Office of Fossil Energy's Solid Oxide Fuel Cell (SOFC) Program Overview

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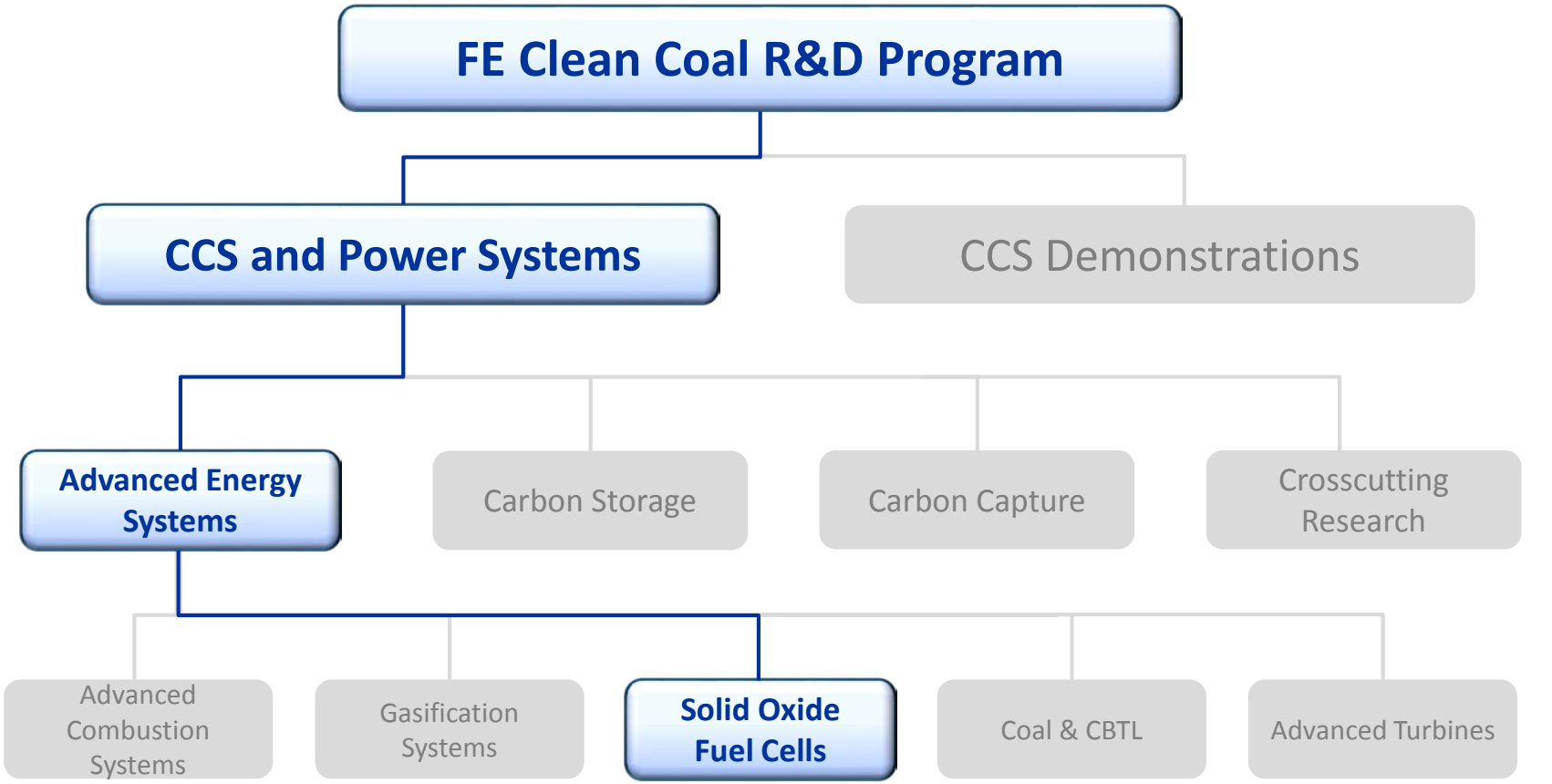
DOE Office of Fossil Energy (FE)

Solid Oxide Fuel Cell (SOFC) Program



DOE's Clean Coal R&D Program is focused on developing and demonstrating advanced power generation and Carbon Capture and Storage (CCS) technologies

