Reliable Electricity Based on ELectrochemical Systems (REBELS)

Program Overview

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Outline

REBELS Motivation

- Changing Nature of the Grid
- Materials Opportunities

Program Overview

Early, Exciting Results

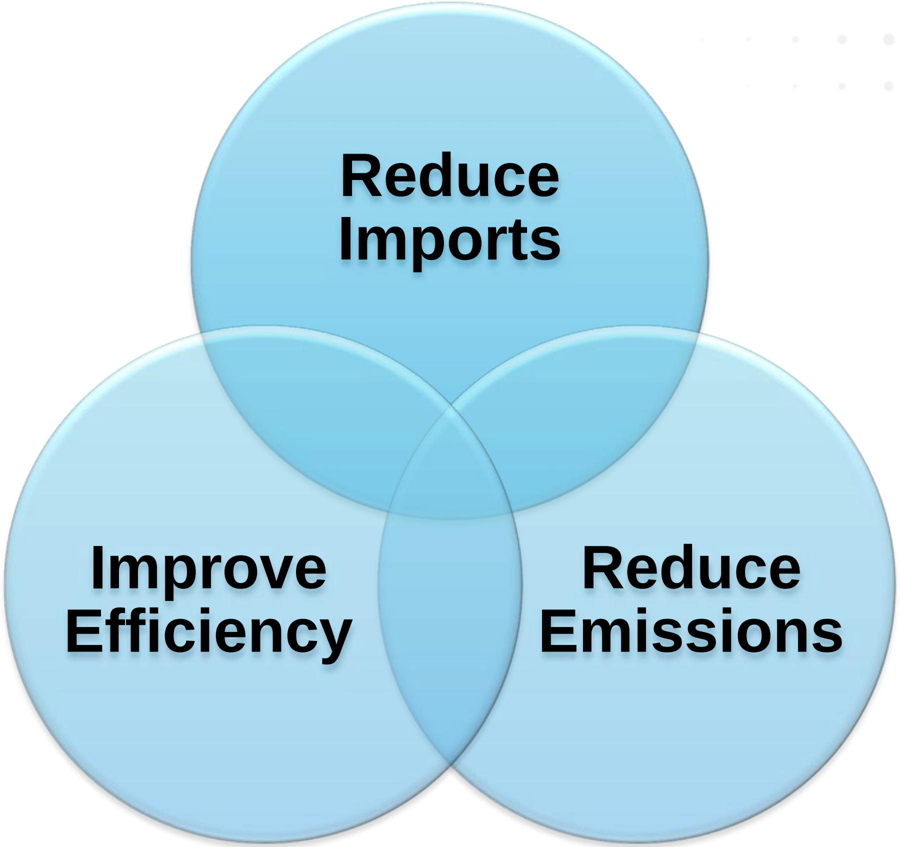
Summary

The ARPA-E Mission

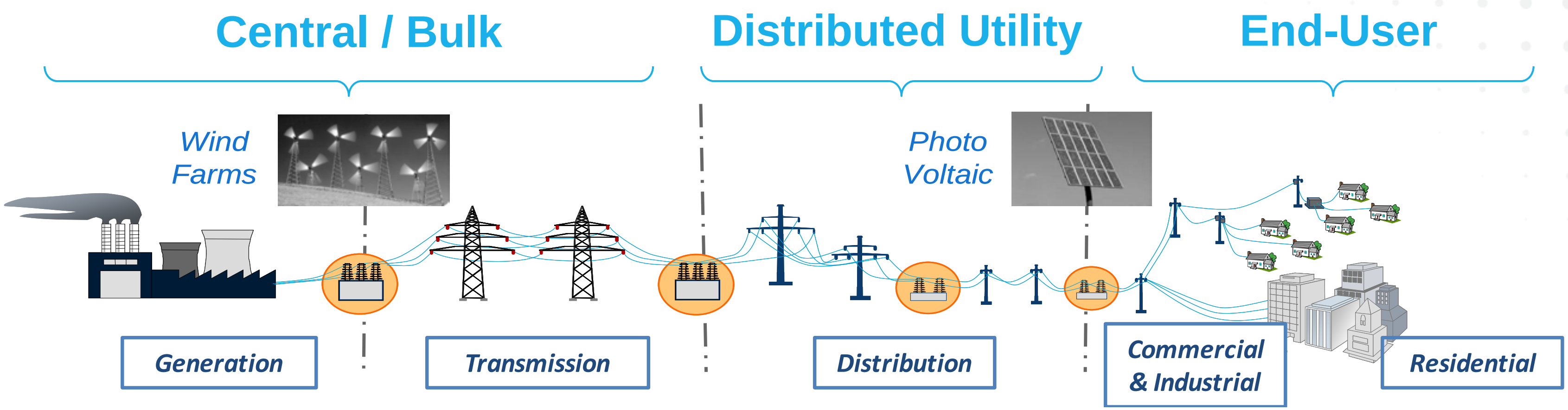
Catalyze and support the development of transformational, high-impact energy technologies

