Program
Turbines Program Goals

• Efficiency
  – 3 - 5 % points by 2015 above the baseline
  – 4 % points improvement (14 % above baseline) in overall IGCC plant efficiency with CCS

• Cost Reduction
  – 20 – 30 % reduction in CC capital cost
  – 25 % reduction in COE for IGCC w/ CCS

• Emissions
  – Turbine NOx emissions in single digits (@15 % O2)
  – IGCC plant optimized for firing temperature with 2 ppm NOx at the stack

Technologies Developed under the Turbines Program can:
  Improve Efficiencies and Reduce CO2 Emissions across Multiple Fuel Types, Including Syngas and Natural Gas
Targeted R&D Areas for H₂ Turbines

**Turbine**
Improved aerodynamics, longer airfoils for a larger annulus / higher mass flow and improved internal cooling designs to minimize cooling flows while at higher temperatures.

**Combustor**
Combustion of hydrogen fuels with single digit NOx, no flashback and minimal combustion instability.

**Compressor**
Improved compressor efficiency through three dimensional aero dynamics for higher pressure ratio.

**Exhaust Diffuser**
Improved diffuser designs for higher temperature exhaust, lower pressure drop with increased mass flow.

**Materials**
Improved TBC, bond coats and base alloys for higher heat flux, thermal cycling and aggressive conditions (erosion, corrosion and deposition) in IGCC applications.

**Rotor**
Increase rotor torque for higher power output and the potential for lowering capital cost ($/kW).

**Leakage**
Reduced leakage at tip and wall interface and reduced recirculation at nozzle/rotating airfoil interface for higher turbine efficiency and less purge.
Advanced Combustion Systems
Advanced Combustion Systems Program

Advanced Energy Systems

Technology Areas
- Gasification Systems
- Advanced Combustion Systems
- Advanced Turbines
- Solid Oxide Fuel Cells

Key Technologies
- Oxy-Combustion
- Chemical Looping Combustion

Research Focus
- Atmospheric Pressure Oxy-Combustion
- Pressurized Oxy-Combustion
- O₂ Membrane Advanced Power System
- Chemical Looping Combustion
- A-USC Oxy-Combustion Materials
- Integrated High-Temperature/Pressure Combustion System Materials

Coordinated with Crosscutting Research Technology Area
Advanced Combustion Systems Program

OXY-COMBUSTION SYSTEM COMPONENTS

**1**St-Generation Technology
Atmospheric Pressure Oxy-Combustion
- Cryogenic ASU
- Conventional Boiler
- CO₂ Recycle
- Supercritical Steam
- Conventional Purification
- Conventional Compression

**2**Nd-Generation Technology
Atmospheric Pressure Oxy-Combustion
- Advanced Cryogenic ASU
- Advanced Oxy-Boiler
- Advanced Ultra-Supercritical Steam
- Advanced Purification
- Advanced Compression

**Transformational Technologies**

**Pressurized Oxy-Combustion**
- Advanced Cryogenic ASU or O₂ Membrane
- High-Pressure Combustor
- Advanced Ultra-Supercritical Steam Conditions
- Supercritical CO₂ Power Cycle
- Advanced Purification
- Advanced Compression

**OTM Power Cycle**
- Natural Gas OTM Reformer
- OTM Partial Oxidizer
- OTM Boiler
- Advanced Ultra-Supercritical Steam Conditions
- Advanced Purification
- Advanced Compression

Focus on Transformational Technologies
Questions ?