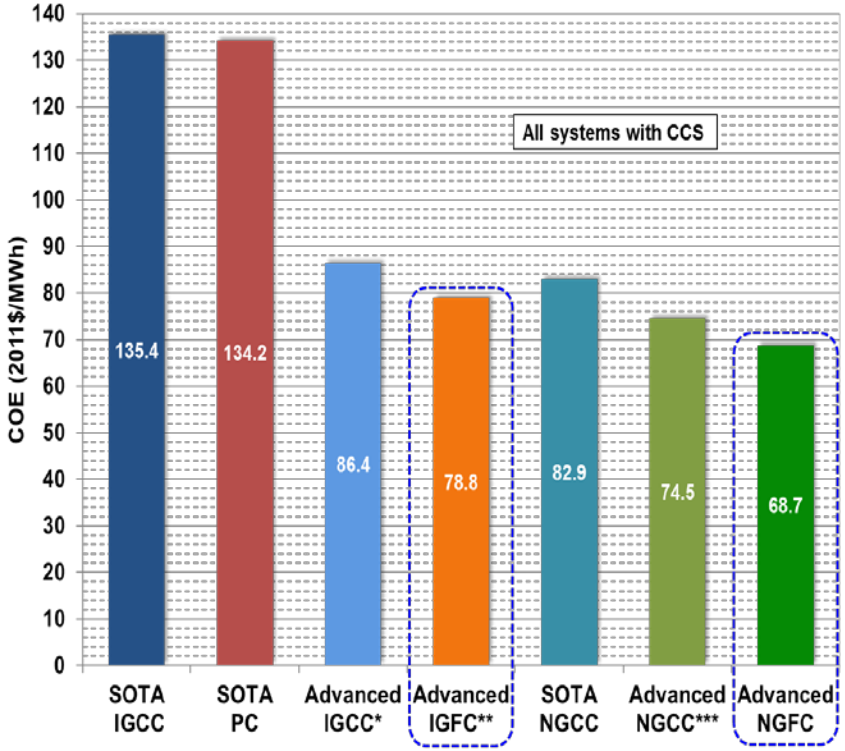
CCS: Carbon Capture and Storage

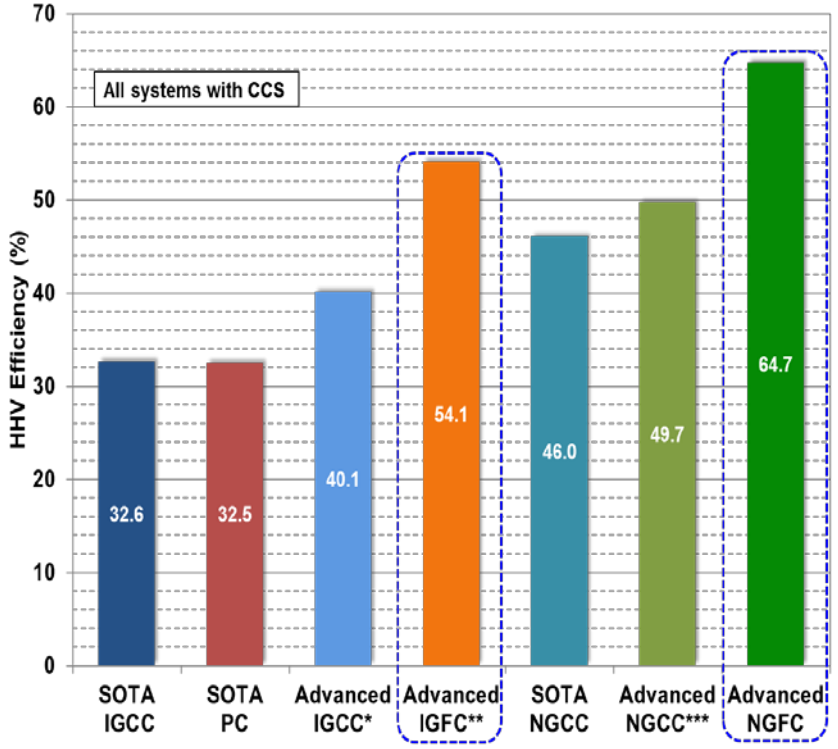
FE SOFC Program Mission

- **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 solid oxide fuel cell and stack technology.**
- **Provide the technology base to permit natural gas fueled distributed generation (DG) 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

