U.S. DOE Office of Fossil Energy Solid Oxide Fuel Cell (SOFC) Program

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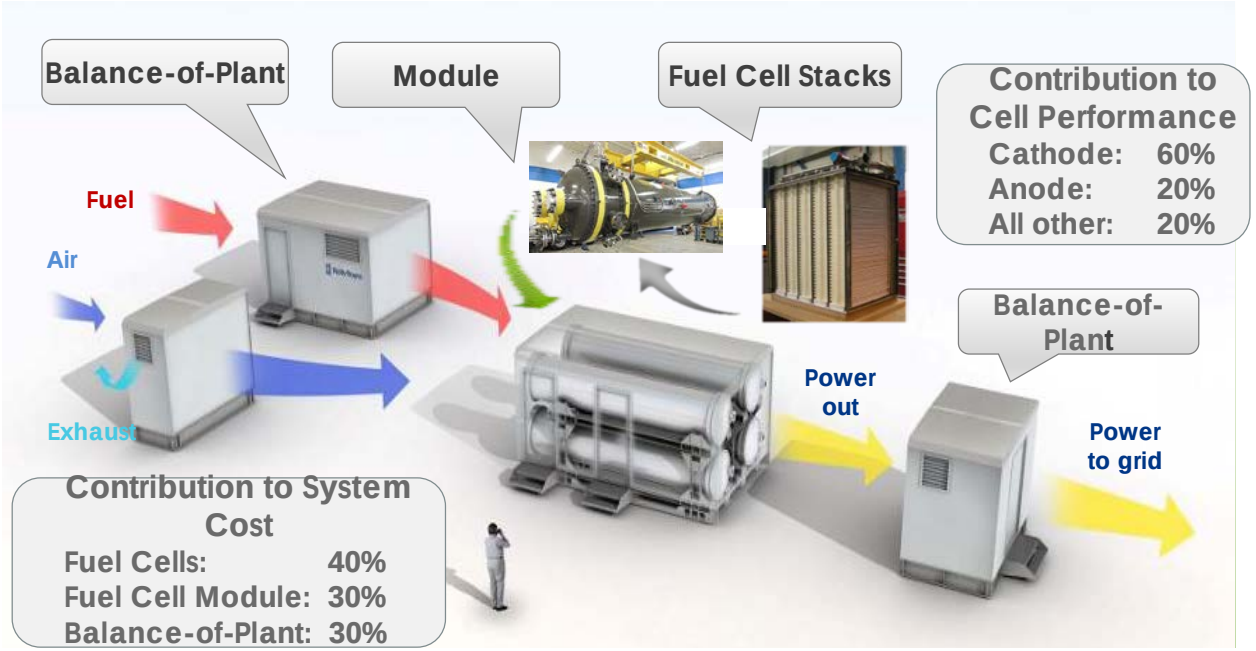
Fuel Cells Are…..

- Energy conversion devices
- Highly efficient
- Modular
- A family of technologies characterized by the electrolyte:
  - Low Temperature
    - Proton Exchange Membrane (PEM)
    - Phosphoric Acid (PAFC)
  - High Temperature
    - Molten Carbonate (MCFC)
    - Solid Oxide (SOFC)