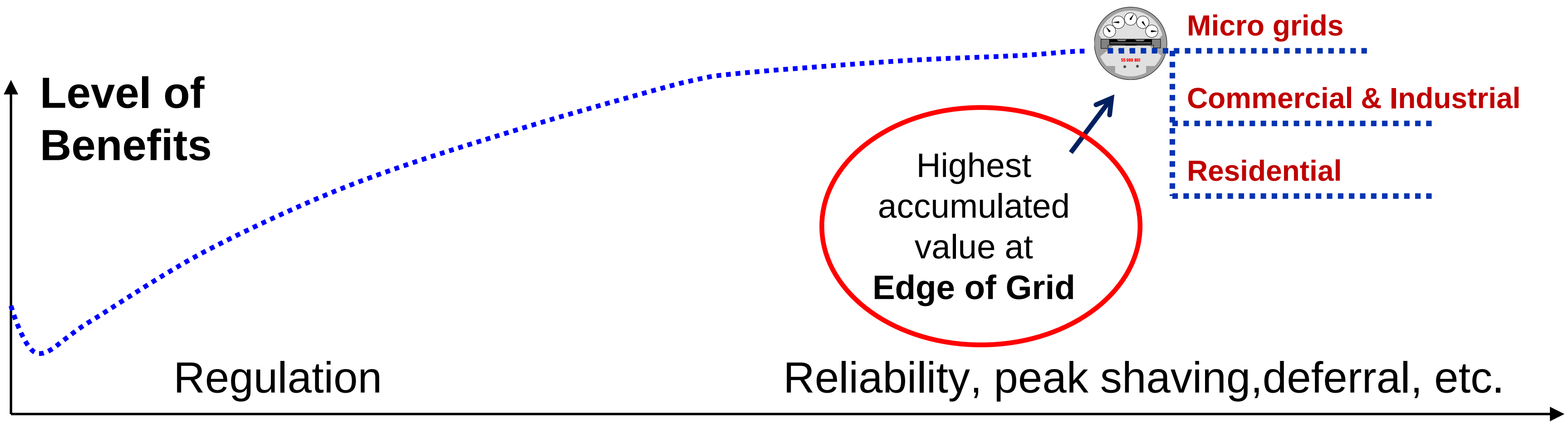
Ensure America's

- National Security
- Economic Security
- Energy Security
- Technological Lead



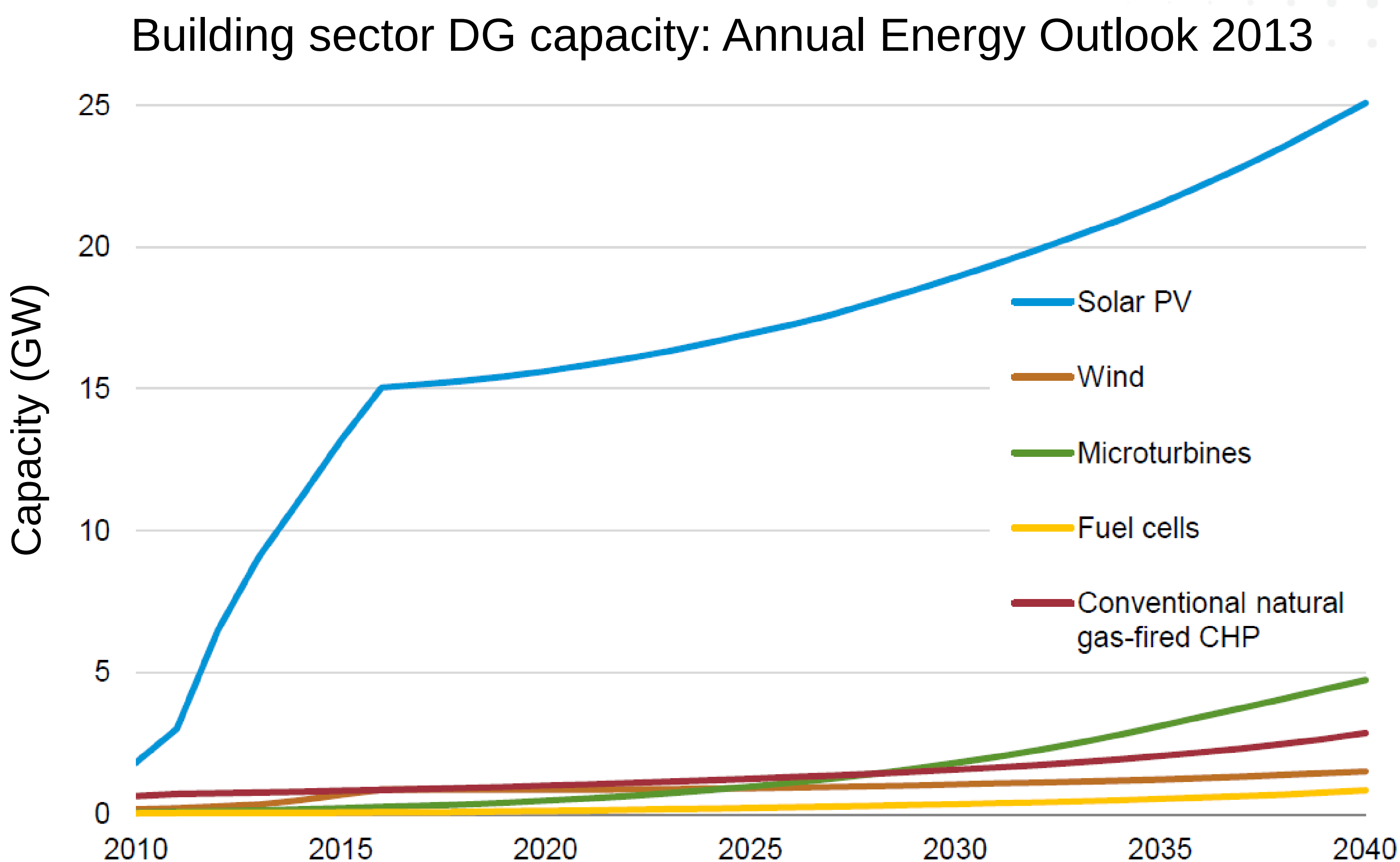
The Value of Distributed Generation (DG)





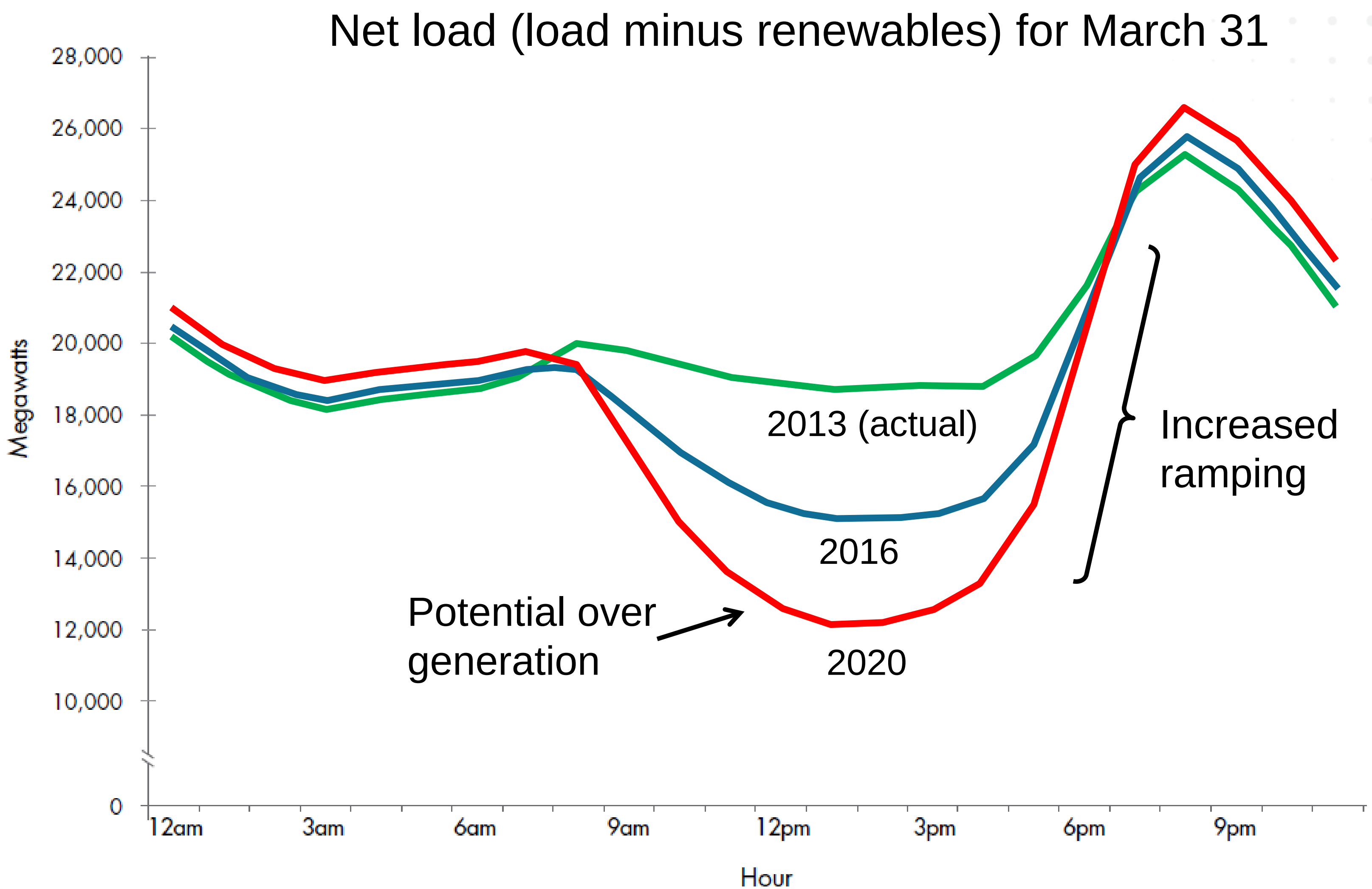
Distributed Generation Markets – Impact of Future Fuel Cell Applications, DNV KEMA report prepared for ARPA-E (2013); Cost-Effectiveness of Distributed Generation Technologies, Iton, submitted to PG&E, 2011