Techno-Economic Analysis of Utility-Scale Power Plants





SOTA: State of the Art
IGCC: Integrated Gasification Combined Cycle
PC: Pulverized Coal

IGFC: Integrated Gasification Fuel Cell
NGCC: Natural Gas Combined Cycle
NGFC: Natural Gas Fuel Cell

* 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

Natural gas price: $6.13/MM BTU
Coal price: $2.91/MM BTU

SOFC power systems offer a pathway to low cost, high efficiency electric power generation – with CCS – from fossil fuels

Source: NETL Systems Analysis

SOFC Program Structure

Systems Development

- Multiple teams developing unique and proprietary SOFC technology
- Scope includes cells to fully integrated SOFC power systems
- Pilot-scale and prototype system testing
- Held to a common set of performance and cost metrics

Core Technology

- Applied R&D focused on technologies critical to the commercialization of SOFC technology
- Evaluate, develop and implement advanced technologies to reduce costs and improve performance, reliability and endurance
    - Materials
    - Manufacturing processes
    - Computational tools and modeling

The multi-team approach provides technology diversification and reduces program dependency on a single developer

SOFC Project Portfolio

Systems Development

FuelCell Energy*

LG Fuel Cell Systems*

Cell Development

ANL
Boston University
Case Western Reserve University
Georgia Tech
MSRI
NETL-ORD
NexTech
ORNL
PNNL
Pneumaticoat
Sandia
SMI
Sonata*
Stanford
University of Connecticut
University of Maryland
University of Pennsylvania
University of South Carolina
University of Wisconsin
West Virginia University*

Core Technology

Interconnects

NexTech
PNNL

Seals

Michigan State Univ
ORNL
PNNL

Modeling & Simulation

NETL-ORD
PNNL

Balance-0f-Plant

Mohawk
Innosense
PNNL

Stack Reliability & Testing

Acumentrics
NAVSEA
NREL

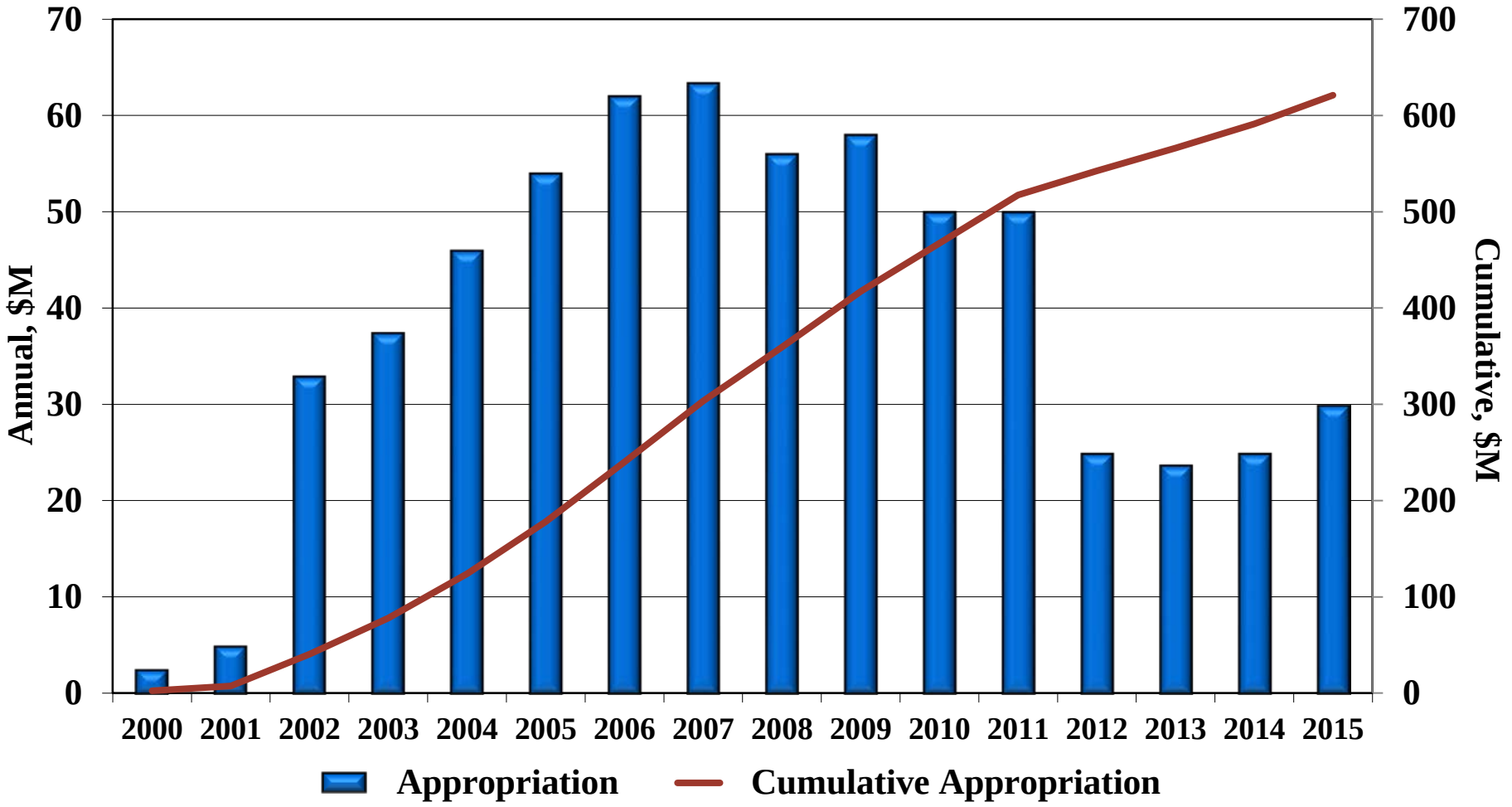
The SOFC Program has a portfolio of more than 30 projects, ranging from bench-scale R&D to system-scale testing

