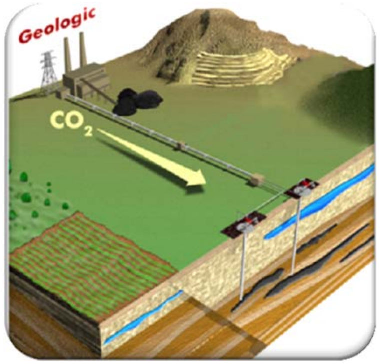

Department of Energy
Office of Fossil Energy
Overview of Crosscutting Research and Advanced Energy Systems

Regis K. Conrad

Director, Division of Cross-cutting Research

Office of Clean Coal

April 2014

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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!

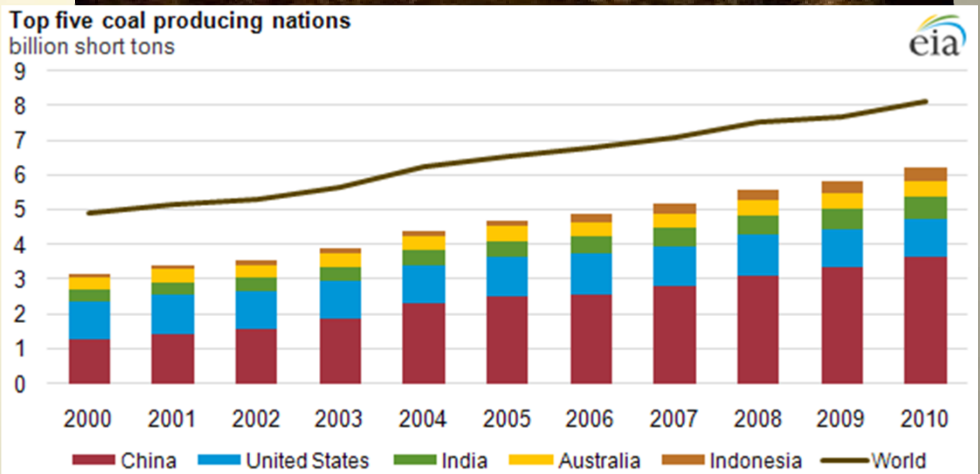
- In Oil and Gas production
- In Innovation

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

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Outline

- Cross-cutting Research Program
    - Sensors and Controls
    - Materials
    - Computational Modeling
    - University Training
    - Water Management
- Advanced Energy Systems Program
    - Gasification & Fuels
    - Solid Oxide Fuel Cells
    - Hydrogen Turbines
    - Advanced Combustion

Crosscutting Research

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Crosscutting Research Program

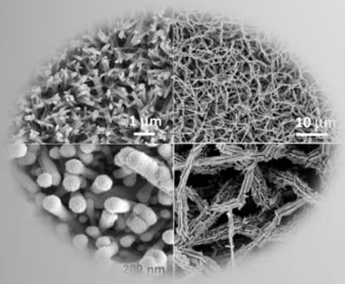
Is an applied research effort with a multidisciplinary approach aimed at addressing barriers to clean fossil energy-based power generation and fosters breakthrough concepts that offer the potential to result in a step-change improvement over current technology.

