Reliable Electricity Based on ELectrochemical Systems (REBELS)

Lower Cost Devices with New Functionality

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Advanced Research Projects Agency - Energy

July 22, 2014

Outline

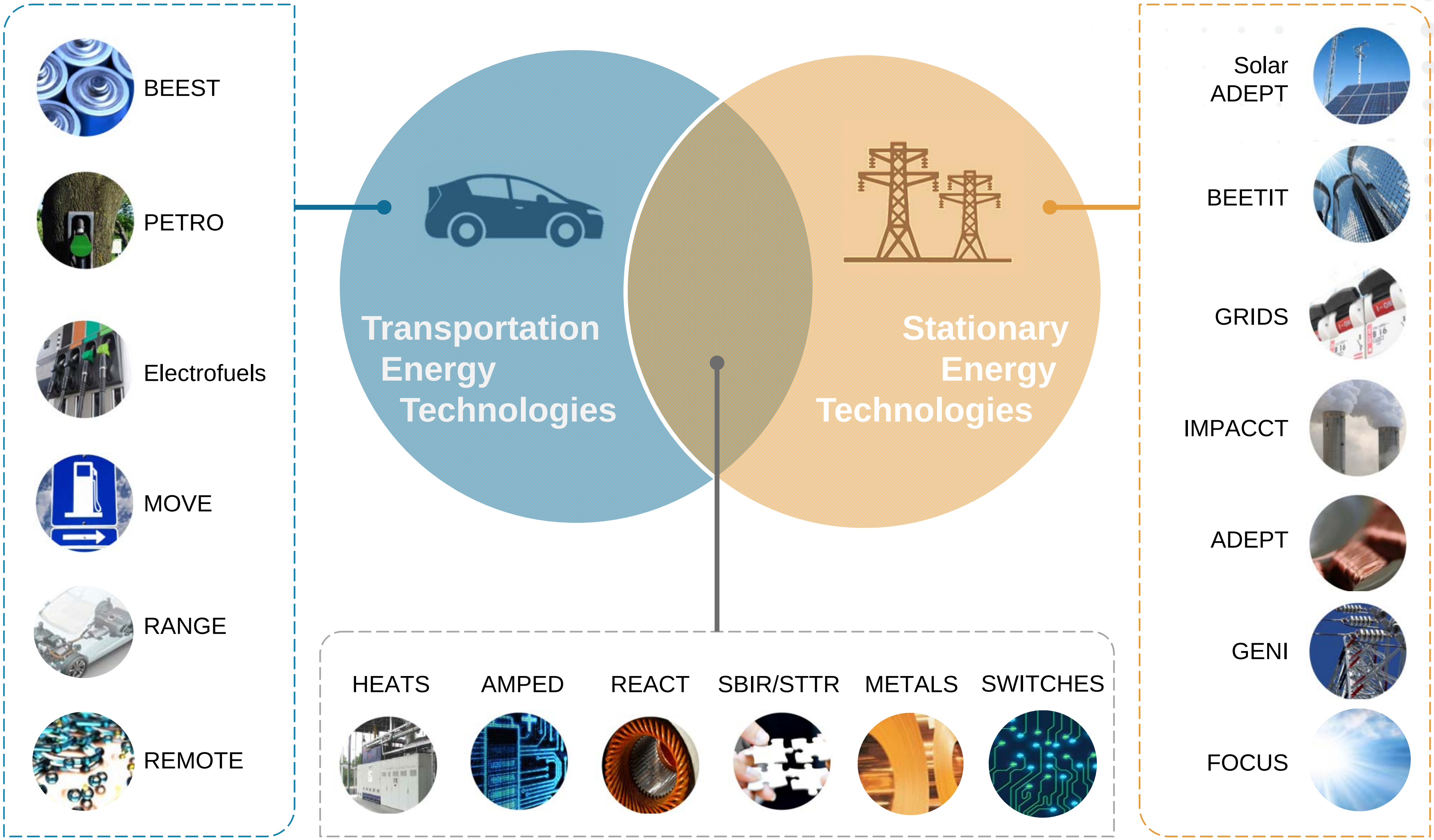
Context Behind REBELS

- Materials
- Distributed Generation Applications

Technical Categories and Project Examples

Summary

Focused Programs



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CHANGING WHAT'S POSSIBLE

Bridge to ~~Nowhere~~ the Future

	Today	Lower Carbon Mid-Term	Zero Carbon Future
Stationary Power	• Coal • NGCC • Nuclear • NG peakers	• NGCC • Renewables + storage	• Renewables + storage • Nuclear • Fossil with CCS
Transportation	• ICEs • Hybrids (3% market share)	• Increasing hybrid penetration	• EVs charged by renewables • FCVs: renew. H_2 • Biofuels