Distributed generation (DG) is rapidly increasing



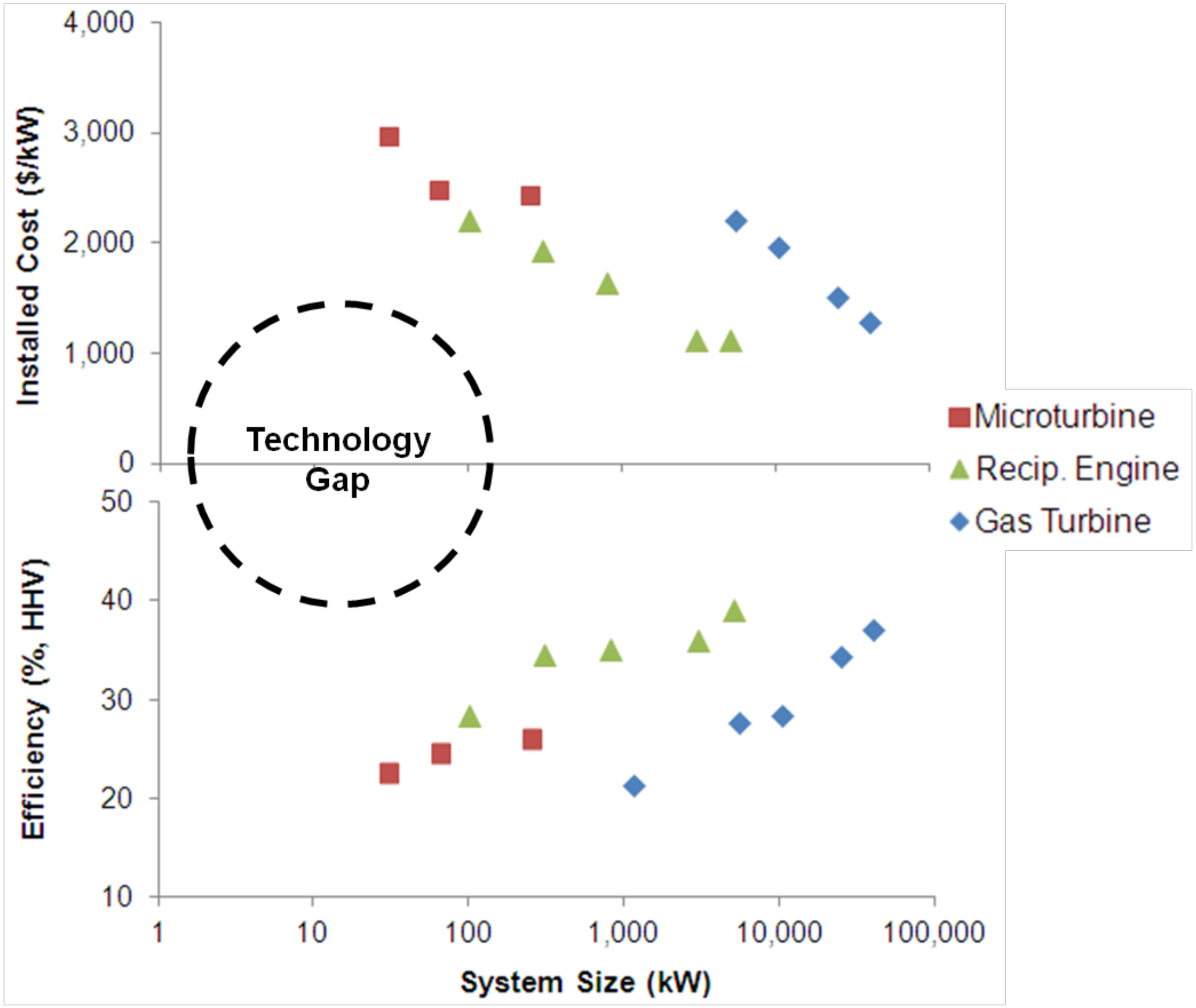
http://www.eia.gov/forecasts/aeo/nems/2013/buildings/pdf/distribgen.pdf

The grid requires more flexible ramping



Adapted from
http://www.caiso.com/Documents/DR-EERoadmap.pdf

Gap in Small DG Prime Movers



Maintenance Intervals (hrs)	
Gas Turbine	4,000-8,000
Microturbine	5,000-8,000
Recip. Engine	1,000-2,000

Opportunities for FCs

- Near-term: increased reliability and resiliency
- Operate more flexibly than engines or turbines
- Long-term: inexpensive, reliable small prime movers

Source: Catalog of CHP Technologies, EPA CHP partnership (2008)

A new fuel cell temperature range

Temperature (^oC)

800

600

400

200

SOFC

Power density

Fuel flexibility

Seals, interconnects

Thermal cycling

Stack lifetime

NETL focus

???