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

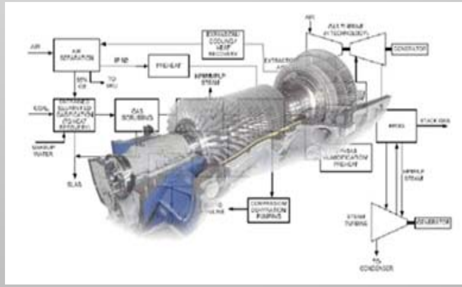
Sensors & Controls

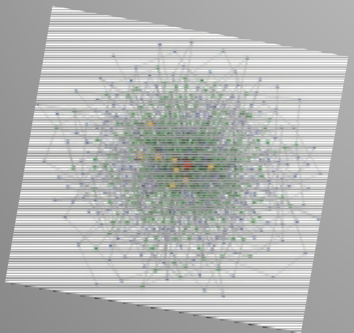


Transformational Development
For On line Monitoring
and Process Control

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

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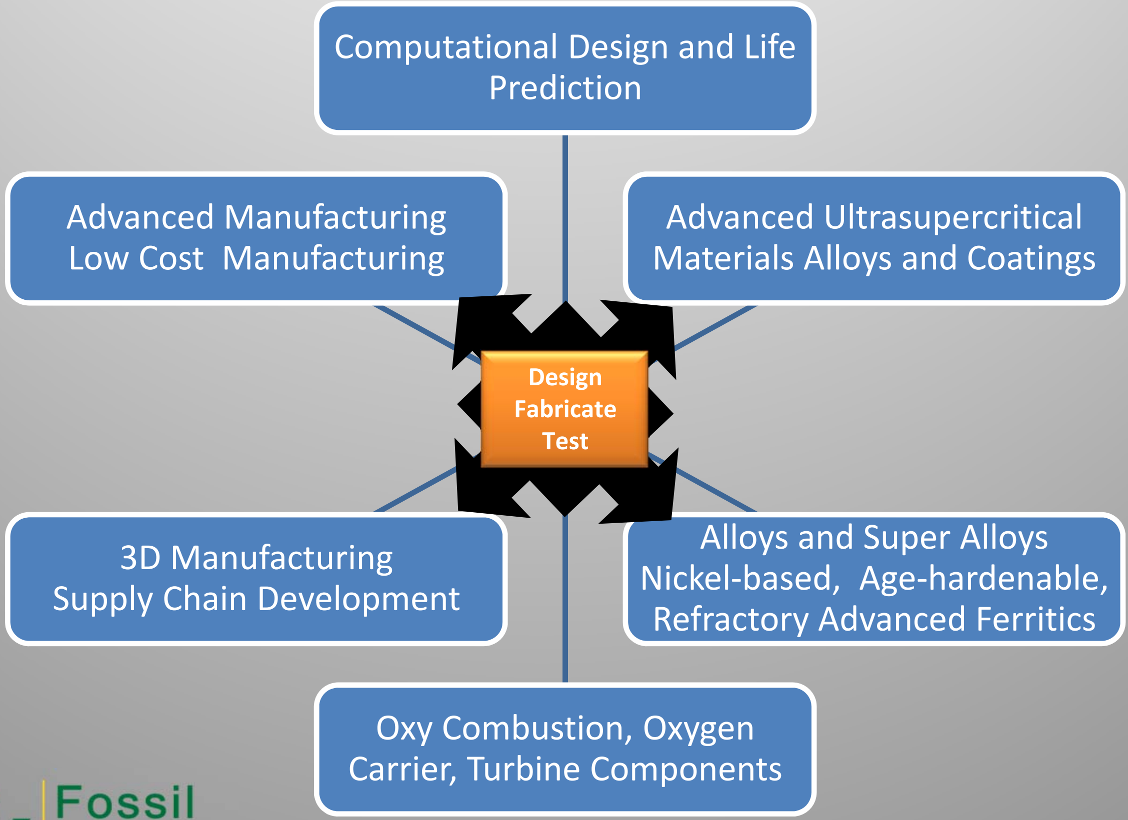
Crosscutting Research

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.



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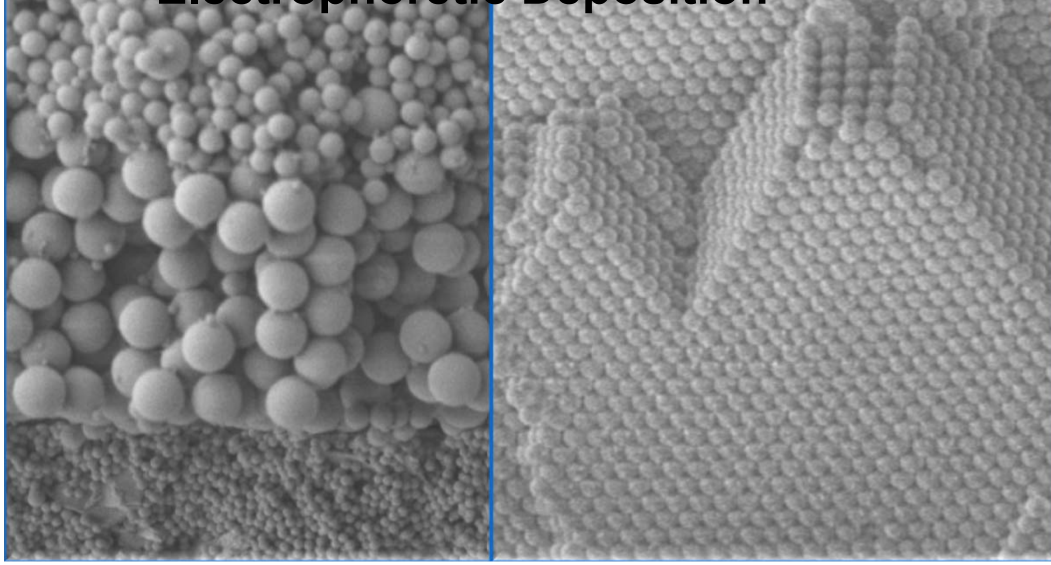
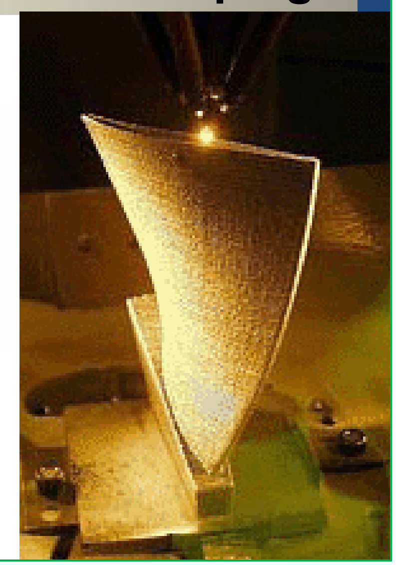
Additive manufacturing has arrived

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



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.

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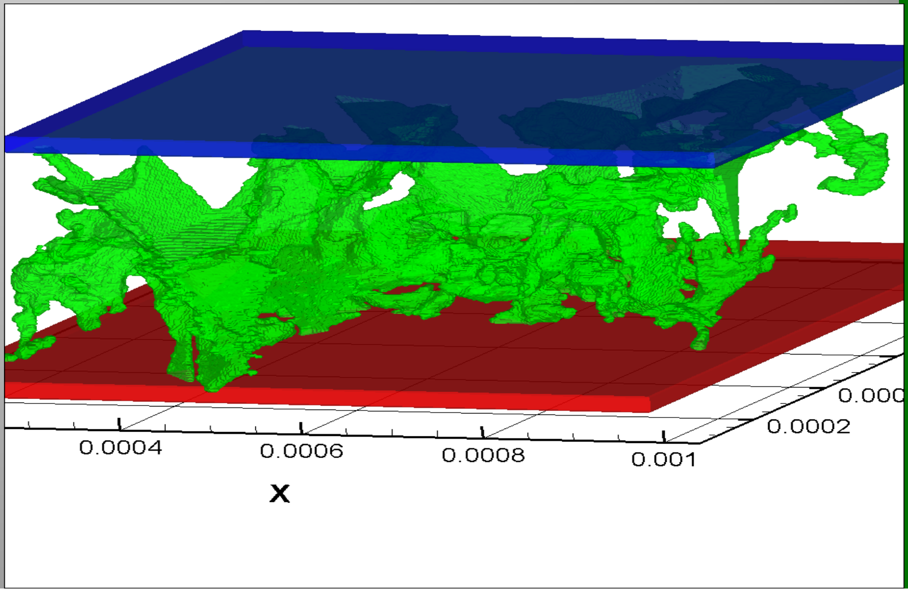
Crosscutting Research

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 CO_2 storage sites.