** Multiple awards*

SOFC FY15 Program Participants

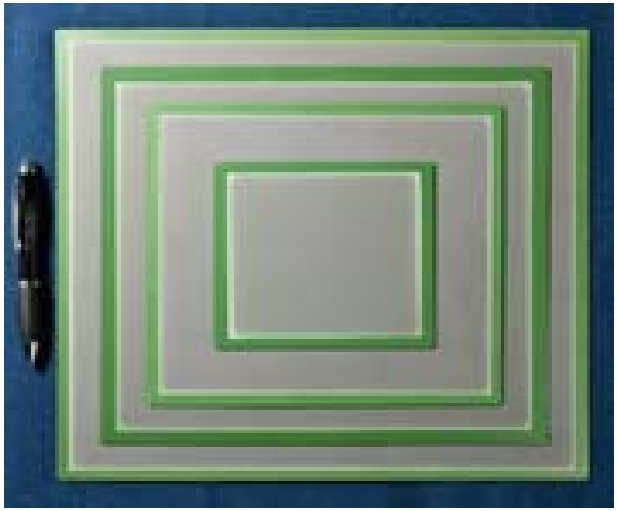
The SOFC Program has a geographically diverse roster of participants

SOFC Program Funding History



Where we were … Where we are …
Cell Development

Component	2000		2015	
Interconnect	Dense La-chromite	Expensive, requires high sintering temp.	Stamped Ferretic SS + Coating	Low-cost, post-processing possible
Cathode	LSM	High Resistance	LSM+YSZ, LSCF-doped-Ceria	Low Resistance
Electrolyte	Thick YSZ	High Resistance, mechanical support	Thin YSZ + doped-Ceria Barrier Layer	Low Resistance
Anode	Thin Ni-YSZ	Screen-printed Functional Layer	Medium Thickness (~500 mm) Ni-YSZ	Tape-cast, mechanical support



- **Developed planar anode-supported cell**
- **Increased cell area by 5x…… scaling to 10x**
- **Increased cell power by 10x**
- **Improved material set for higher performance**
- **Improved manufacturing processes**
- **Reduced operating temperature by ~100°C**
- **Reduced cell degradation to <0.5%/1,000 hrs**