PEM

Rapid start

Simpler materials integration

Pure hydrogen only

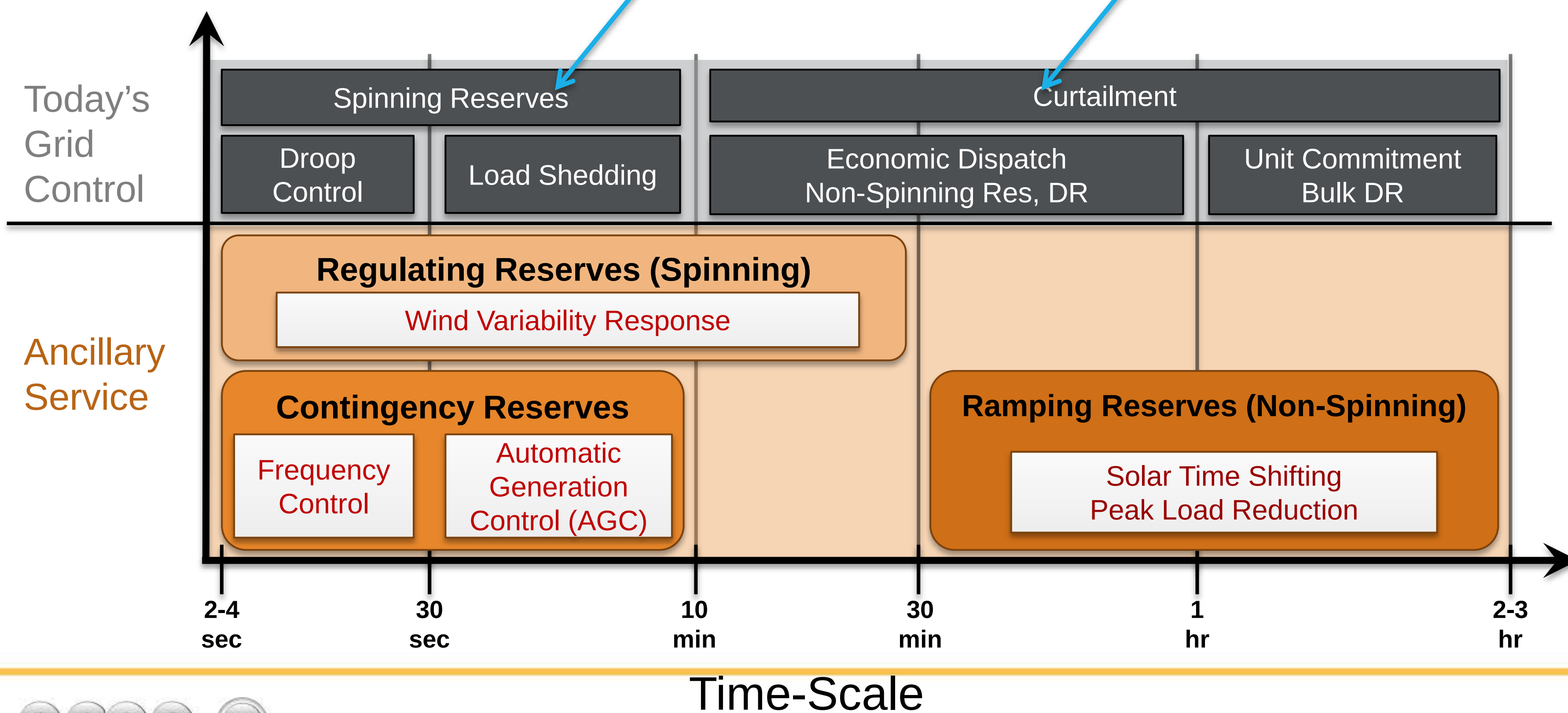
Expensive catalysts

Complex system

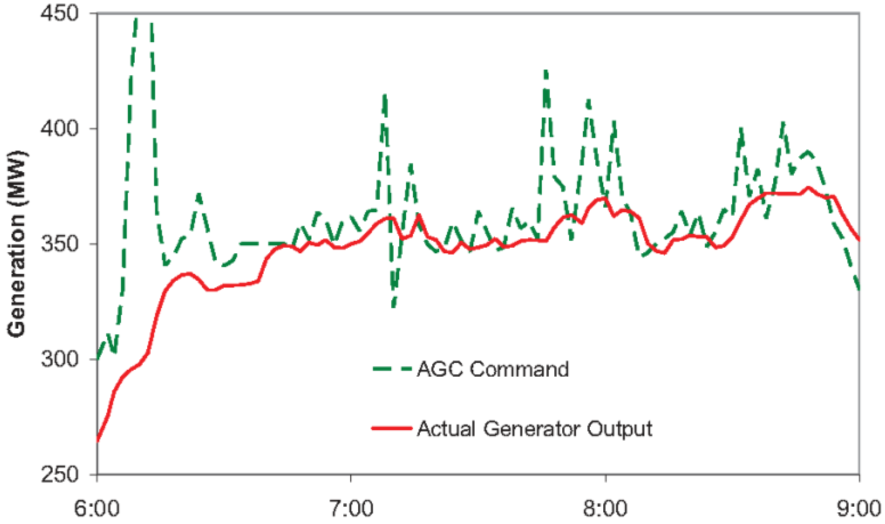
EERE focus

Grid Ancillary Services

- Ancillary Services Categories
  - Contingency reserves
  - Regulating re
  - Ramping reser
- Reserve Control Resources
  - Generators Inertial Response (sec)
  - Spin in)
  - Non-s (min-hrs)

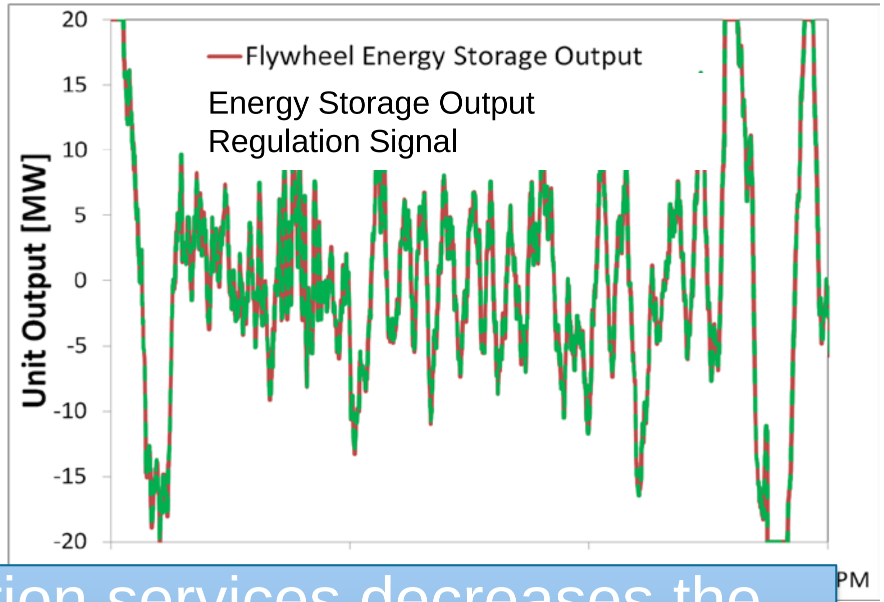


Battery Performance in Regulation



A fossil plant following a regulation command signal. (left)

Energy Storage accurately following a regulation command signal. (right)