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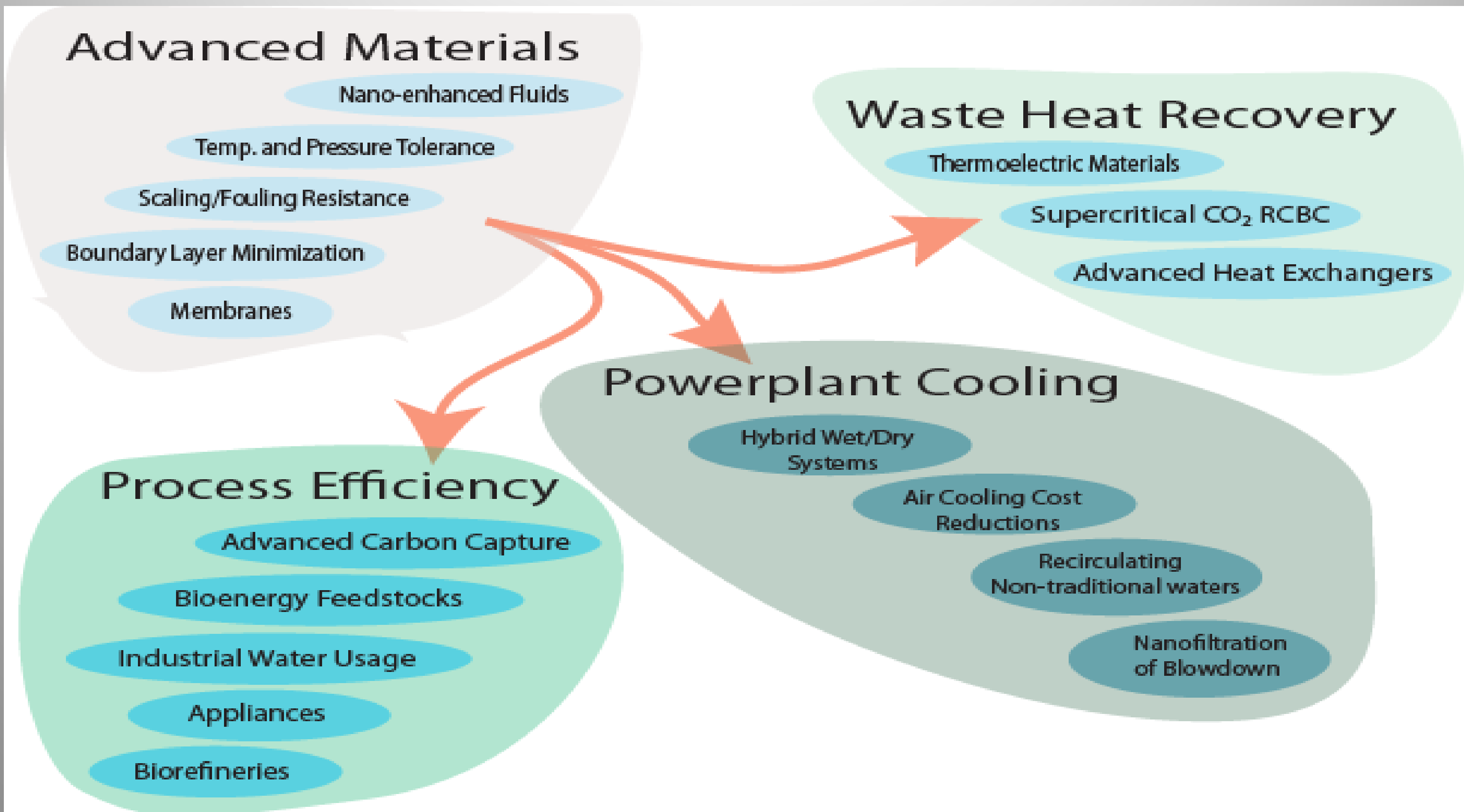
Crosscutting Research

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



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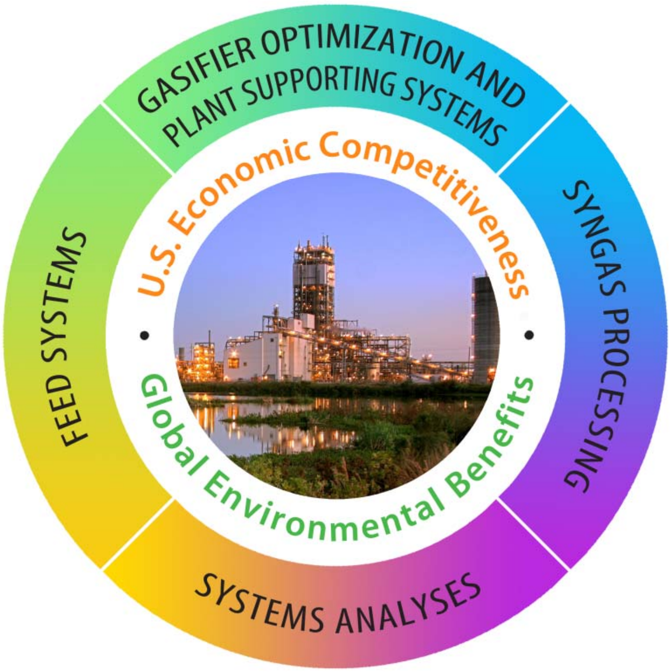