Photo courtesy FuelCell Energy

Where we were … Where we are …

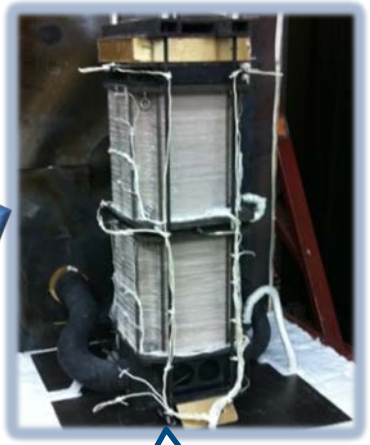
Stack Development

Reduced Cost
- Improved mfg processes
- Simplified design

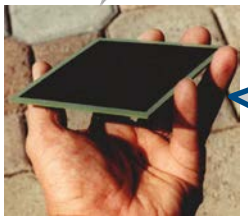
Improved Reliability
- SS interconnects
- Improved seals

Improved Performance
- Improved materials sets
- Modeling tools employed

Scale-Up
- Larger cells
- 1st generation interconnects



30 kW Stack Tower
- 96 cells, low cost interconnects
- Operating temperature <800°C, ΔT<100°C
- Increased power density
- Operation >> 1,000 hrs
- Degradation ~1% per 1,000 hrs



Single Cells & Small Stacks
- < 10 cells, no interconnects
- Operating temperature >800°C, ΔT undefined
- Low power density
- Limited operation, <1,000 hrs
- High degradation

Photo courtesy FuelCell Energy

Where we were … Where we are …
Performance and Reliability Testing

2000 – 2005
Technology Validation

- Single cells
- 1 -3 kW small stacks
- Degradation >4% per 1,000 hrs
- Limited operating hrs

