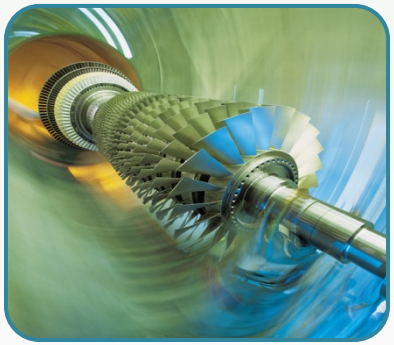

SOFC Program Overview

Dr. Darren Mollot

Director, Clean Energy Systems

Office of Clean Coal

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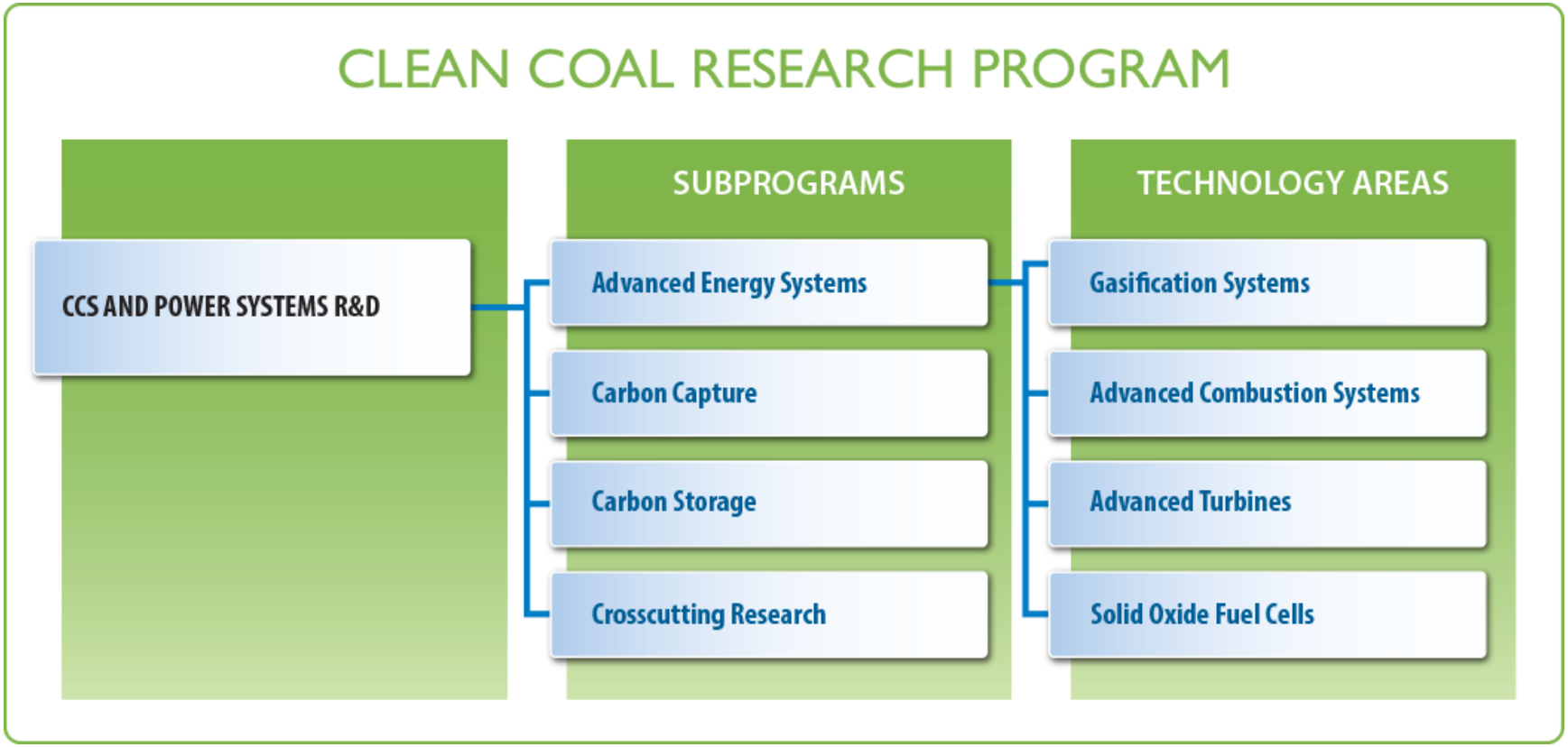
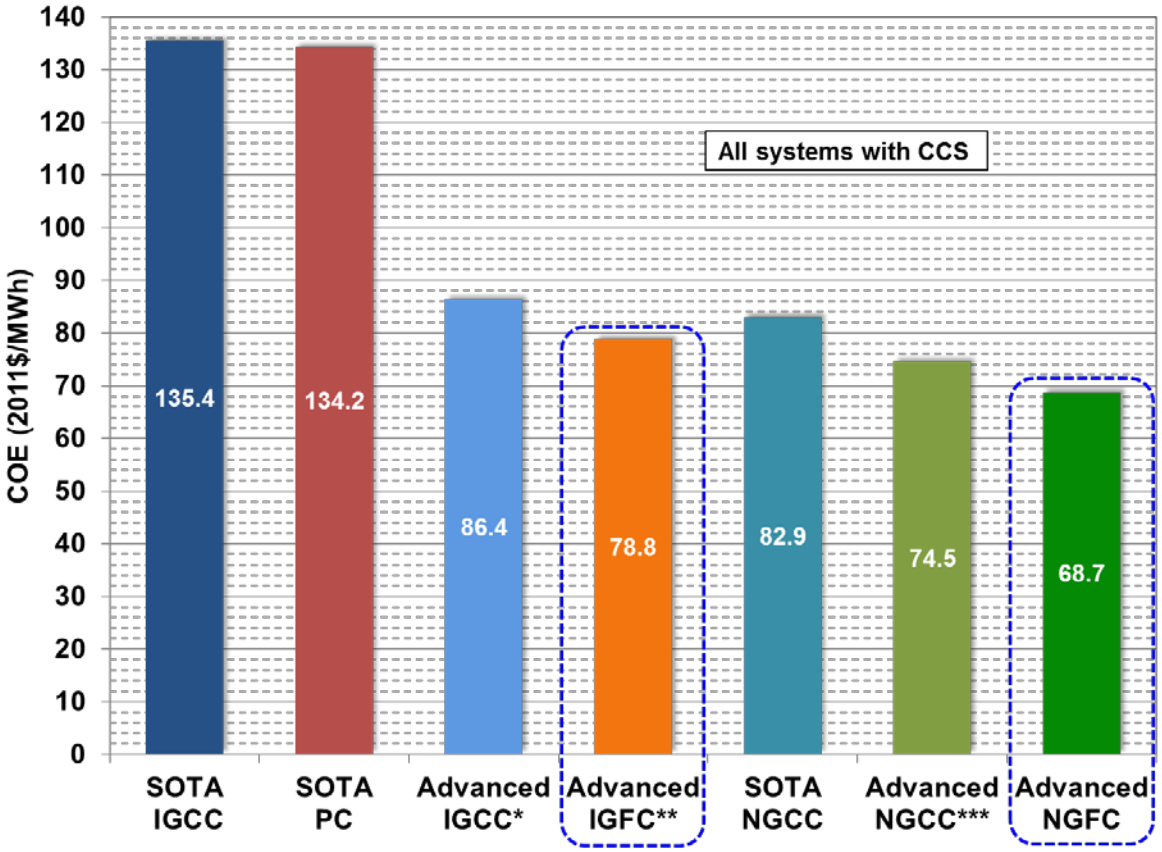
Clean Coal Research Program