Advanced Energy Systems

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Integrated Fossil Energy Solutions

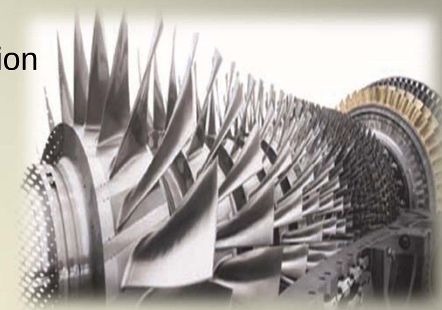
Advanced Combustion

5 MWE Oxycombustion Pilot

- ❑ Pressurized
- ❑ O_2 membrane
- ❑ Chemical looping
- ❑ USC Materials

Advanced Energy Systems

- ❑ Gasification
- ❑ Turbines
- ❑ Supercritical CO_2
- ❑ Direct Power Extraction



Advanced Turbines

Efficiencies > 45%

↓ Capital Cost by 50%

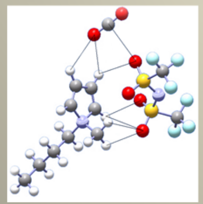
\$40/tonne CO_2 Captured

Near-zero GHGs

Near-zero criteria pollutants

Near-zero water usage

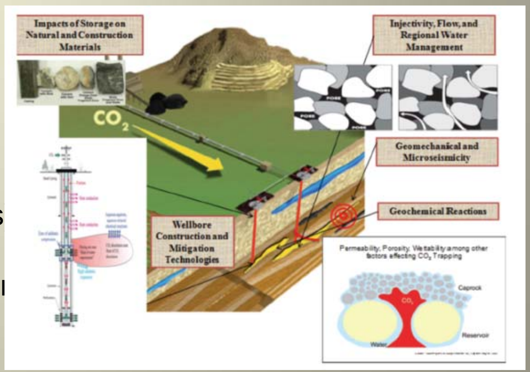
Advanced CO_2 Capture and Compression



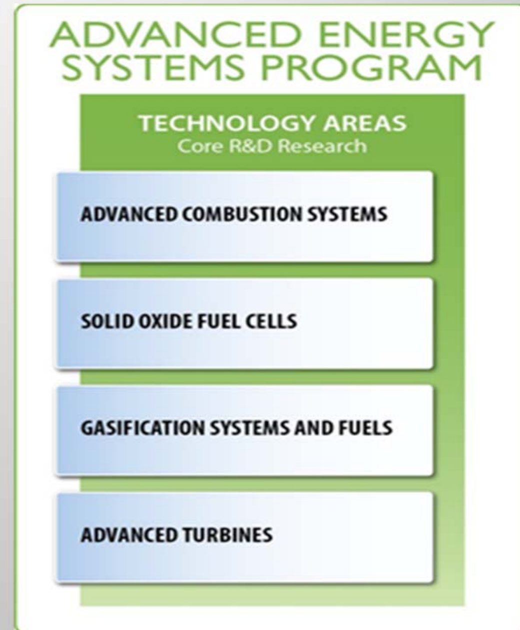
- ❑ Solvents
- ❑ Sorbents
- ❑ Membranes
- ❑ Hybrid
- ❑ Process Intensification
- ❑ Cryogenic Capture

CO_2 Storage

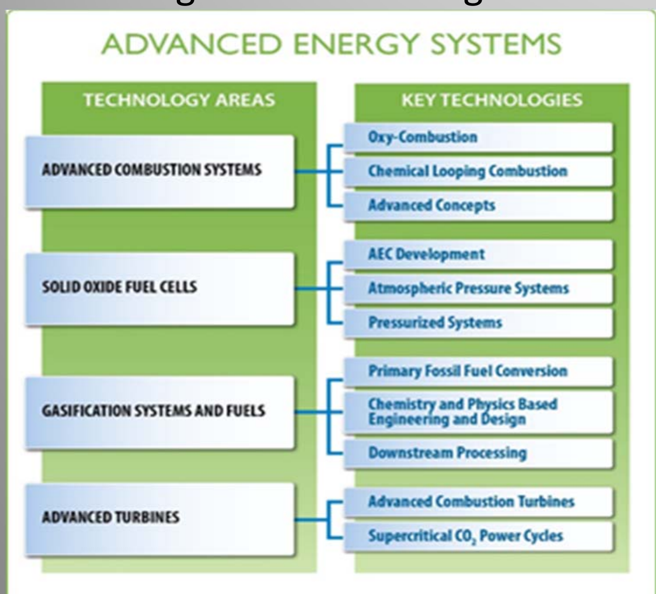
- ❑ Carbon Utilization (EOR)
- ❑ Infrastructure (RCSPs
- ❑ Geological Storage
- ❑ Monitoring, Verificatio and Accounting



The AES program consists of four Technology Areas. Each of these Technology Areas is further subdivided into key technologies