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Problem: anything 'better' than NGCC or hybrid vehicles costs too much

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Stationary Power Today

Strengths

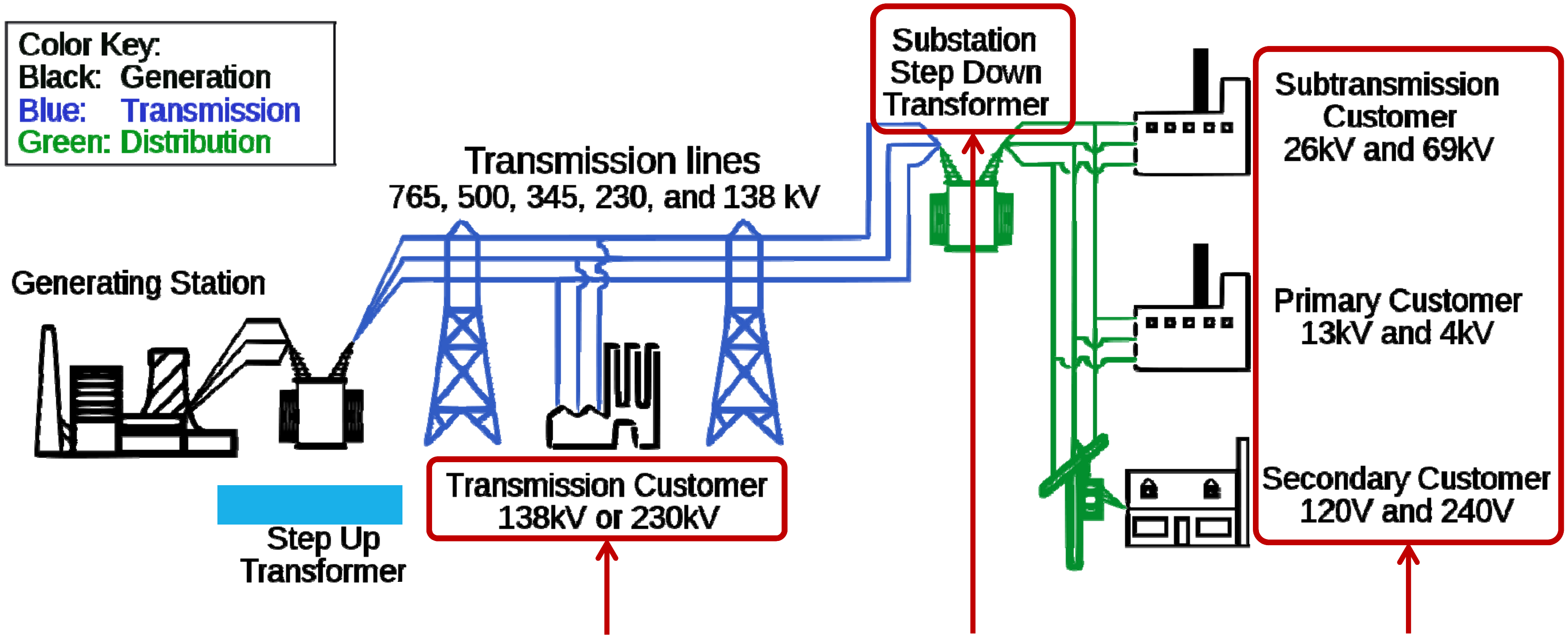
- ~55% efficiency (HHV) for NGCC
- CO_2 point source for future CCS
- High capacity factor
- Mature technology

Weaknesses

- T&D Losses
- Grid vulnerability to natural disasters and terrorist attacks
- Difficulty in integrating intermittent renewable technologies
- Future efficiency gains incremental

Future generation dominated by NGCC and increasing renewables

Energy Loss in Today's Grid



Typical losses on Transmission level: 2.5% - 5%

Typical losses on Substation level: 1.0% - 2.5%

Typical losses on Distribution level: 6.0% - 8.0%

Note: The losses above are at peak load, based from a study of AEP'sT&D system. The ranges above do not directly correlate to the previous page due to differences in source data