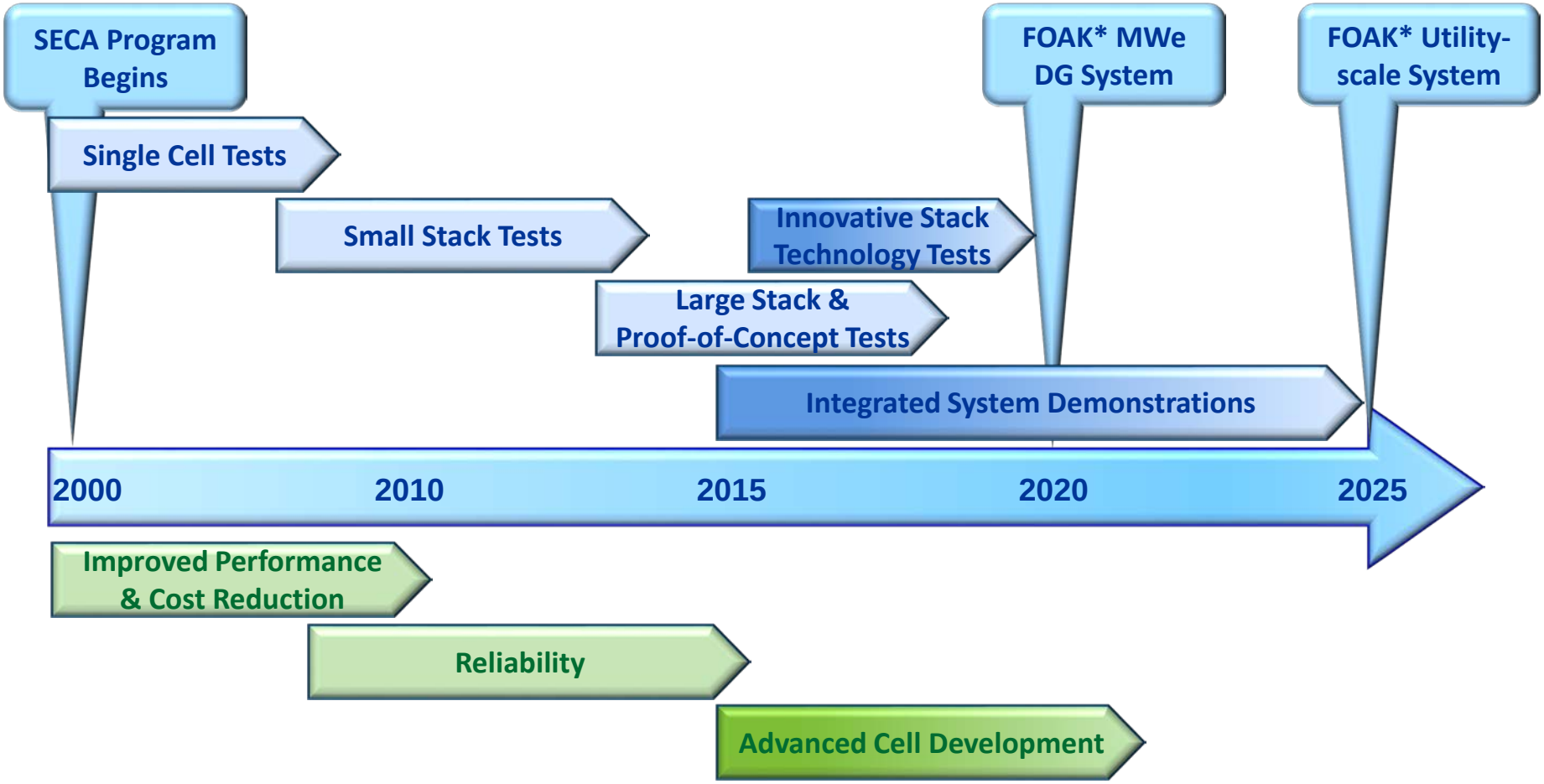
2006 – 2010
Performance Improvement

- 10 kW-class stacks
- Degradation <2% per 1,000 hrs
- Operating hrs >1,500

2011 – 2015
Proof-of-Concept

- 100 kWe-class stacks
- Thermally-self sustaining
- Natural gas- fueled
- Degradation 1 – 1.5% per 1,000 hrs

SOFC Program Evolution



A cost-effective, natural gas fueled DG system is planned for 2020 followed by a initiation of Utility-scale demonstration for 2025