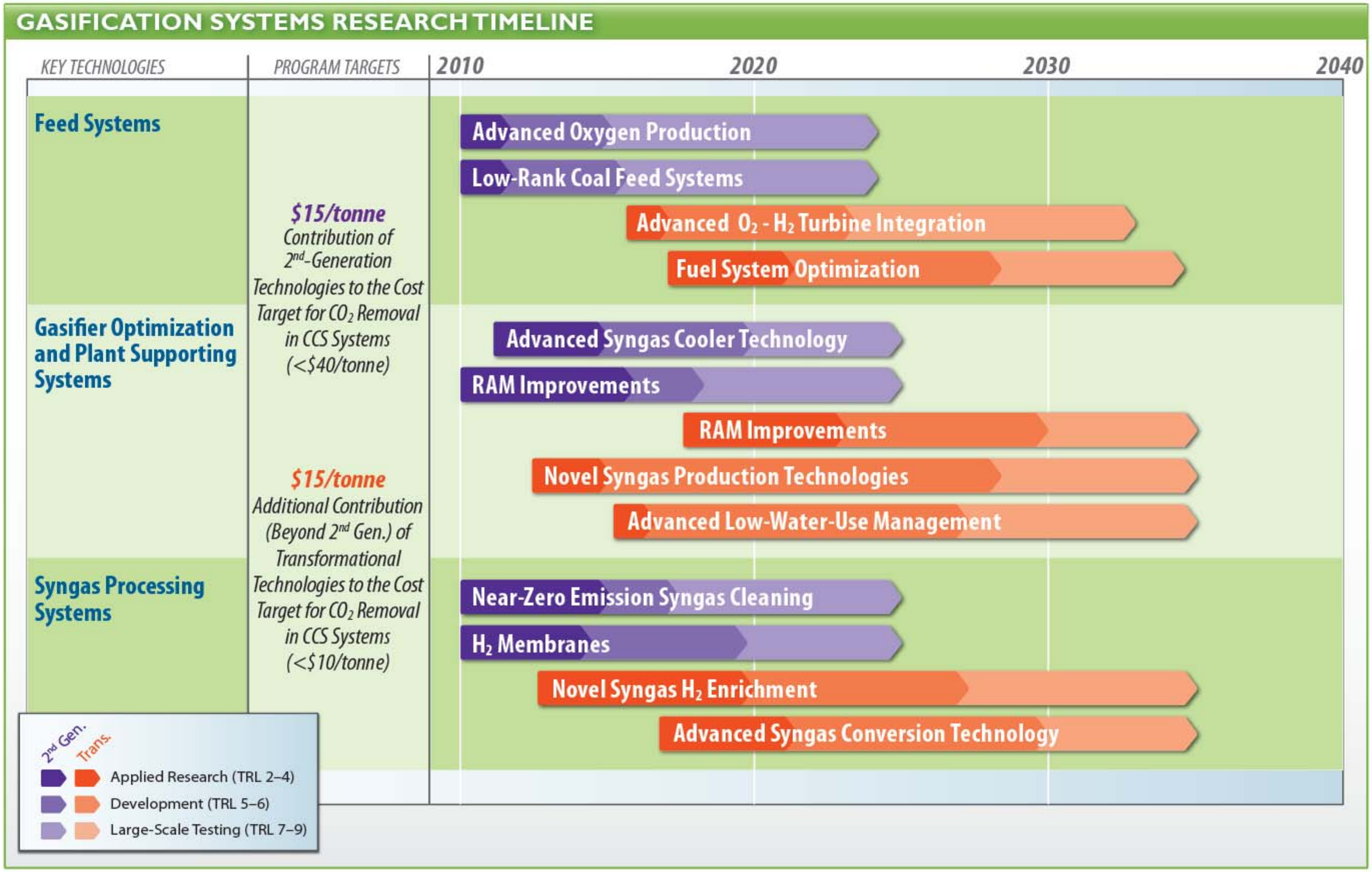
- Research focused on the continued development of oxy- combustion technologies.
- Research focused on developing low-cost, highly efficient, solid oxide fuel cell (SOFC) power systems that are capable of simultaneously producing electric power from coal with carbon capture when integrated with coal 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 (CO_2)-based power cycles, and advanced steam turbines

Gasification Technology Roadmap

R&D Timelines



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

Direct Coal Liquefaction – Shenua, China

Fischer-Tropsch Synthesis Rig

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Solid Oxide Fuel Cells

SOFC power systems, which have the potential to achieve greater than 60 percent efficiency, will produce less CO_2 per unit of electricity, reducing the amount of CO_2 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 CO_2.

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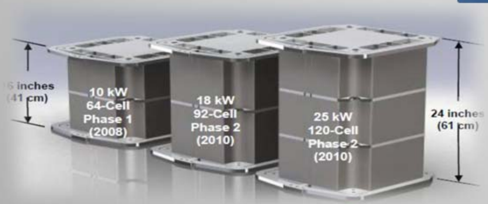
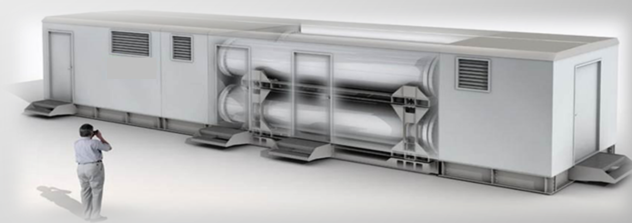
SOFC Program Timeline