SOFC Power System

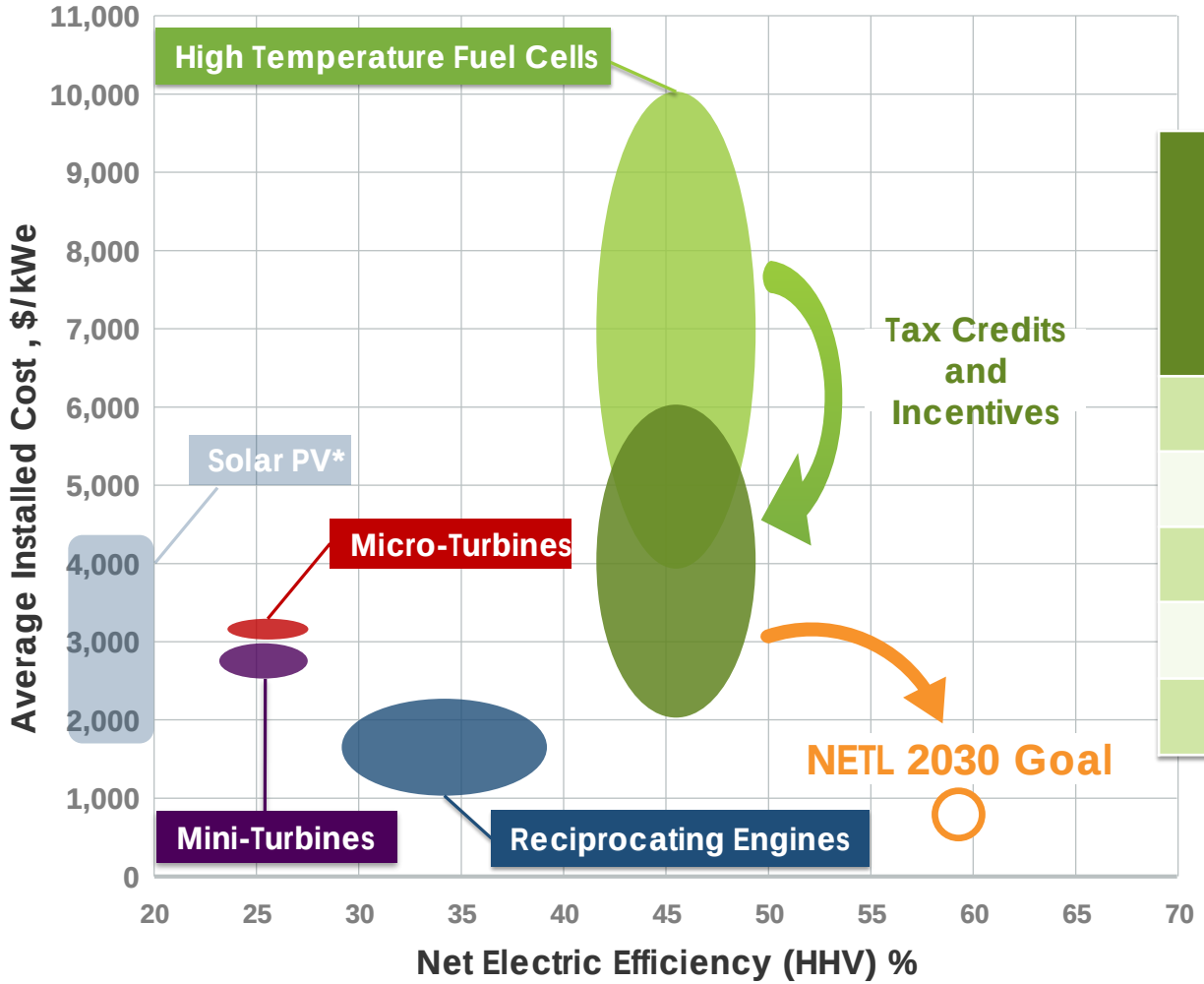
Figure courtesy LG Fuel Cell Systems

SOFC Program Mission

To enable the generation of efficient, low-cost electricity with intrinsic carbon capture capabilities for:

- Near term: Natural gas-based distributed generation
- Long term: Coal and natural gas utility-scale applications with Carbon Capture and Sequestration (CCS)