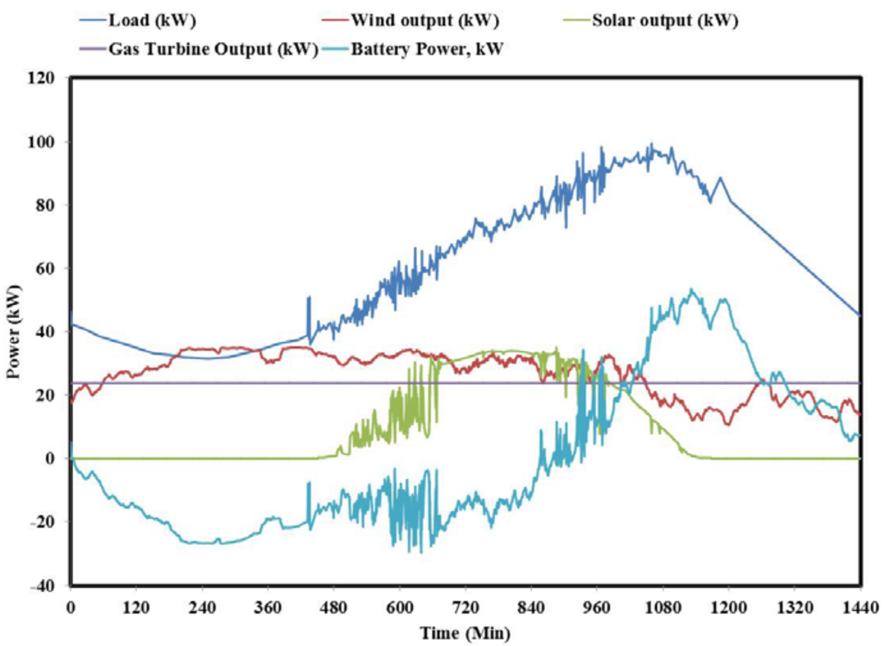


The high value of regulation services decreases the cost constraints for grid storage that can meet performance requirements.

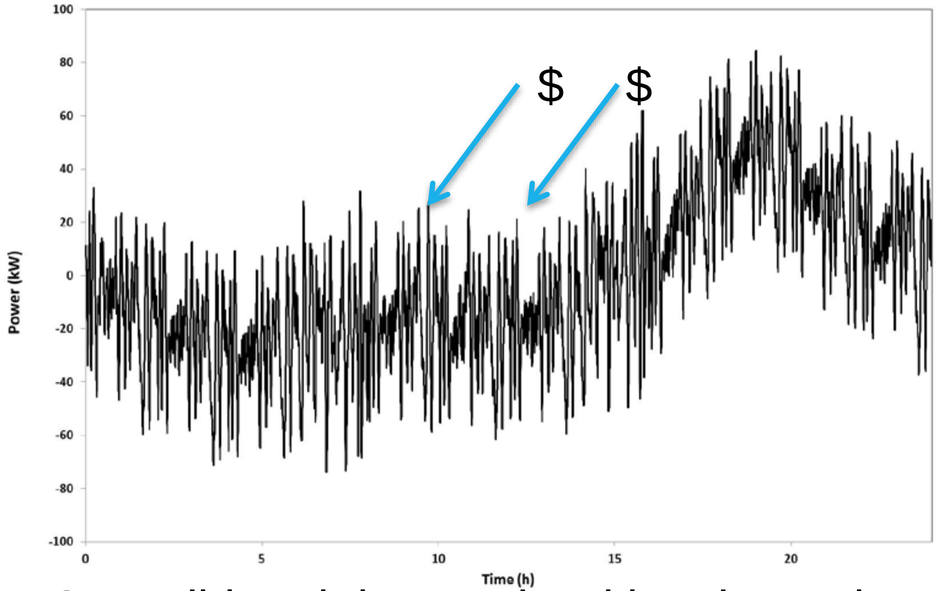
Courtesy Scott Baker, PJM

Predicted Ramping Requirements (CAISO)

Load and generation mix for micro-grid



Micro grid ES duty cycle

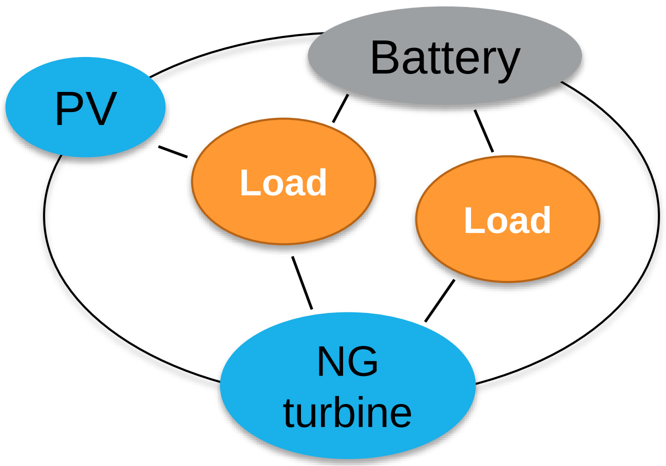


Consolidated duty cycle with solar and wind smoothing with regulation.

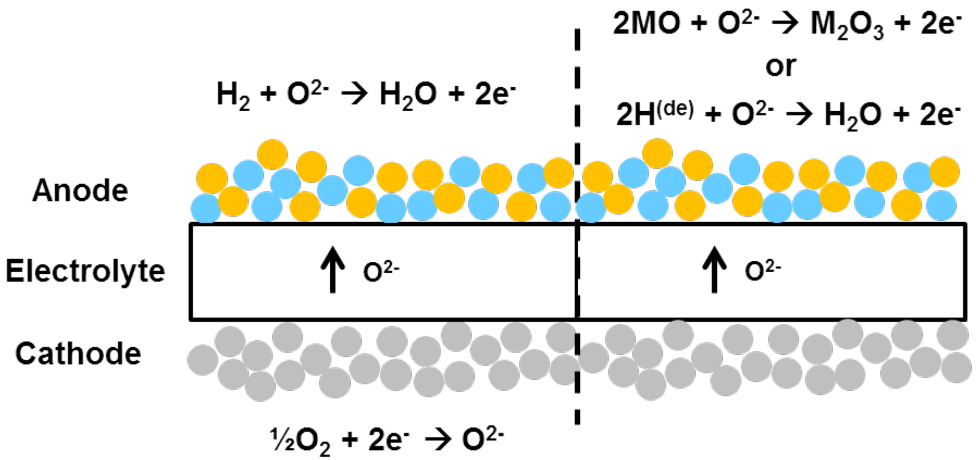
Stacking multiple grid application with different values increases the value of grid storage.