* First-of-a-kind

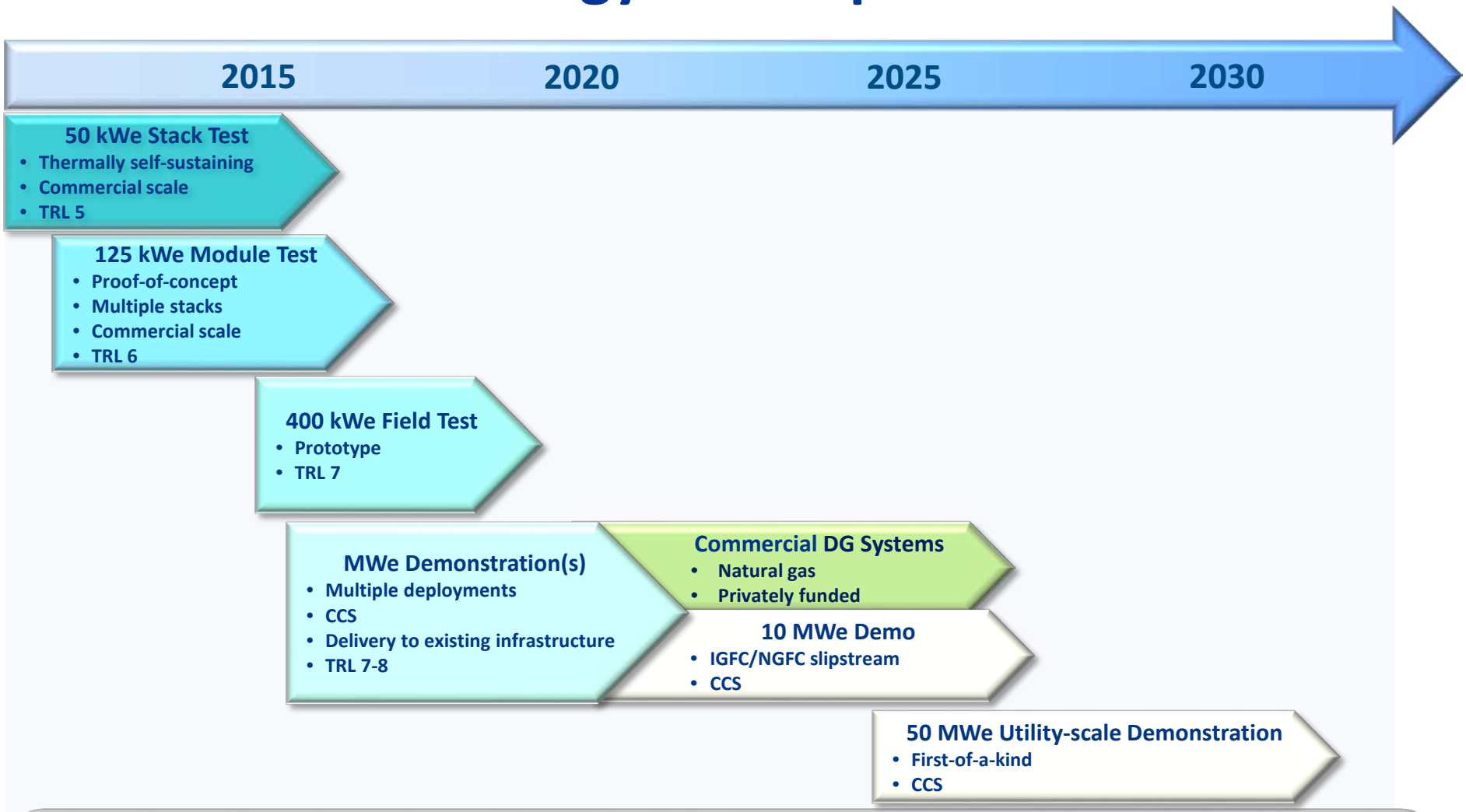
Where we're going …

- Test progressively larger stacks
- Initiate field test of a 400 kWe-class prototype power system
- Continue R&D to reduce cost, improve performance, and improve reliability
- Explore new cell and stack concepts to significantly undercut cost targets

FY15 SOFC Program Update

- **Two competitive solicitations**
  - **FOA-0001244: 400 kWe SOFC Prototype System Testing**
    - 400 kWe SOFC Field Test
    - One award, ~$6M, 30% Participant Cost Share
  - **FOA-0001229: SOFC Innovative Concepts and Core Technology Research**
    - Topic Area 1: Innovative Systems
      - R&D with potential to significantly undercut current DOE cost targets
      - 5 – 10 kWe-scale stack test, 1000 hrs
      - Five awards, ~$2.5M per award, 20% Participant Cost Share
    - Topic Area 2: SOFC Core Technology
      - R&D that improves performance, reliability, and/or endurance of cell or stack technology
      - Lab or bench scale testing on any cell or stack component
      - Ten awards, ~$200k per award, 20% Participant Cost Share
- **Four new SBIR Projects**
- **Closer collaboration with ARPA-E**

SOFC Technology Development Timeline



Natural gas fueled DG systems will establish the manufacturing and operational experience necessary to validate and advance the technology for both natural gas and gasified coal-based central power generation

SOFC Program … *Key Takeaways*

- **Emphasis on increased reliability**
- **Awarded the 1st prototype system field test**
- **Five new projects are focusing on advanced stack/system concepts**
- **Ten new projects developing innovative cell/stack components**

16th Annual SOFC Workshop - Overview

Tuesday

- *Plenary Session: Dr. Grace Bochenek, Director NETL*
- *Industry Team Presentations*
- *Core Technology Teams: Reliability, Robustness, & Endurance*
- *ARPA-E REBELS Projects: IT Fuels Cells for DG*

Tuesday Evening Poster Session and Reception

Wednesday

- *National Laboratories*
- *Core Technology Teams: Reliability, Robustness, & Endurance*
- *ARPA-E REBELS Projects: IT Fuels Cells for DG*
- *ARPA-E REBELS Projects: Load-Following IT Fuels Cells*

Thursday

- *Core Technology Teams: Reliability, Robustness, & Endurance*
- *ARPA-E REBELS Projects: Liquid Fuel-Producing IT Fuels Cells*
- *ARPA-E REBELS Projects: Load-Following IT Fuels Cells*
- *ARPA-E REBELS Projects: SOFC Projects*