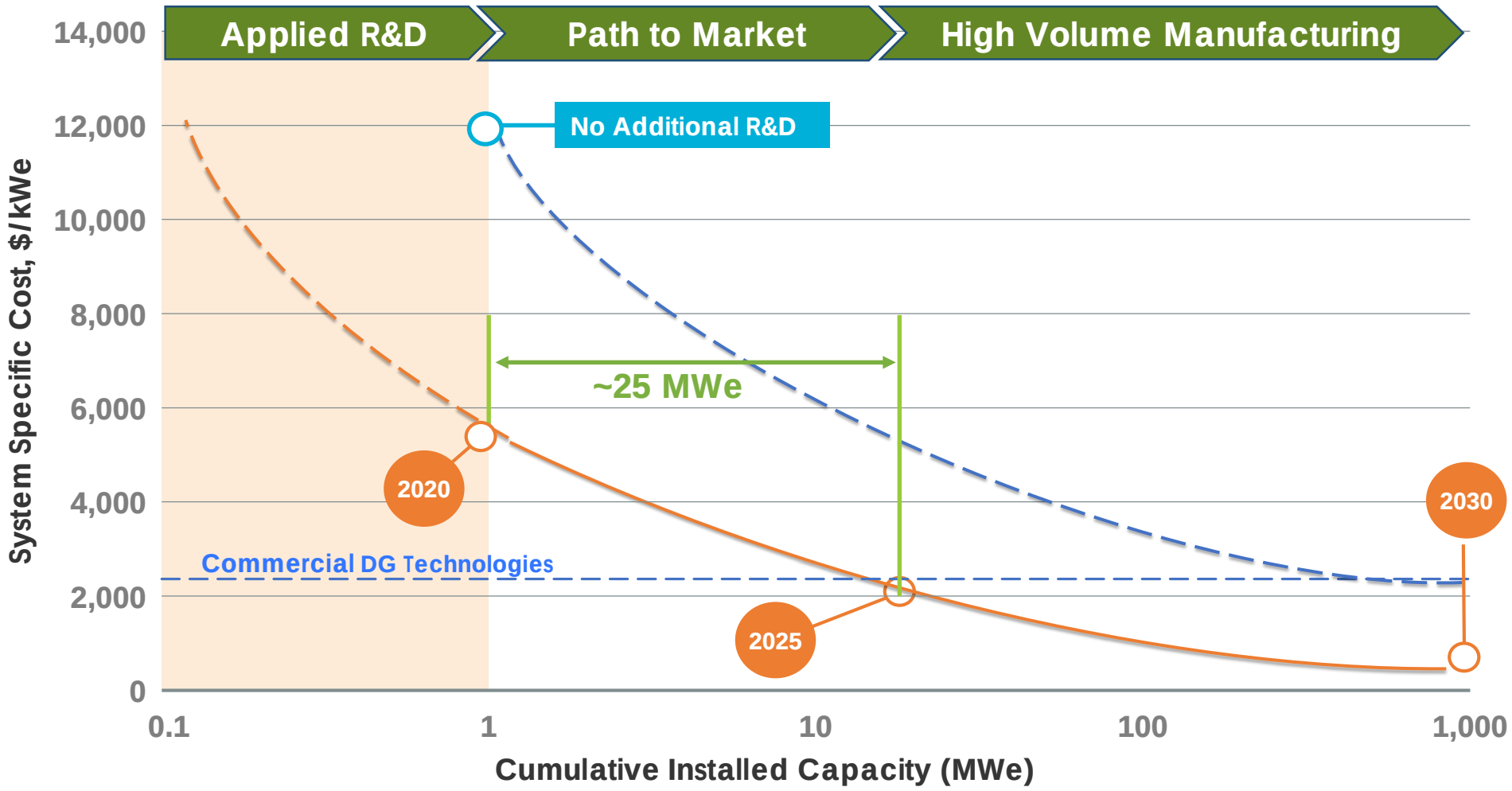
Distributed Generation Technologies



DG TECHNOLOGY	RATED POWER RANGE (kW)	
	LOW	HIGH
Micro-Turbines	65	250
Mini-Turbines	300	3,000
Reciprocating Engines	100	5,000
Solar PV	100	1000
High-Temperature Fuel Cells	300	1,200