SOFC Power Systems - COE



* Advanced IGCC system includes: coal feed pump, warm gas cleanup, H_2 membrane, advanced H_2 turbine, and ITM

** Advanced IGFC system includes catalytic gasifier, 0.2% degradation rate, and internal reforming

*** Advanced NGCC system features a J-class turbine with a state-of-the-art carbon capture system

Source: NETL Systems Analysis

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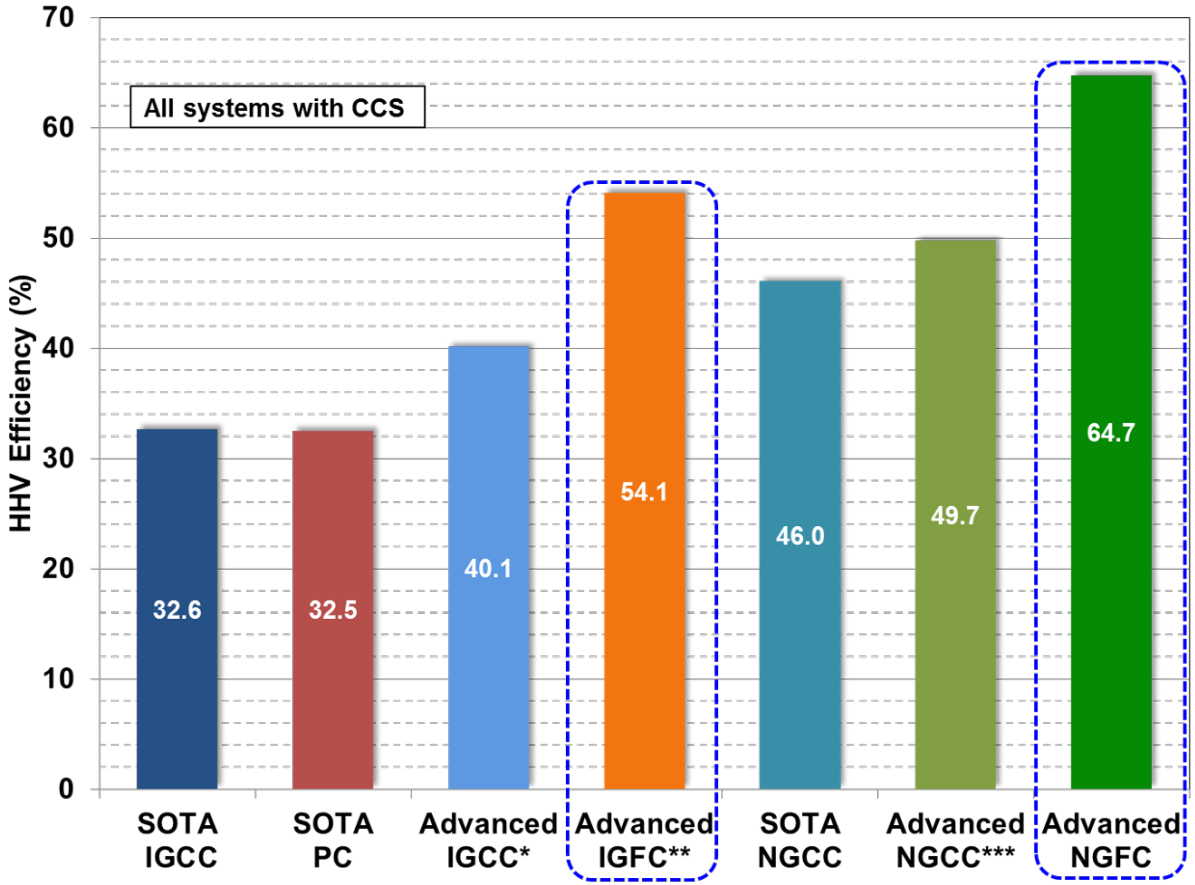
SOFC Power Systems - Efficiency