2010	2015	2020	2025	2030

Demonstrations

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



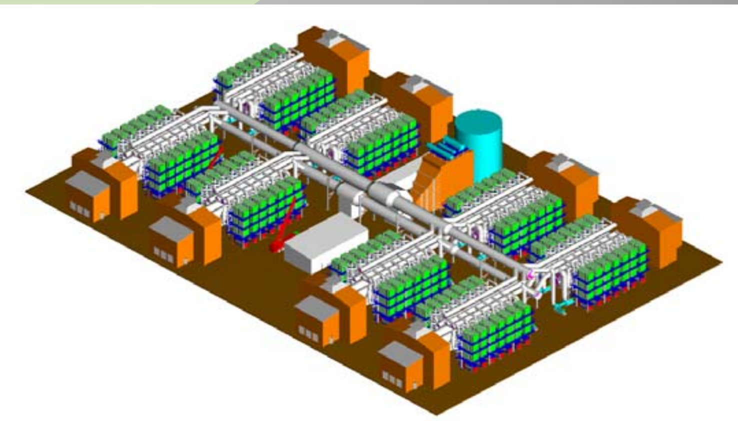


R &D

Technologies critical to commercialization

Research Focus

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



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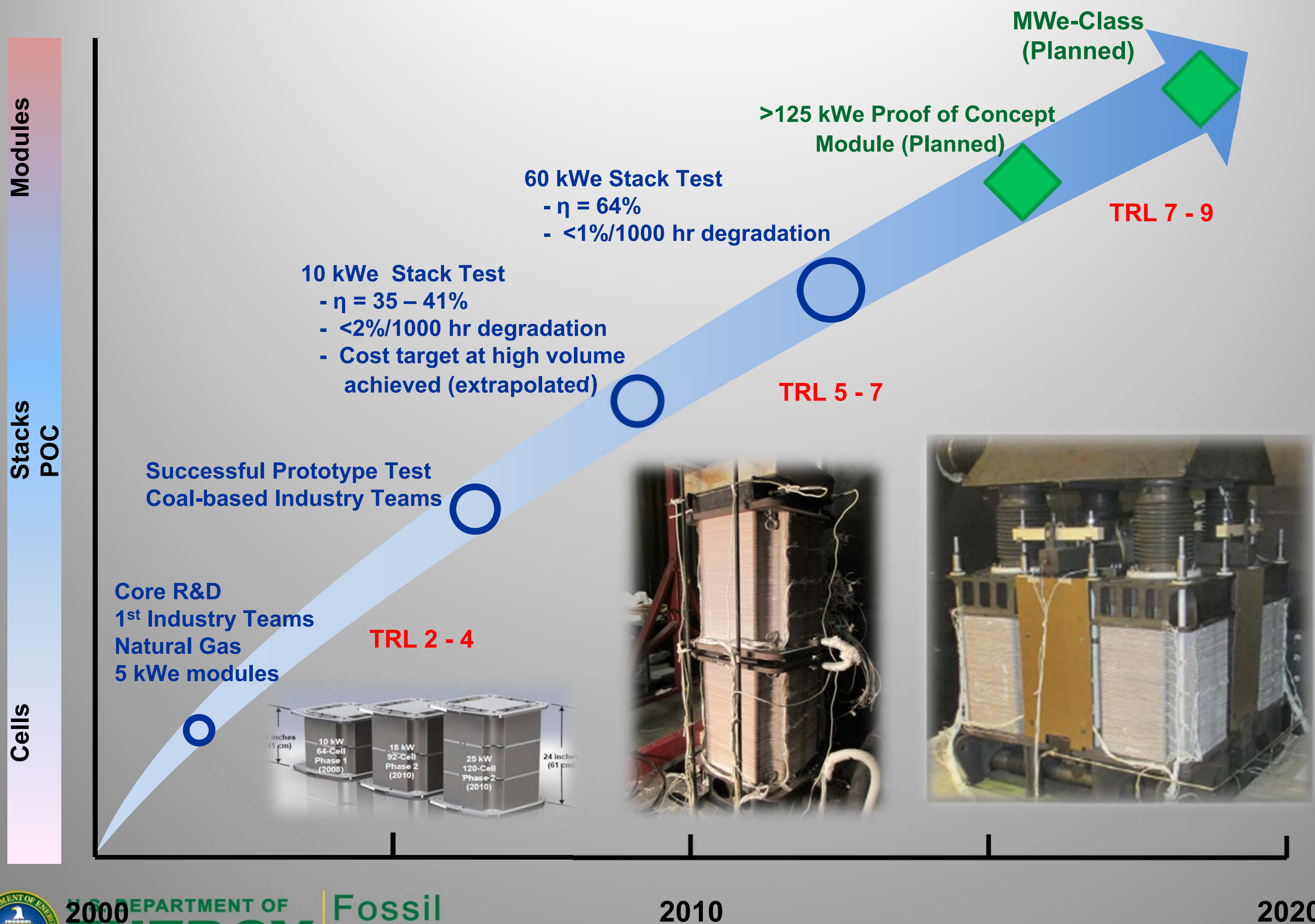
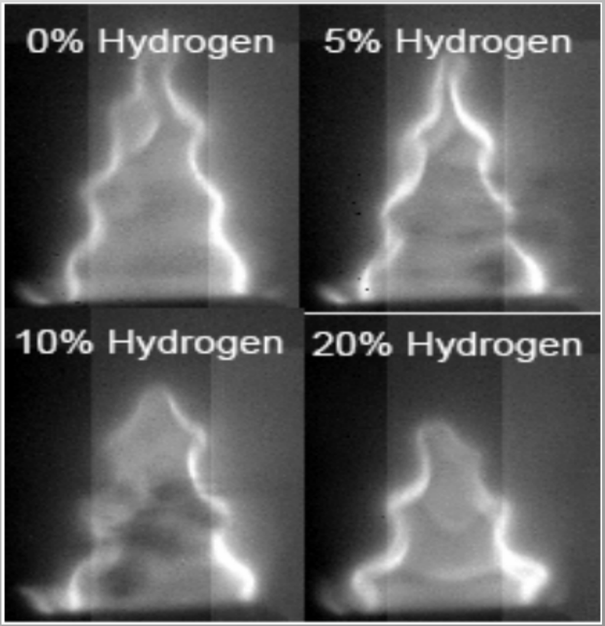
SOFC Program Technology Progress