**For non-grid-support applications storage costs (2000 $/kW – 3000 $/kW) may need to be included*

SOFC DG System Cost Reduction
via RD&D and high volume manufacturing



SOFC Program Structure

Key Technologies

TECHNOLOGY AREA	KEY TECHNOLOGIES
SOLID OXIDE FUEL CELLS	Cell Development
	Core Technology
	Systems Development

Figure courtesy NETL

Figure courtesy LG Fuel Cell Syster

Figure courtesy FuelCell Energy

SOFC Program

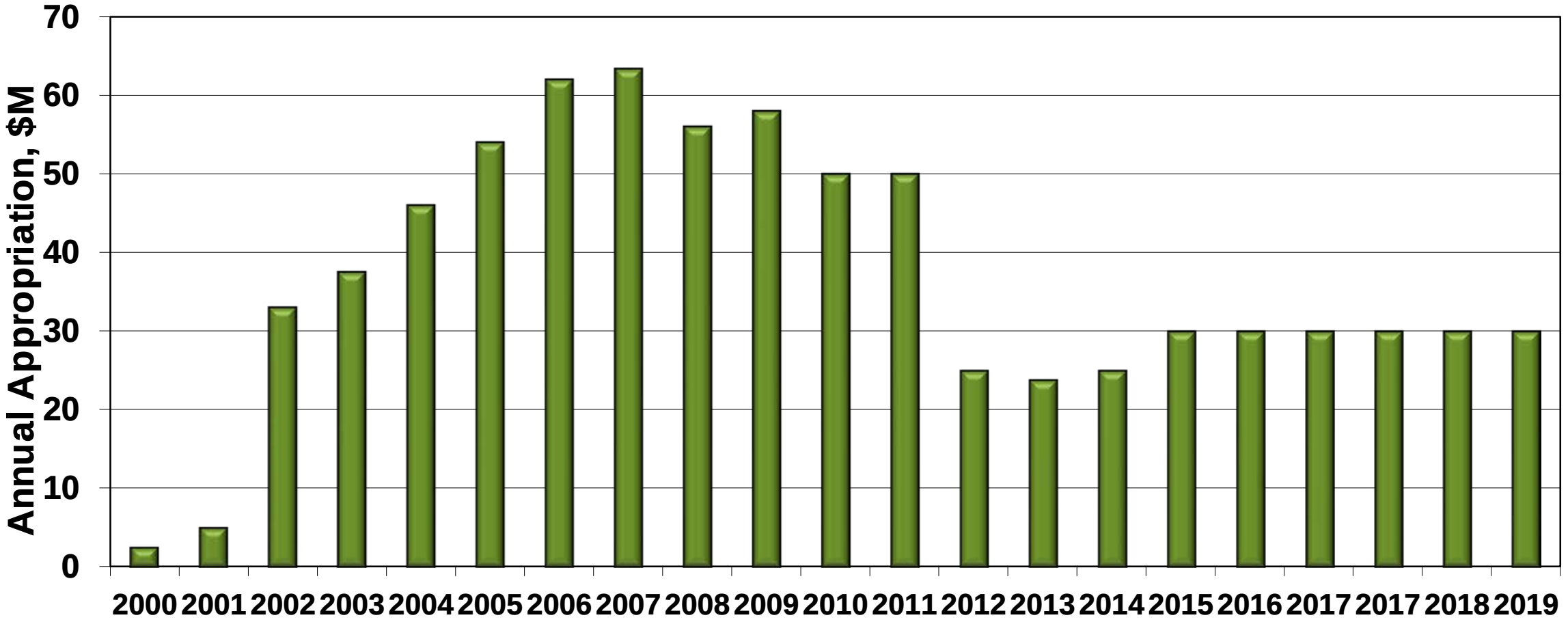
R&D Approach

- **Applied Research**
  - Cell and Core Technologies
  - TRL 2 – 5
  - Collaboration with an SOFC developer (industry) encouraged

- **Development**
  - State-of-the-Art systems development
  - Innovative Concepts
  - TRL 5 – 6