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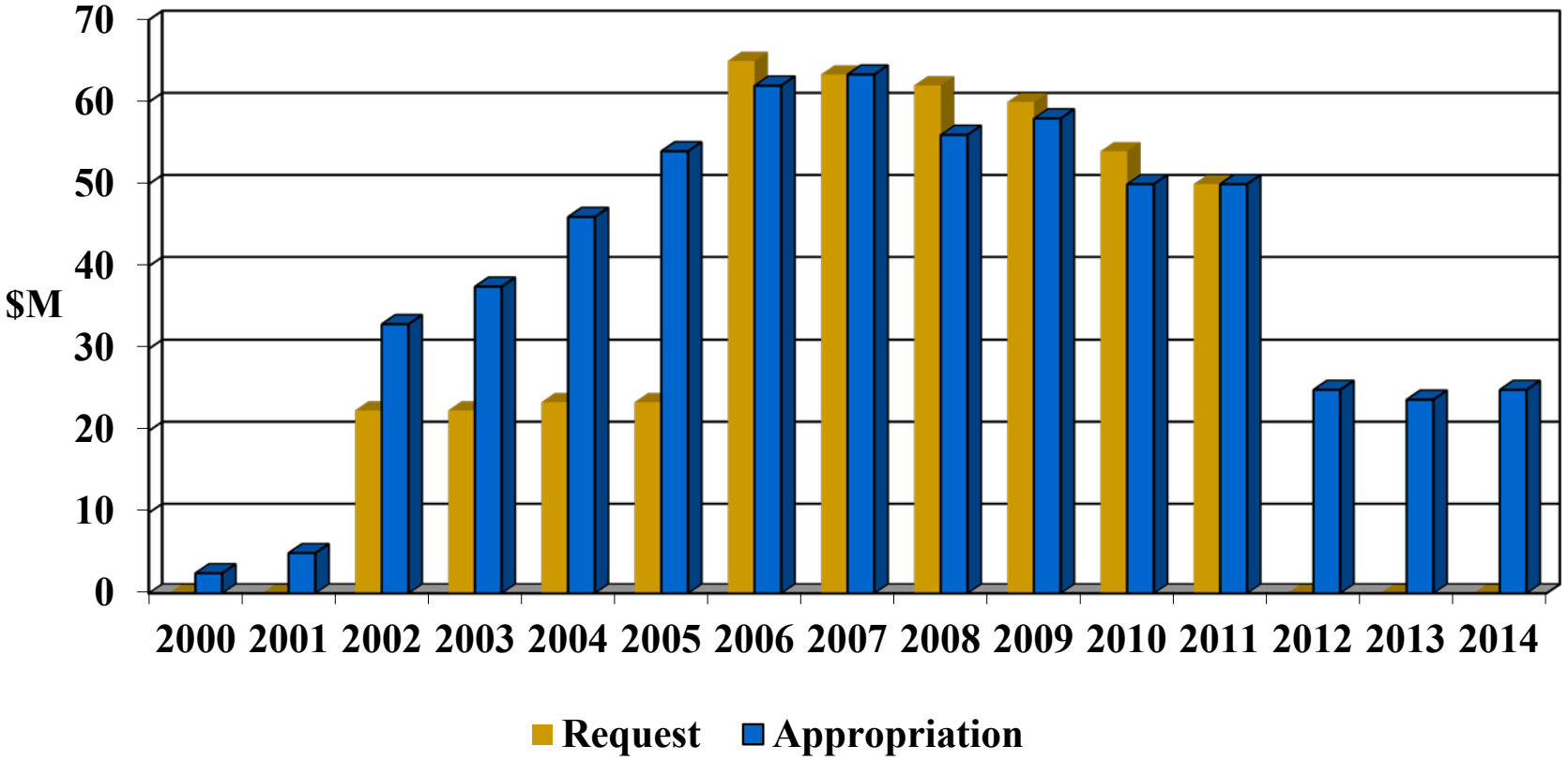
Solid Oxide Fuel Cell Program

Budget History



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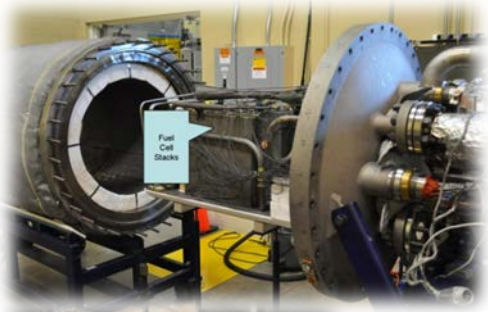
FE SOFC Program Mission

- **Enable the generation of efficient, low-cost electricity from domestic coal and natural gas with near-zero emissions of CO_2 and air pollutants and minimal use of water in central power generation applications.**
- **Increase reliability, robustness, and durability of cell and stack technology.**
- **Provide the technology base to permit grid-independent distributed generation applications.**

60% Efficiency (Coal HHV)	***≥ 97% CO_2 Capture***	***<0.5ppm NOx, low H_2O use***	**Low Cost, similar footprint to IGCC**	**Modular Technology**	**Fuel-Flexible: Syngas, NG, H_2, Diesel, etc.**