Adding flexibility: integrating generation and storage

System Level

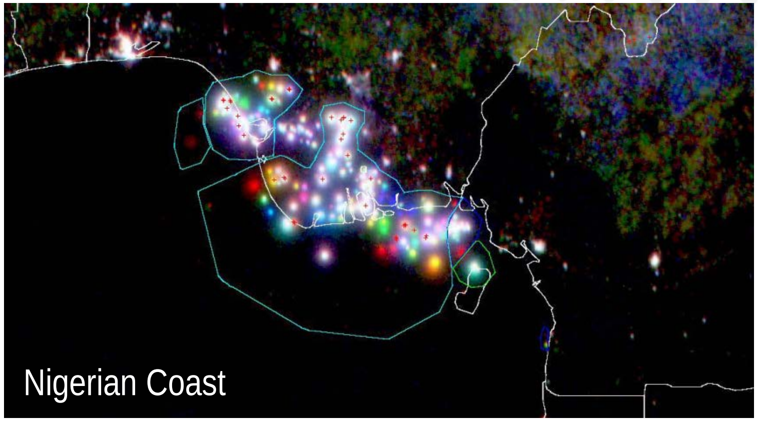


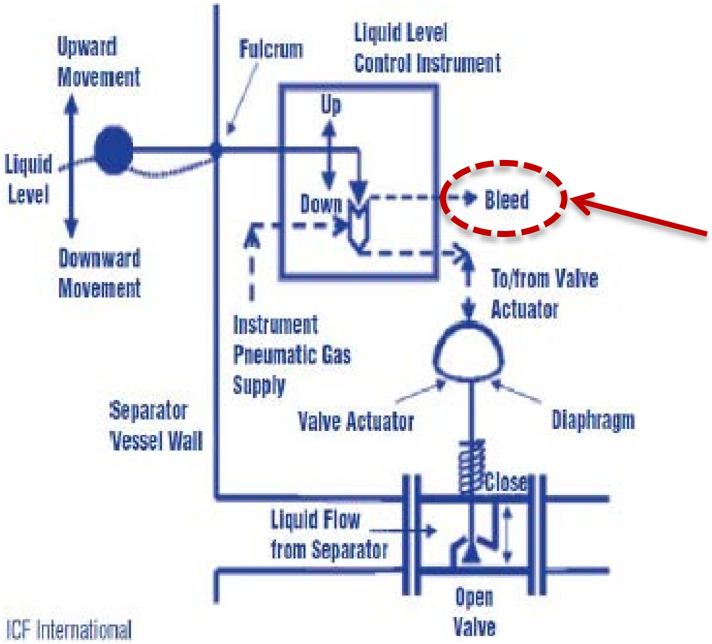
Device Level



Flaring and venting of stranded NG

- 5.3 trillion cubic feet of natural gas flared annually
  - 5 quadrillion BTUs
  - 25% US electricity production

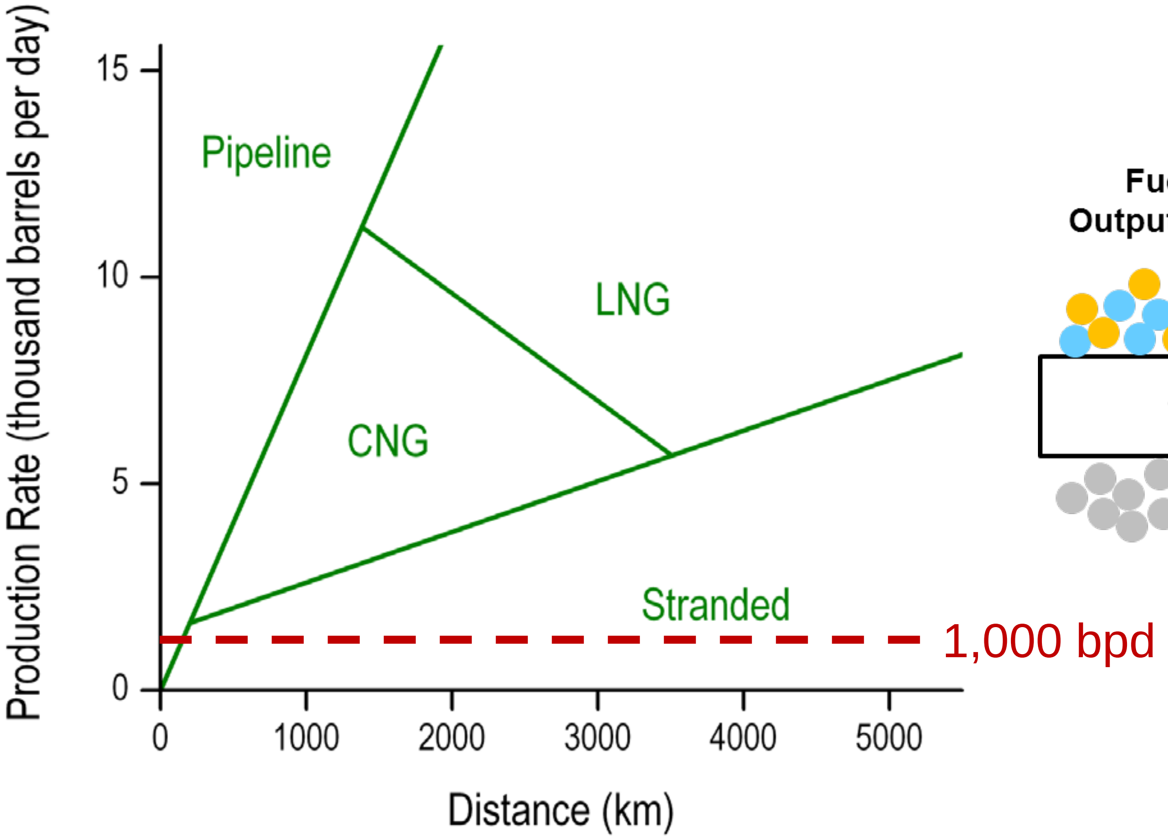


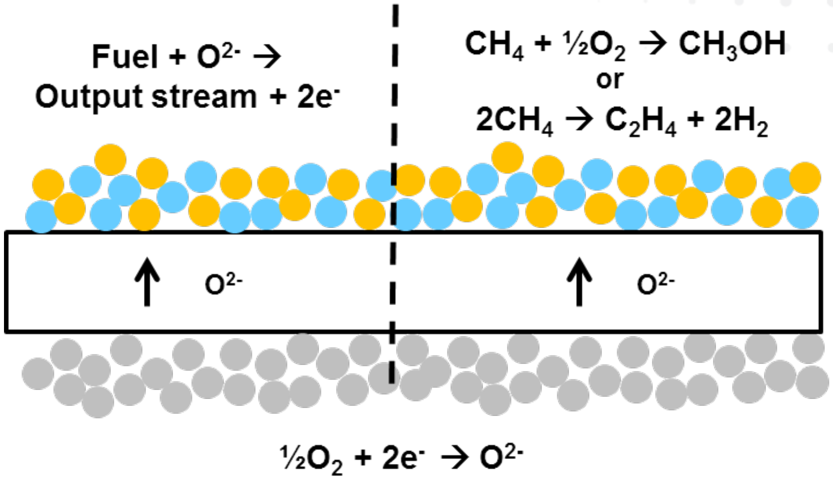


- Pneumatic devices use NG pressure to drive pumps, regulators, and valves & then vent
- > 20 million tons CO_2 eq. annually: 20-35% of production-related emissions

Source: World Bank, Global Gas Flaring Reduction Partnership, 2012

Adding flexibility: using stranded natural gas





Source: D. Hawkins, TransOcean,Global, Gas Flaring Reduction Conference, Paris Dec 13-15, 2006