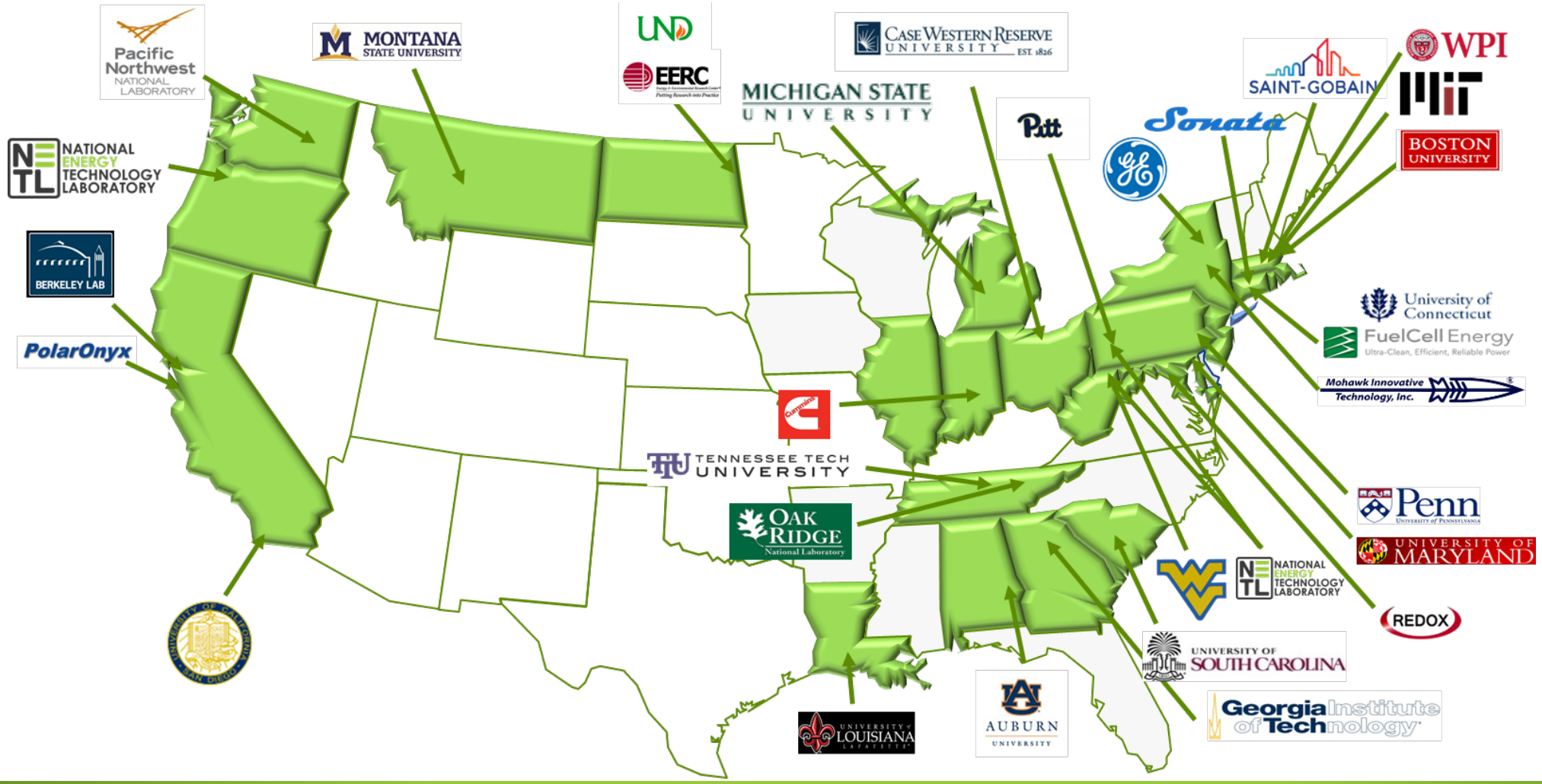
SOFC Program

Funding History



SOFC Program Project Portfolio

FY19 Participants



SOFC Program Technology Evolution

MODULES

STACKS

CELLS

SYSTEMS

10 kWe-Class Stack Tests
- Improved efficiency, 35 – 41%
- Reduced degradation, <2%/1000 hr
- Cost target at high volume achieved (extrapolated)