SOFC Program Structure

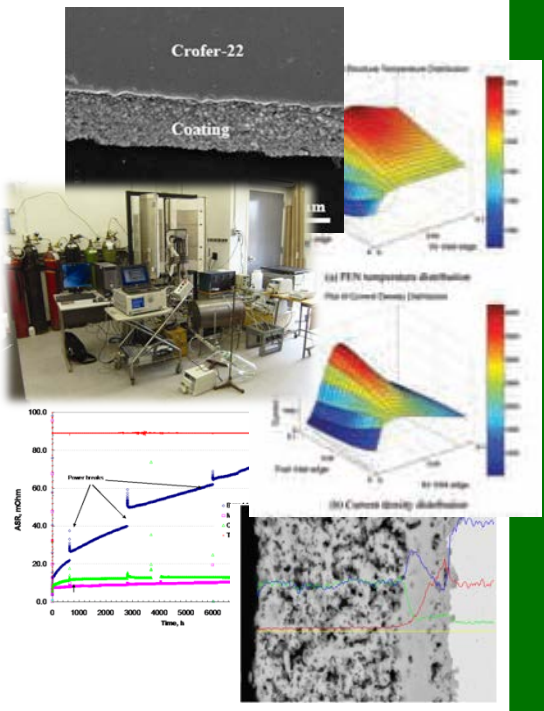


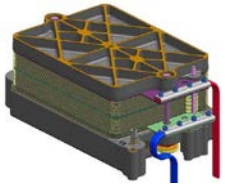
R &D Needs
Research Topics

Core Technology Program
(Universities, NLs)

Technology Transfer

Industry Teams





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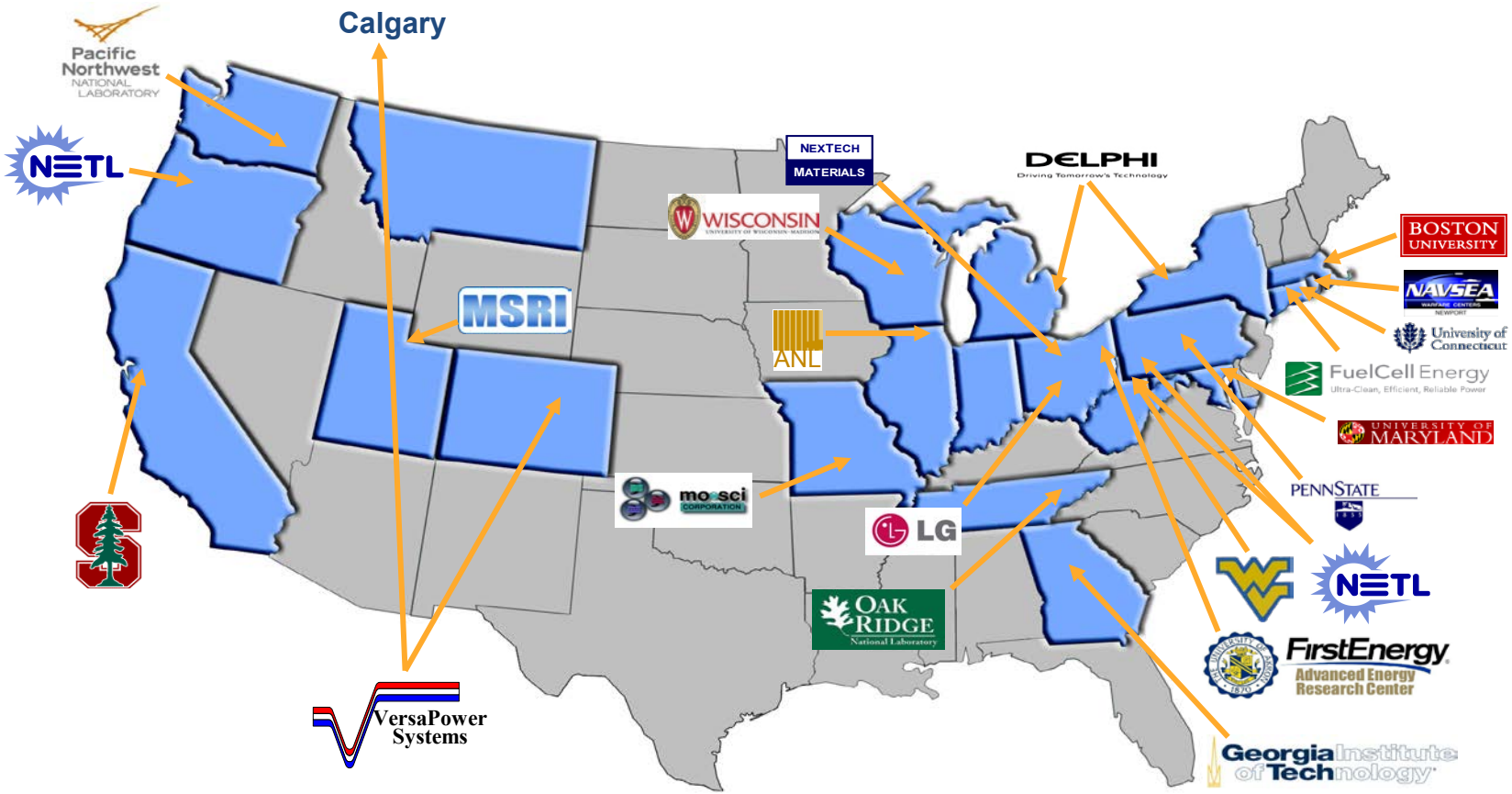
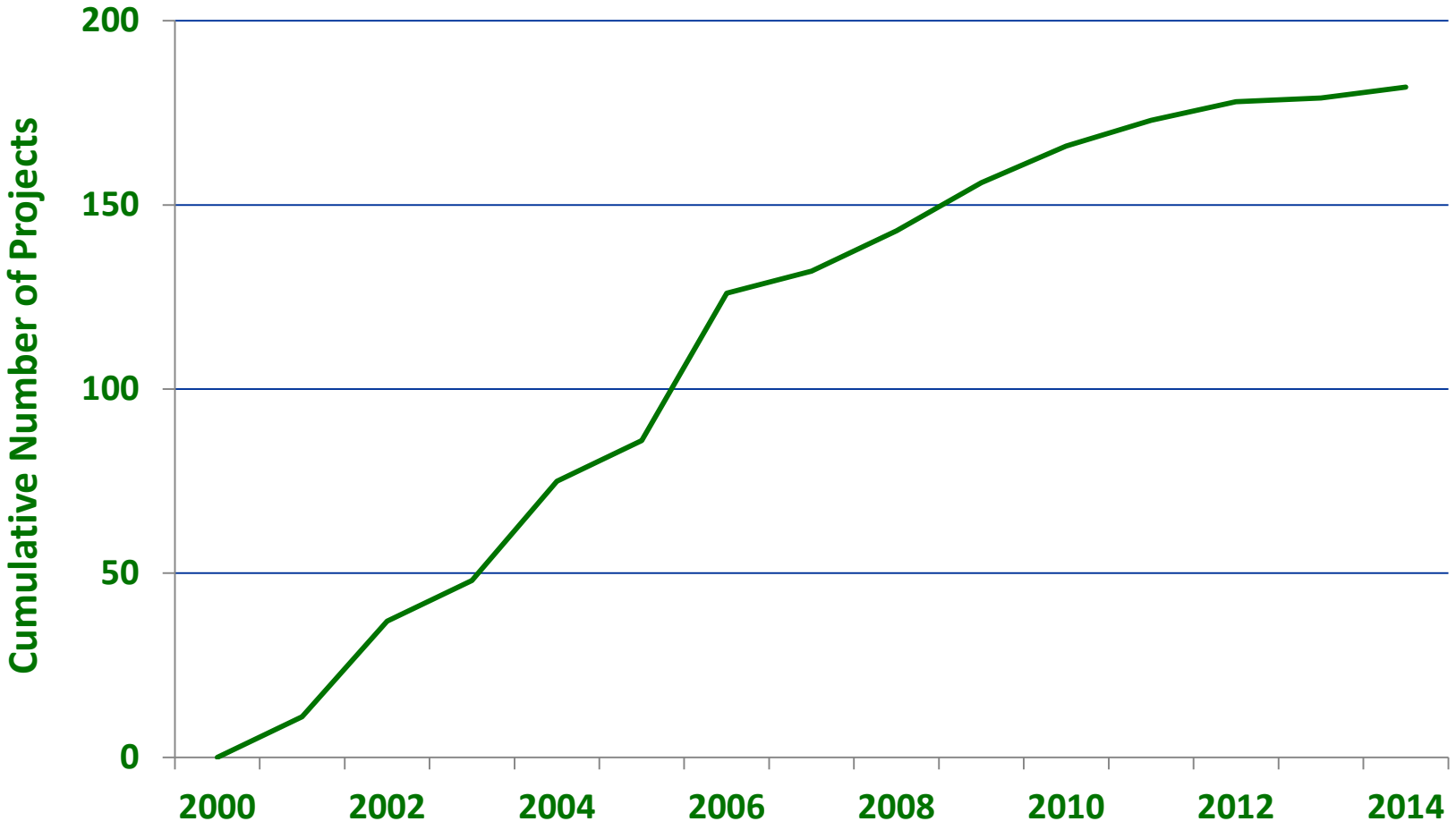
SOFC Project Portfolio