New(er) electrolytes for IT fuel cells

Not an exclusive list:

LT SOFCs

- Composite electrolytes with interfacial pathways
- Multilayer electrolytes

IT Proton Conductors

- Ba(Zr, Ce, Y)O_3
- Solid acid fuel cells
- Indium tin pyrophospate

Other Ionic Conductors

- HT alkaline
- HT phos acid
- LT molten carbonate

Intermediate temperature fuel cells (ITFCs)

	Compared to Low T	Compared to High T
Strengths	• Lower PGM loading • Less fuel processing • Less cooling required	• Cheaper interconnects & seals • Fewer CTE problems • Greater ability to ramp/cycle
Weaknesses	• Longer start-up • Cycling ability less clear	• Higher resistance & overpotentials • Fuel reforming issues

Reliable Electricity Based on ELectrochemical Systems (REBELS)

200-500 °C fuel cell operation

Nearer-term to market

Longer-term to market

FUEL CELL

REDOX – Redox Power Systems, LLC

SAFCell

Oak Ridge National Laboratory

United Technologies Research Center

Colorado School of Mines – Earth • Energy • Environment

parc – Palo Alto Research Center

Georgia Tech

FUEL CELL + BATTERY MODE

Si Energy Systems, LLC – An Allied Minds Company

University of South Carolina

UCLA

FUEL CELL + FUEL PRODUCTION

FuelCell Energy – Ultra-Clean, Efficient, Reliable Power

MSRI – Materials and Systems Research, Inc.

Argonne National Laboratory

Duration of stored energy →

Category 1 Projects

Colorado School of Mines (Earth • Energy • Environment)	Mixed proton, oxygen ion conducting electrolyte, single reduced T firing step
Georgia Tech	Nanostructured cell materials, low temperature reforming catalysts
Oak Ridge National Laboratory	Nanostructured SAFC electrode with low Pt loading, modify reformer for lower T operation
parc® Palo Alto Research Center	Novel electrolyte that transports oxygen in a form that enables direct reaction with fuel
REDOX (Redox Power Systems, LLC)	Bismuth oxide/ceria bilayer electrolytes, ceramic redox-stable anodes for fuel flexibility & cycling
SAFCell	SAFC electrodes with carbon nanotubes and metal-organic framework catalysts to eliminate Pt
United Technologies Research Center	IT electrolyte in a metal-supported cell where the reformer is integrated with the stack

Category 2 Projects

Si Energy Systems, LLC — An Allied Minds Company

Multifunctional anode for direct hydrocarbon operation & charge storage; thin film platform

University of South Carolina

SOFC / metal-air redox battery with new solid electrolyte and Fe-based redox-active chemical bed

UCLA

Metal oxide electrodes with high electronic and protonic conductivity; high charge storage capacity

Category 3 Projects

Argonne National Laboratory

IT conversion of methane to ethylene enabled by a hydrogen pump

FuelCell Energy — Ultra-Clean, Efficient, Reliable Power

Develop IT methane-to-methanol catalysts and fabricate via reactive spray deposition technique

MSRI — Materials and Systems Research, Inc.

All thin-film ITSOFC made by mass production-enabled process with optimized electrode morphology