SOFC FY15 Program Participants

Websites and Contact Information

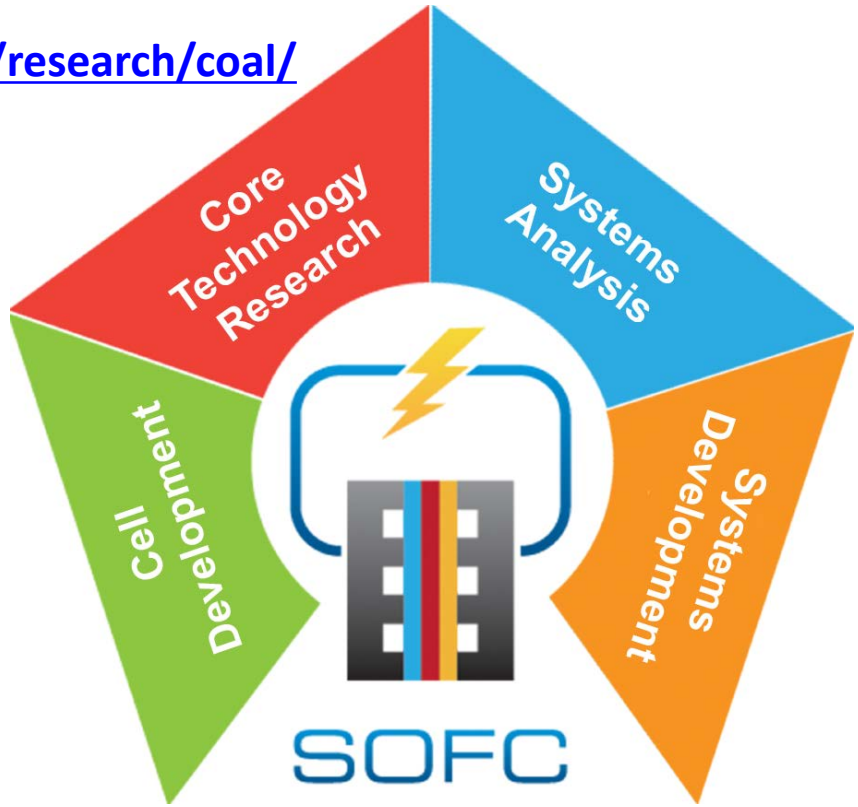
Office of Fossil Energy: www.energy.gov/fe/office-fossil-energy

NETL Website: www.netl.doe.gov/

SOFC Program website: www.netl.doe.gov/research/coal/energy-systems/fuel-cells

Reference Shelf:

- SOFC Program FY15 Project Portfolio
- SOFC Technology Program Plan
- Technology Readiness Assessment
- Past SECA Workshop Proceedings
- Systems Analysis
- Fuel Cell Handbook



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www.netl.doe.gov/research/coal/energy-systems/fuel-cells

SOFC Program – FY15 Awards

FOA-0001229: SOFC Innovative Concepts and Core Technology Research	
Topic Area 1 - Innovative Systems	
LG Fuel Cell Systems	Advanced Materials and Manufacturing Processes for MW-scale SOFC Power Systems for Improved Stack Reliability, Durability and Cost.
FuelCell Energy	Innovative SOFC Technologies
General Electric	Development of a Thermal Spray Redox Stable, Ceramic Anode for Metal Supported SOFC
Redox Power Systems	High Power, Low Cost SOFC Stacks For Robust And Reliable Distributed Generation
U.C. San Diego	Innovative Versatile and Cost-Effective Solid Oxide Fuel Cell Stack Concept
Topic Area 2 - SOFC Core Technology	
Acumentrics	Matrix Study of Aged SOFC Performance and Materials Degradation
Boston University	Processing of SOFC Anodes for Enhanced Intermediate Temperature Catalytic Activity at High Fuel Utilization
Georgia Tech	Low-Cost, Durable, Contaminant-Tolerant Cathodes for SOFCs
Kettering University	LSCF-CDZ Composite Cathodes for Improved SOFC Electrical Performance
MIT	Self-regulating surface chemistry for more robust highly durable solid oxide fuel cell cathodes
Montana State University	Enhancing High Temperature Anode Performance with 2° Anchoring Phases
Tennessee Tech. University	Development of Low-Cost, Highly-Sinterable, Co-Free (Ni,Fe)3O4 Spinel-Based Contact Materials for SOFC Cathode-Side Contact Application
University of Maryland	In-Operando Evaluation of SOFC Cathodes for Enhanced ORR Activity and Durability
University of South Carolina	Developing Accelerated Test Protocols and Tuning Microstructures of the Common Materials to Improve Robustness, Reliability, and Endurance of SOFC Cells
West Virginia University	Scalable Nano-Scaffold Architecture On the Internal Surface of SOFC Anode For Direct Hydrocarbon Utilization
FOA-0001244: 400 kWe SOFC Prototype System Testing	
FuelCell Energy	SOFC Prototype System Test