The SOFC program maintains a diversified portfolio of more than 20 short-, mid-, and long-term R&D projects

The SECA Program – A Decade of Growth



Since its inception in 1999 as SECA, the SOFC Program has funded approximately 175 projects

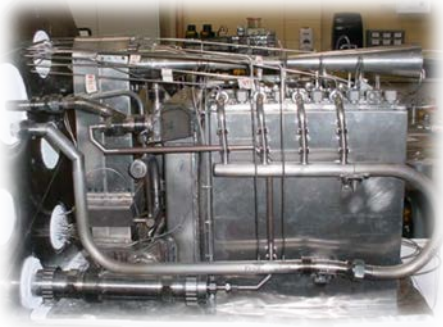
SOFC Program Core Technology Program

- **Focus on:**
  - **Technologies critical to the commercialization of SOFC technology**
  - **Cost reduction, improved performance, reduced degradation**
  - **Computational tools and modeling**
  - **Novel cell and stack concepts, advanced processing techniques, and novel fuel cell power systems**

The Core Technology Program, made up of universities, national laboratories, small businesses, and other R&D organizations, addresses applied technological issues common to all Industry Teams.

SOFC Program Industry Teams
FY13 Status

- **LG Fuel Cell Systems**
  - **Pressurized Technology**
  - **18 kWe stack test; 3,000 hrs**
  - **Degradation rate ~1.1% /1,000 hrs**
  - **TRL 5**



- **Delphi**
  - **Atmospheric Pressure Technology**
  - **9 kWe stack test; 3,500 hrs**
  - **Degradation rate <0.5% /1,000 hrs**
  - **TRL 5**