200 kWe Prototype Field Test
(two in-progress)

10 MWe Pilot
(planned)

50 MWe Utility-Scale Demo
(planned)

Cell and Stack Performance Improvements
- Increased cell area by 5x
- Increased cell power by 10x
- Degradation reduced to 0.2 - 0.5%/1,000 hrs

MWe-Class Pilot
(planned)

Cell Development
- increased power
- Established material set
- Improved reliability
- Reduced cost

Proof-of-Concept Systems
- Two POC systems, 50kW & 200 kW
- Efficiency improvements to >55%

200 kWe POC
(courtesy LG Fuel Cell Systems)

50 kWe POC
(courtesy FuelCell Energy)

Technology Validation

2000 2010 2020 2030

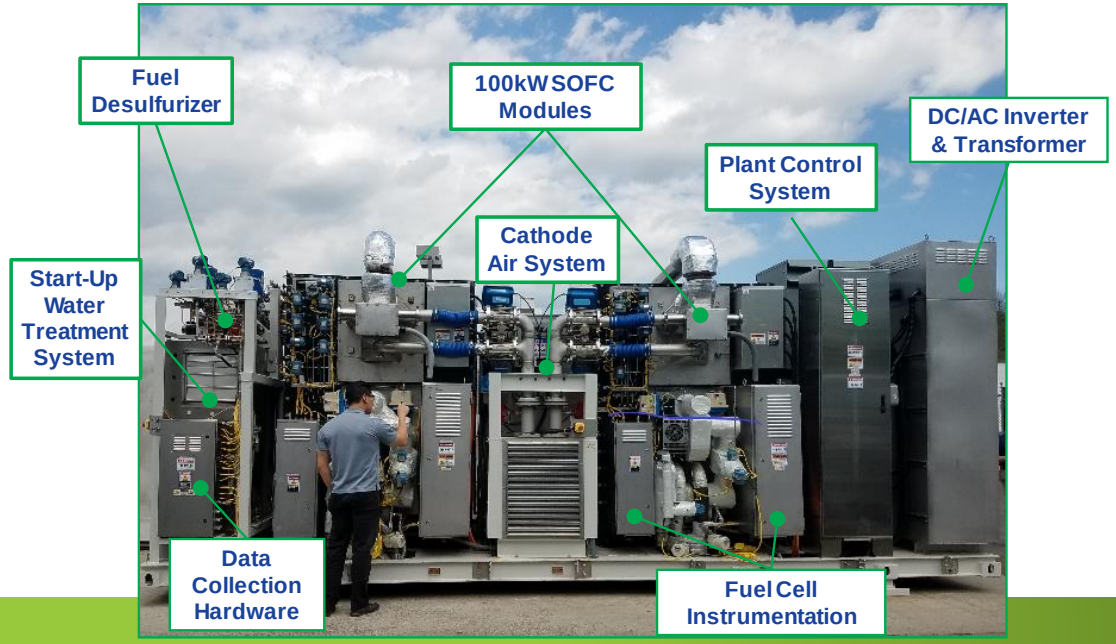
SOFC Program Metrics

Metric	Current	2020 Target	2025/2030 Target
System Cost (100 kW- 1MW)	**>$12,000/kWe**	**$6,000/kWe**	**$900/kWe**
Single Cell Degradation	0.2 - 0.5% per 1,000 hrs		
Cell Manufacturing Approach	Batch	Semi- Continuous	Continuous
System Degradation	**1 – 1.5% per 1,000 hrs**	**0.5 - 1.0% per 1,000 hrs**	**<0.2% per 1,000 hrs**
Fuel Reformation	Primarily external natural gas conditioning/reforming	100% integrated natural gas reformation inside cell stack	
Durability	**<2,000 hrs**	**5,000 hrs**	**5 years**
Platform	Proof-of-Concept	Prototype/Pilot	DG: Commercial Utility-scale: Pilot
Configuration	Breadboard/Integrated systems	Fully packaged	Fully packaged
Fuel	**Natural gas**	**Natural gas Simulated syngas**	**Natural gas Coal-derived syngas**
Demonstration Scale	**50 kWe – 200 kWe**	**200 kWe – 1 MWe**	**DG: MWe-class Utility-scale: 10 – 50 MWe**