Hydrogen Turbines Program



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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

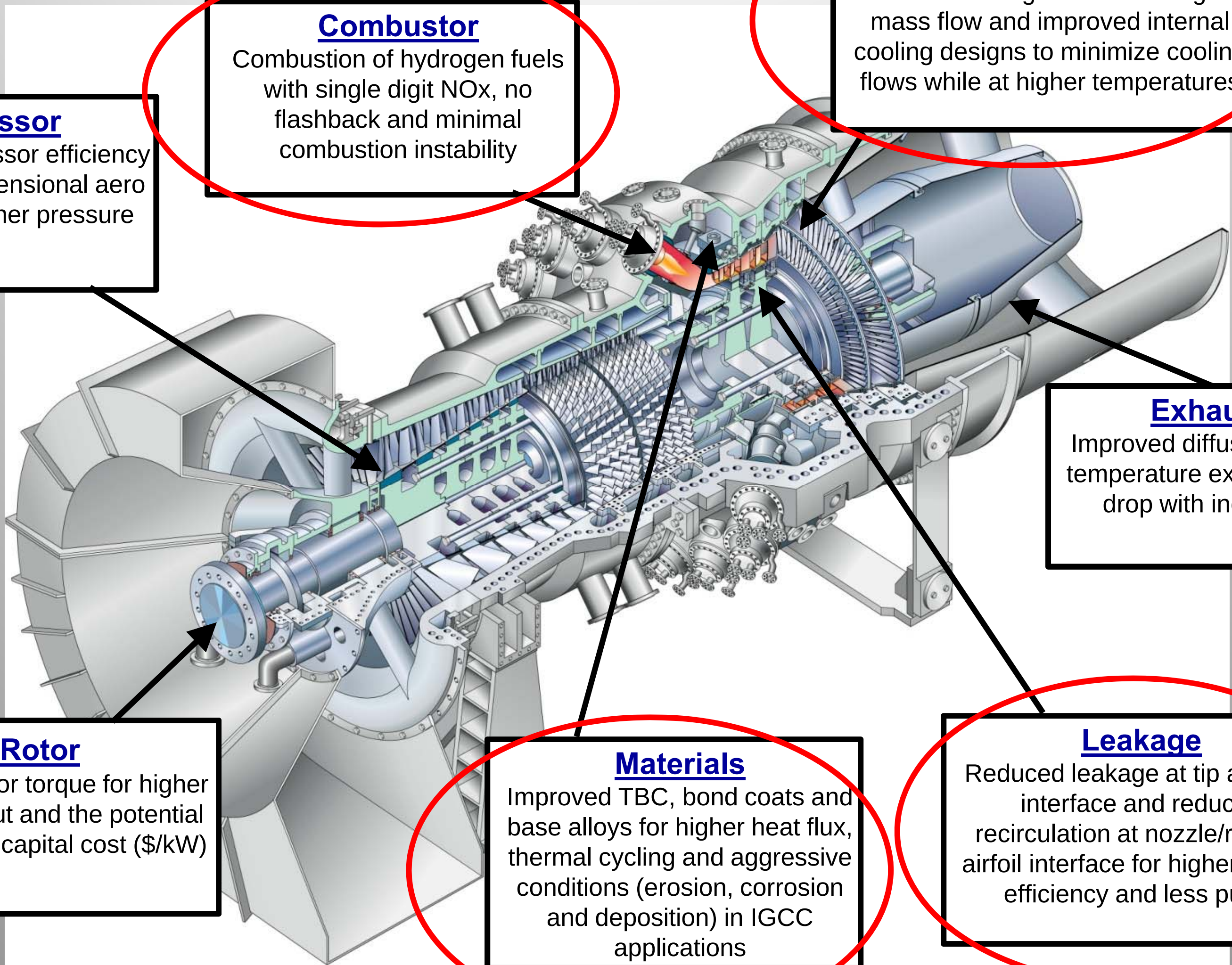
Technologies Developed under the Turbines Program can:
Improve Efficiencies and Reduce CO2 Emissions across Multiple Fuel Types, Including Syngas and Natural Gas

Targeted R&D Areas for H_2 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

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

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

Leakage
Reduced leakage at tip and wall interface and reduced recirculation at nozzle/rotating airfoil interface for higher turbine efficiency and less purge