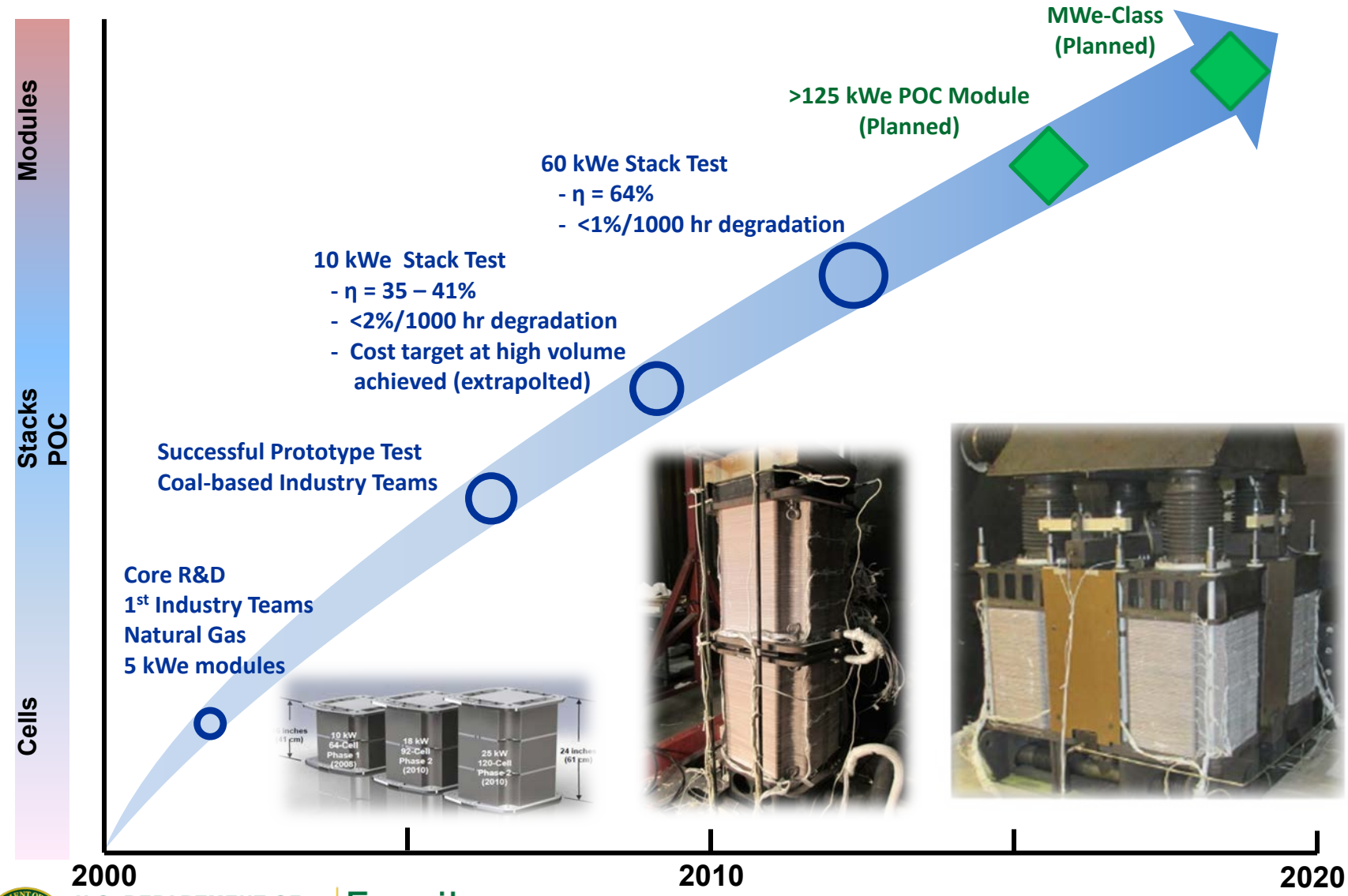
- **Fuel Cell Energy**
  - **Atmospheric Pressure Technology**
  - **60 kWe stack test; 1,130 hrs**
  - **Degradation rate <1% /1,000 hrs**
  - **TRL 6**

SOFC Program Industry Teams

- Developing unique and proprietary SOFC technology
- Scope includes cells to fully integrated SOFC power systems
- Pilot-scale and first-of-a-kind commercial demonstrations
- Held to a common set of performance and cost metrics
  - Stack cost: $225/kWe
  - System cost: $900/kWe
  - System degradation: 0.2% /1000 hrs

The multi-team approach provides technology diversification, offers insurance against business environment risk, and reduces program dependency on single developer

SOFC Program Technology Progress



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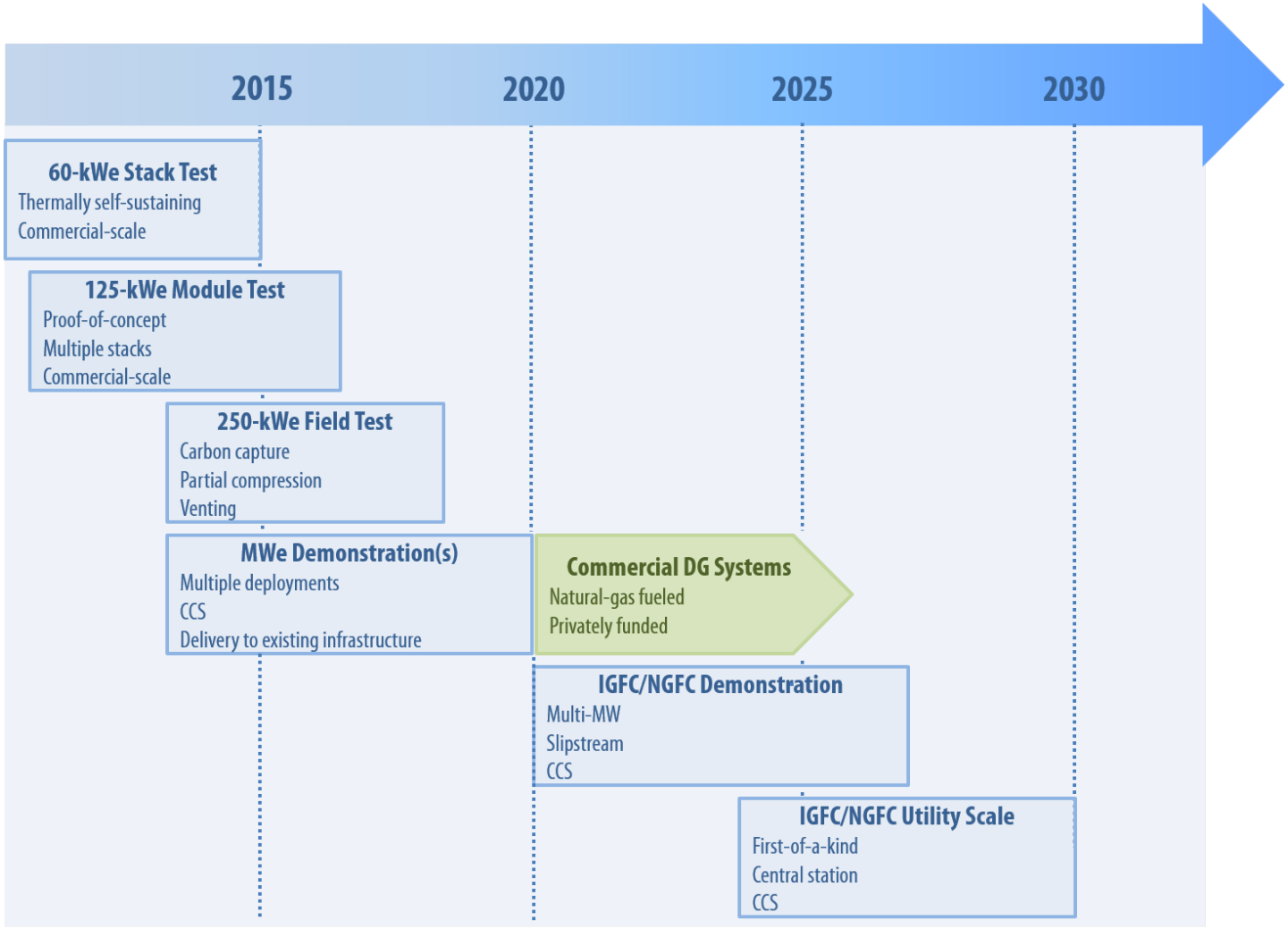
SOFC Program Timeline