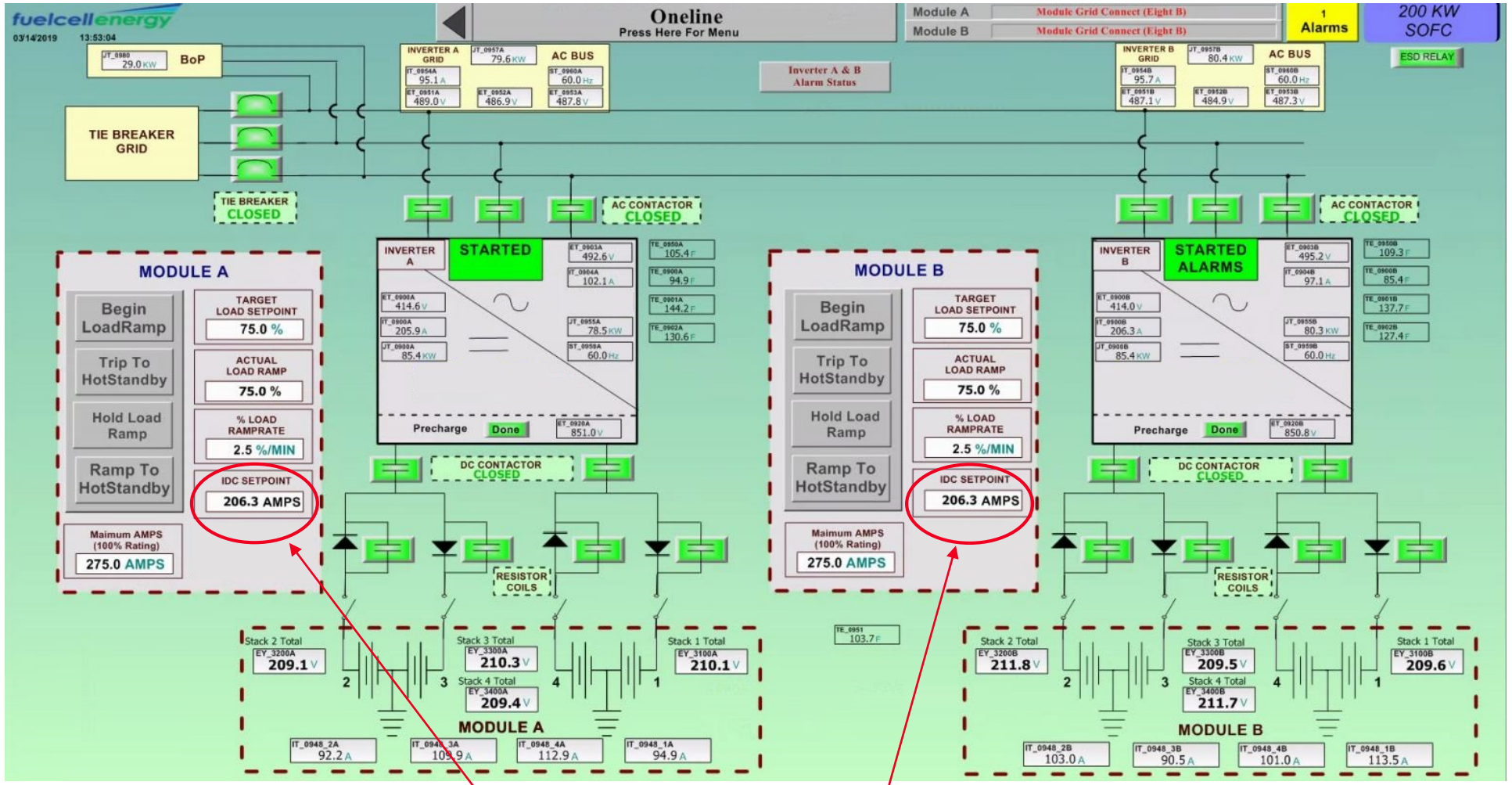
Single-cell performance and degradation are acceptable; stack and system performance, reliability and endurance need to be demonstrated