Photo courtesy of Siemens Energy

Advanced Combustion Systems

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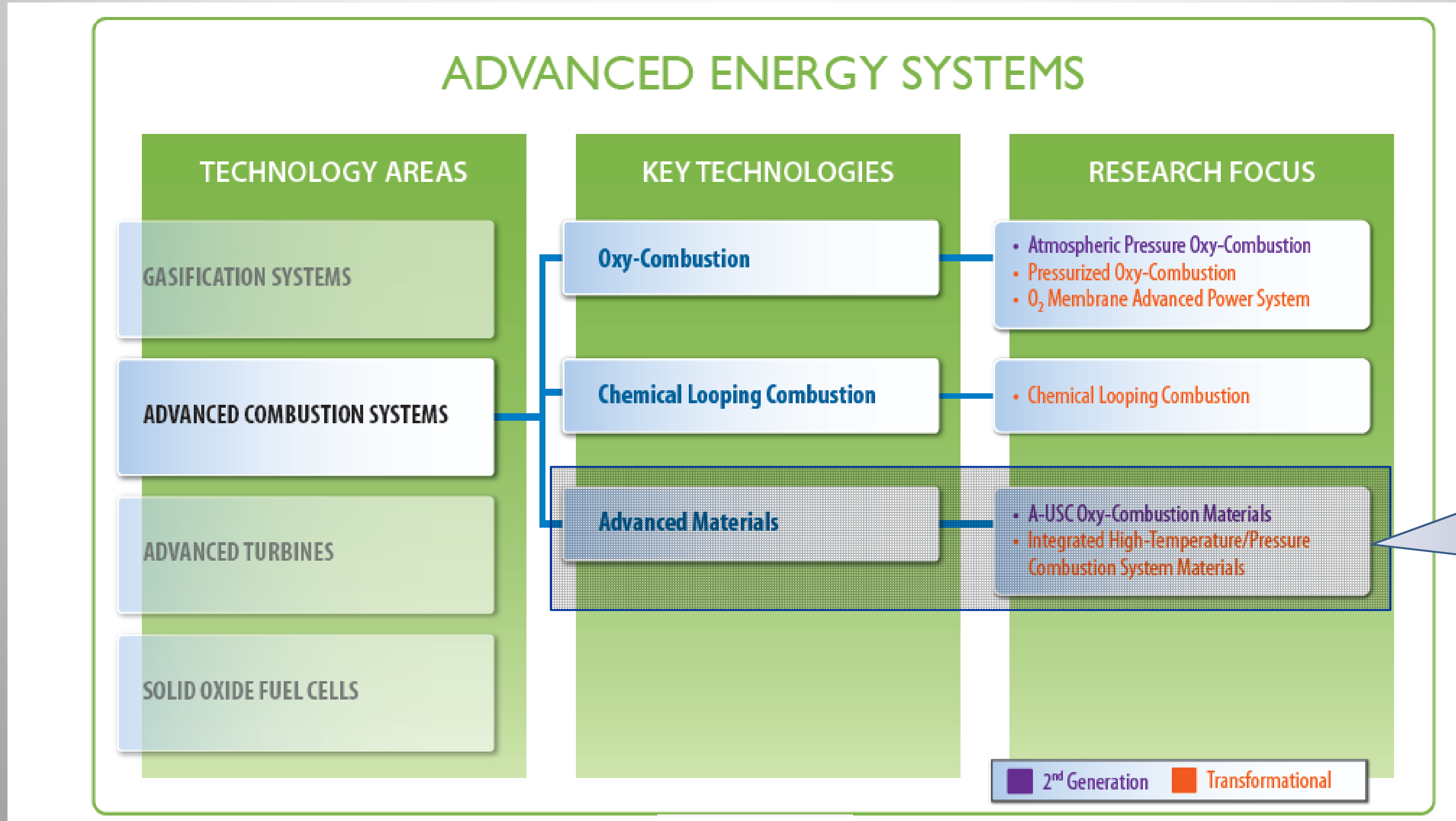
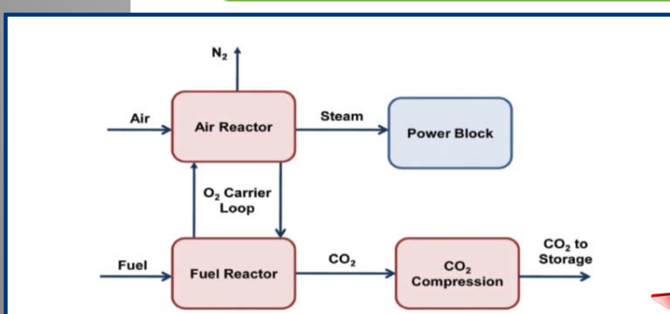
Advanced Combustion Systems Program

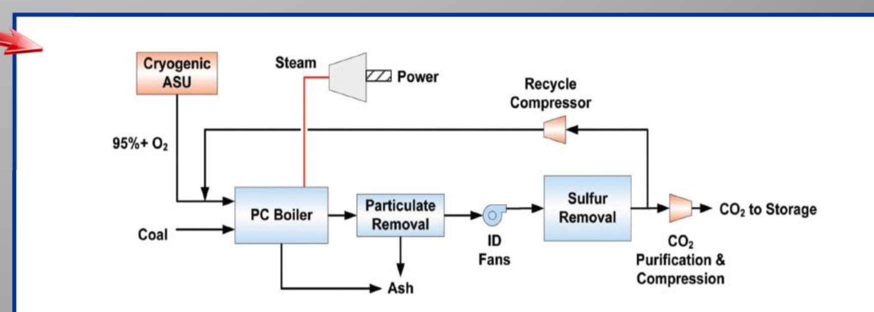


Coordinated with Crosscutting Research Technology Area



Oxy-Combustion

Chemical Looping



Advanced Combustion Systems Program

OXY-COMBUSTION SYSTEM COMPONENTS

1ST-GENERATION TECHNOLOGY
Atmospheric Pressure Oxy-Combustion

- Cryogenic ASU
- Conventional Boiler
- CO_2 Recycle
- Supercritical Steam
- Conventional Purification
- Conventional Compression

2ND-GENERATION TECHNOLOGY
Atmospheric Pressure Oxy-Combustion

- Advanced Cryogenic ASU
- Advanced Oxy-Boiler
- Advanced Ultra-Supercritical Steam
- Advanced Purification
- Advanced Compression

Focus on Transformational Technologies

TRANSFORMATIONAL TECHNOLOGIES

Pressurized Oxy-Combustion

- Advanced Cryogenic ASU or O_2 Membrane
- High-Pressure Combustor
- Advanced Ultra-Supercritical Steam Conditions
- Supercritical CO_2 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

Questions

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