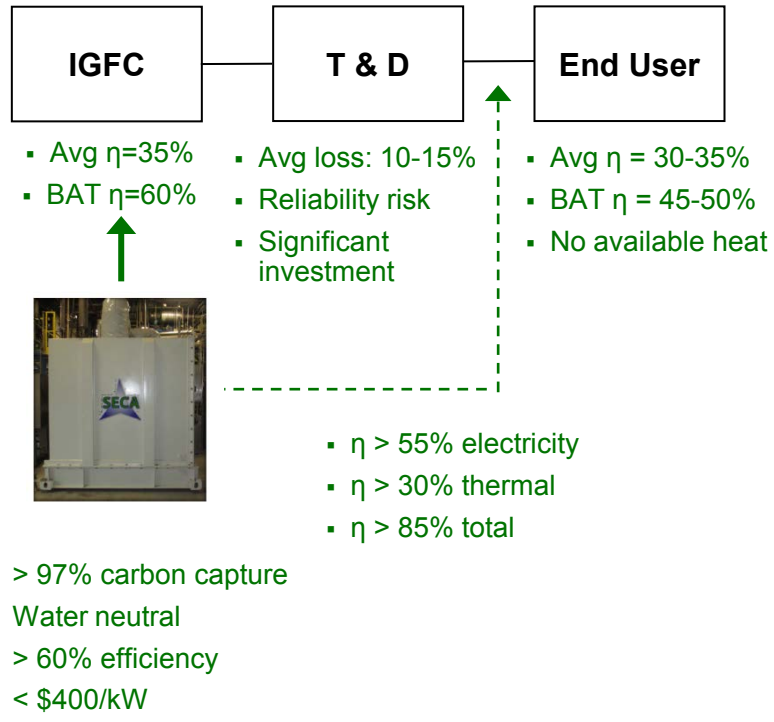


SOFC is a Transformational CCS Technology

Trends / Drivers / Benefits

- Green technology
  - Low emissions
  - >97% CO_2 capture potential
  - Renewable fuel
- High quality heat & power
- High efficiency
- High reliability/availability
- Low O&M cost, minimal moving parts
- Low degradation
- No water consumption (except startup)
- Quiet (65 DBA @ 10 m)
- Recyclable at the end of useful life
- Siting flexibility, easily permitted
- Enhances energy independence and security

Technology Attributes



SOFC: Meets DG Market Need

Path to Utility Scale Power Generation w/o CO_2 Emissions

- **Distributed generation market opportunity: electric power (5 kWe to MWe-class units)**
- **SOFC DG electric power application**
  - Provides > 20 percentage point gain in efficiency
  - Results in significant CO_2 emission reduction
- **Commercial, cost-competitive, high efficiency SOFC DG product by 2025**
  - Consistent with technology development plan
  - ~30 MWe installed capacity to achieve competitive cost; assumes R&D reduces system cost to ~$6,000/kWe
- **Projected learning to achieve competitive cost is consistent with similar technology commercialization experience**

SOFC DG applications provide pathway to utility scale coal and natural gas-fueled power plants with efficiencies >60% and >97% carbon capture

Summary

- SOFC offers a potential pathway to low cost CCS for fossil based systems
- Near term opportunities for commercial demonstration and deployment exist in the distributed generation market
- SOFC offer other benefits, e.g., high efficiency, deep turndown, fuel flexibility, sulfur tolerance, modular design, high grade waste heat