IT enables new electrodes

Conductivity and stability of a new cathode

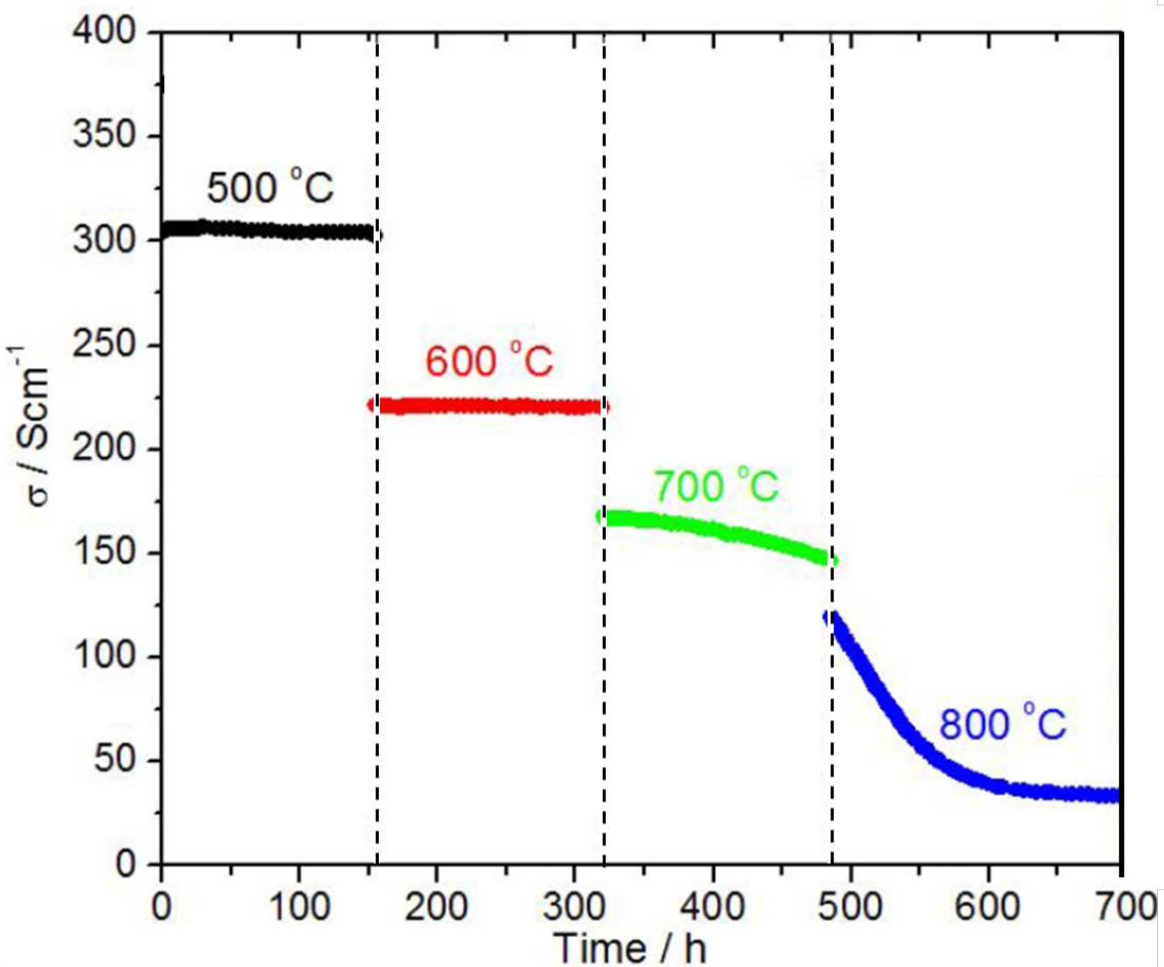


Figure courtesy of K. Huang, University of South Carolina

Direct operation on methane at IT

140 mA/cm² at 0.78 V at 500 °C

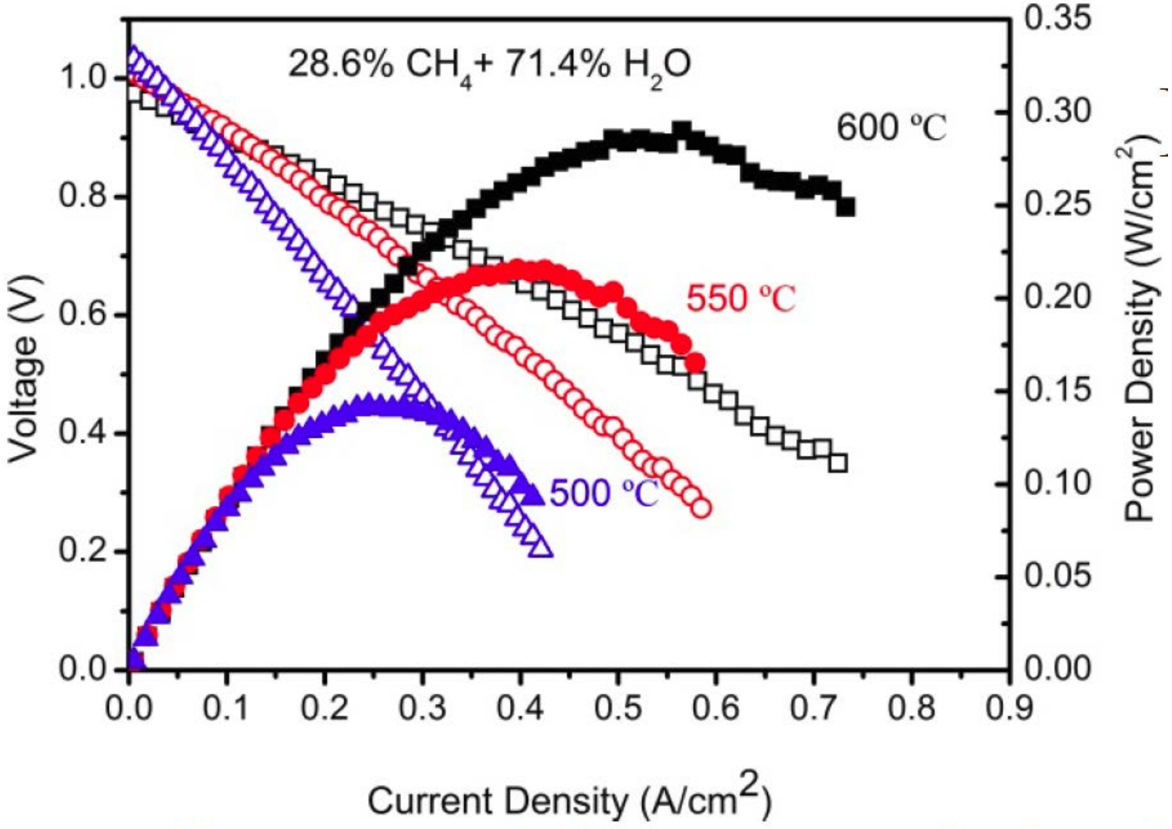


Figure courtesy of R. O'Hayre, Colorado School of Mines. Accepted for publication, *Science* (2015)

Dynamic fuel cell operation

Short stack operating at 550-600 ºC shows fast response to cycling between 0-15 A

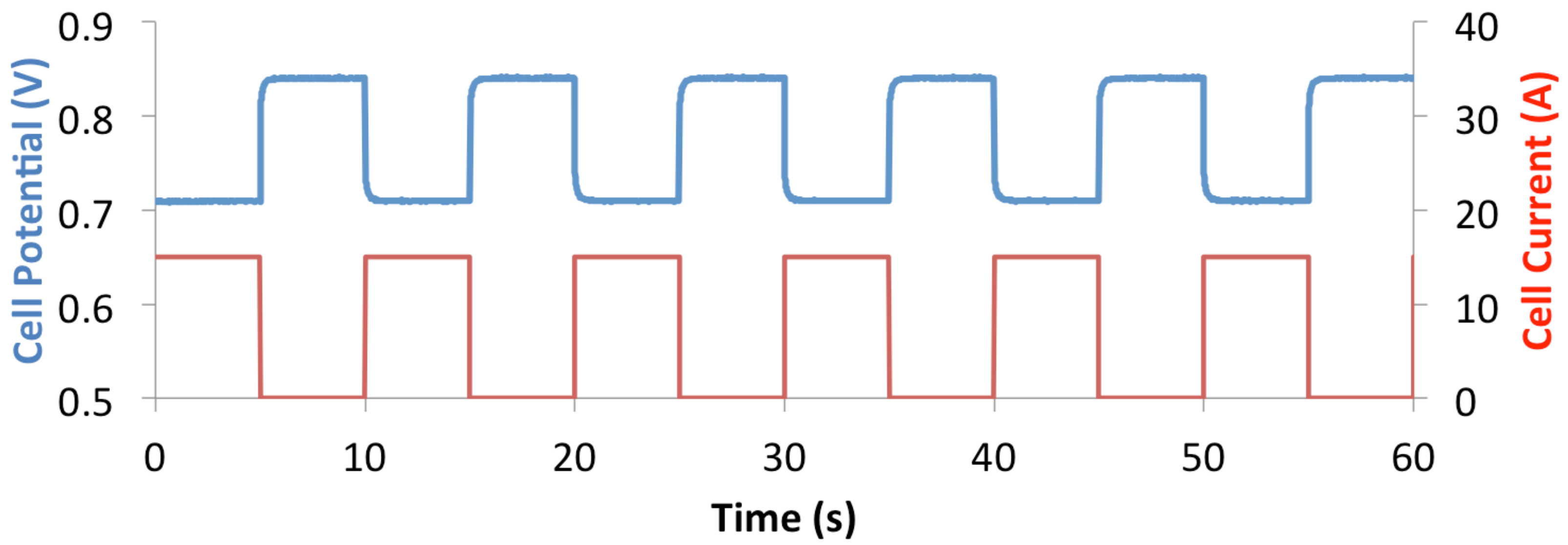


Figure courtesy of B. Blackburn, Redox Power Systems

Summary

- The nature of electricity generation is changing with increased renewables and DG. Can new fuel cell technologies address ramping and other high value grid ancillary services while providing baseload.
- REBELS at 3Qrts.
  - Need electrochemical performance and stability
  - Detailed techno-economic models
- Early results are very encouraging
- REBELS teams would benefit from lessons learned from NETL and its awardees

How ITFCs Could Help Shape the Future Grid

- Cost-effective and low maintenance small DG and CHP systems (1-50 kW) desirable for end-users who value reliability, efficiency, and resiliency

- Ability to meet future emissions targets: CO_2, PM, NO_x, SO_x, etc.

- Ability to ramp up/down and modulate output without large efficiency, emissions, and lifetime penalties