SOFC Power System
FuelCell Energy 200 kW Prototype Field-Test

- 200 kWe integrated SOFC Power System
- Test site: NRG Energy Center Pittsburgh, PA
- Natural gas fuel
- Grid Connected
- ~3,000 hours of operation



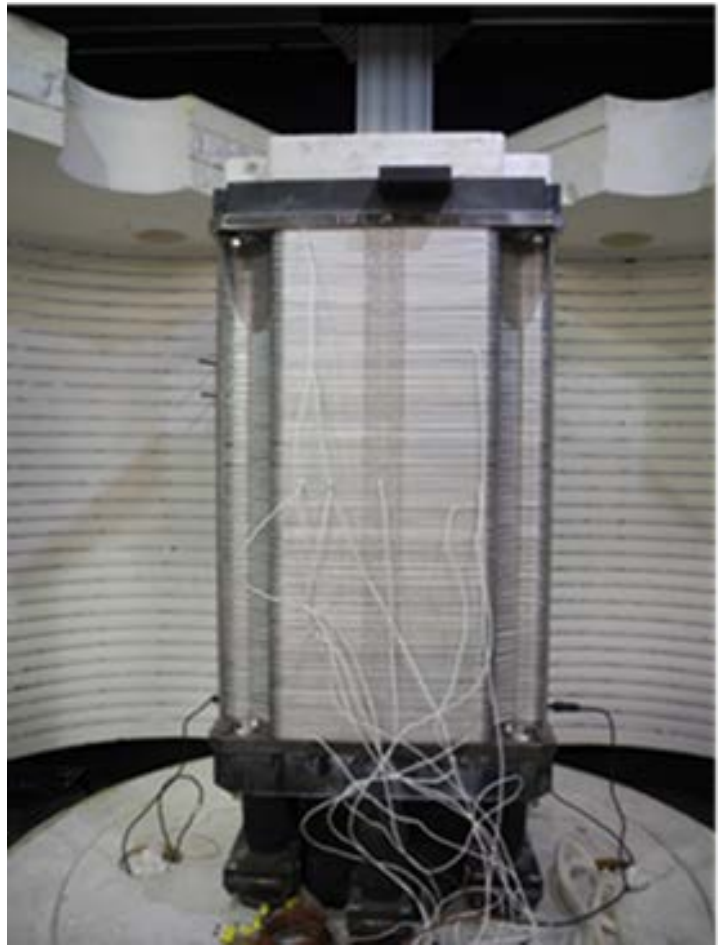
200 kW SOFC Oneline HMI Screen



Current Control:

Individual set-point sent to respective Inverter

Next Generation Stack Technology



Baseline Large Area Stack (LAS):

- 76 W/kg
- 185 W/L

Compact SOFC Architecture (CSA)

Full Height CSA Stack:

- 470 W/kg
- 780 W/L

SOFC Program

Key Takeaways

- Program emphasizing the resolution of design, operation, and performance considerations at the system level
- Acquiring fabricating and operational experience on integrated, prototype field tests based on state-of-the-art cell and stack technology
- Cell Development and Core Technology research continues and is well aligned with industry need

For Additional Information

Office of Fossil Energy: www.energy.gov/fe/office-fossil-energy
NETL Website: www.netl.doe.gov/

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