Back-Up

For More Information on the SOFC Program

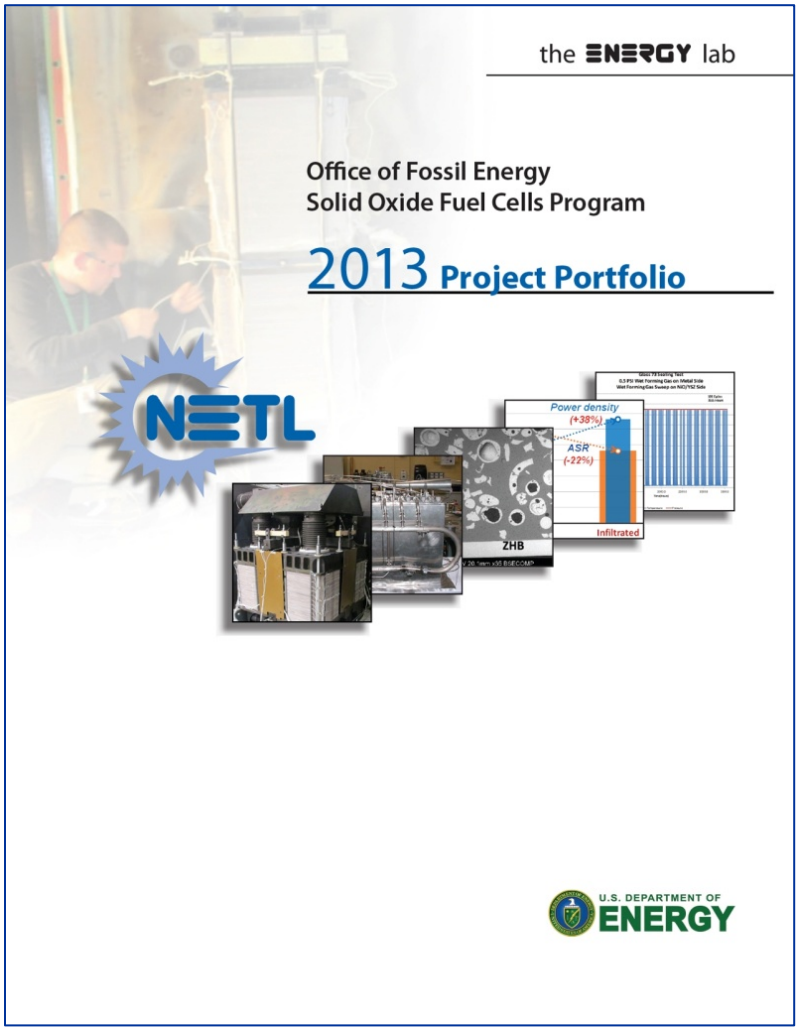
Office of Fossil Energy:
www.energy.gov/fe/office-fossil-energy

NETL Website: www.netl.doe.gov/

SOFC Program:
www.netl.doe.gov/technologies/coalpower/fuelcells/index.html

Reference Shelf:

- SOFC Program FY13 Project Portfolio
- SOFC Technology Program Plan
- Technology Readiness Assessment
- Past SECA Workshop Proceedings
- Systems Analysis
- Fuel Cell Handbook



Fuel Cells 2014 FOAs

1. Improved Reliability of Solid Oxide Fuel Cell Systems
Focused on Industry
Estimated Funding: $15 M (2-3 awards)
Period of Performance: 18 months

2. Solid Oxide Fuel Cell Core Technology Program
Focused on R&D in Support of Industry
Estimated Funding: $6.4 M (5-8 awards)
Period of Performance: 36 months

Issued: February 14, 2014
Close: March 31, 2014

CCS & Power Systems

(dollars in thousands)

	FY 2014 Enacted	FY 2015 Congressional Request	FY 2015 vs FY 2014 $	FY 2015 vs FY 2014 %
CCS AND POWER SYSTEMS				
Carbon Capture	92,000	77,000	(15,000)	-16%
Carbon Storage	108,766	80,084	(28,682)	-26%
Advanced Energy Systems	99,500	51,000	(48,500)	-49%
Crosscutting Research	41,925	35,292	(6,633)	-16%
NETL Coal R&D	50,011	34,031	(15,980)	-32%
TOTAL CCS AND POWER SYSTEMS	**392,202**	**277,407**	**(114,795)**	**-29%**

- The budget request takes into consideration the need for budget restraint across all research and development (R&D) program areas.
- The majority of the reduction is from Advanced Energy Systems. The request continues development of pressurized oxy-combustion and chemical looping combustion systems. Funding for fuel cells is narrowed to materials research essential to commercial viability.
- Carbon Capture and Carbon Storage are reduced but maintaining priority activities associated with capture for fossil fuel-fired plants and large-scale injection and monitoring operations.
- The NETL Coal R&D budget reflects a $16M reduction from FY2014; however, the funding is consistent with levels prior to FY 2014. The FY2014 enacted amount included extra funding to perform a special assessment of recovering rare earth elements.

Advanced Energy Systems

(dollars in thousands)

	FY 2014 Enacted	FY 2015 Congressional Request	FY 2015 vs FY 2014 $	FY 2015 vs FY 2014 %
Advanced Energy Systems				
Advanced Combustion Systems	18,500	15,000	(3,500)	-19%
Gasification Systems	36,000	22,000	(14,000)	-39%
Hydrogen Turbines	15,000	11,000	(4,000)	-27%
Coal and Coal Biomass to Liquids	5,000	-	(5,000)	-100%
Solid Oxide Fuel Cells	25,000	3,000	(22,000)	-88%
TOTAL ADVANCED ENERGY SYSTEMS	**99,500**	**51,000**	**(48,500)**	**-49%**

- The Advanced Energy Systems (AES) mission is to increase the availability and efficiency of fossil energy systems integrated with CO_2 capture, while maintaining the highest environmental standards at the lowest cost.
- Due to funding priority, the Solid Oxide Fuel Cells funding was reduced to focus on the development of CCS technologies. Materials research will continue.
- Coal and Coal Biomass to Liquids will continue collaboration with the DOD, but no funds are requested in FY 2015.
- Gasification Systems will maintain priority development of advanced oxygen production, dry feed technologies, warm-gas cleanup, and hydrogen separation.