The majority of the losses are in the distribution level

N2

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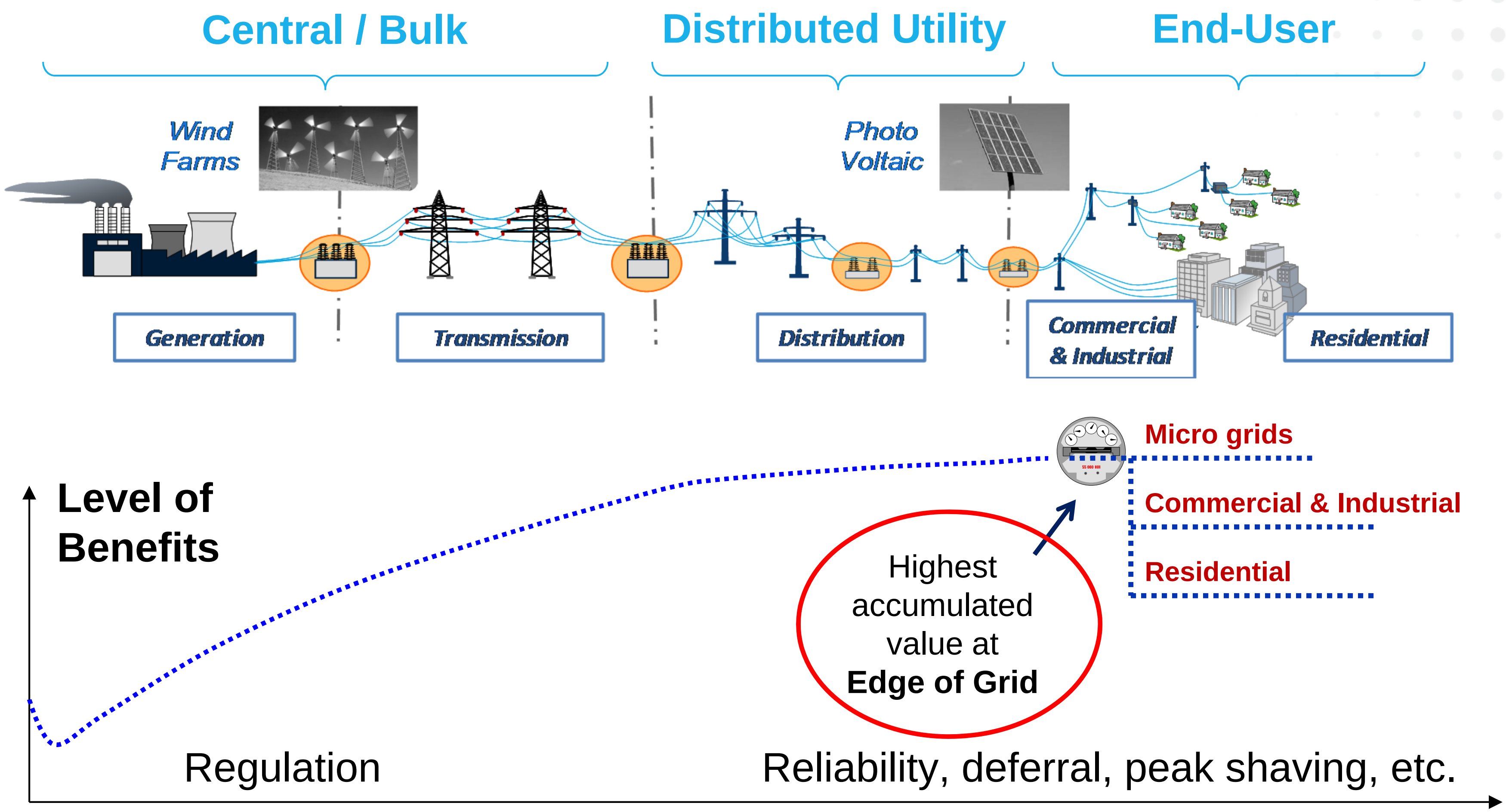
Source: Nourai, et al; "Load Leveling Reduces T&D Line Losses", IEEE Transactions on Power Delivery, 2008

Slide 7

N2 This is something I would emphasize in your voice track. I suggest simply leaving the graphic and speaking to it-losses at different levels.

Nikki.Cope, 2/10/2014

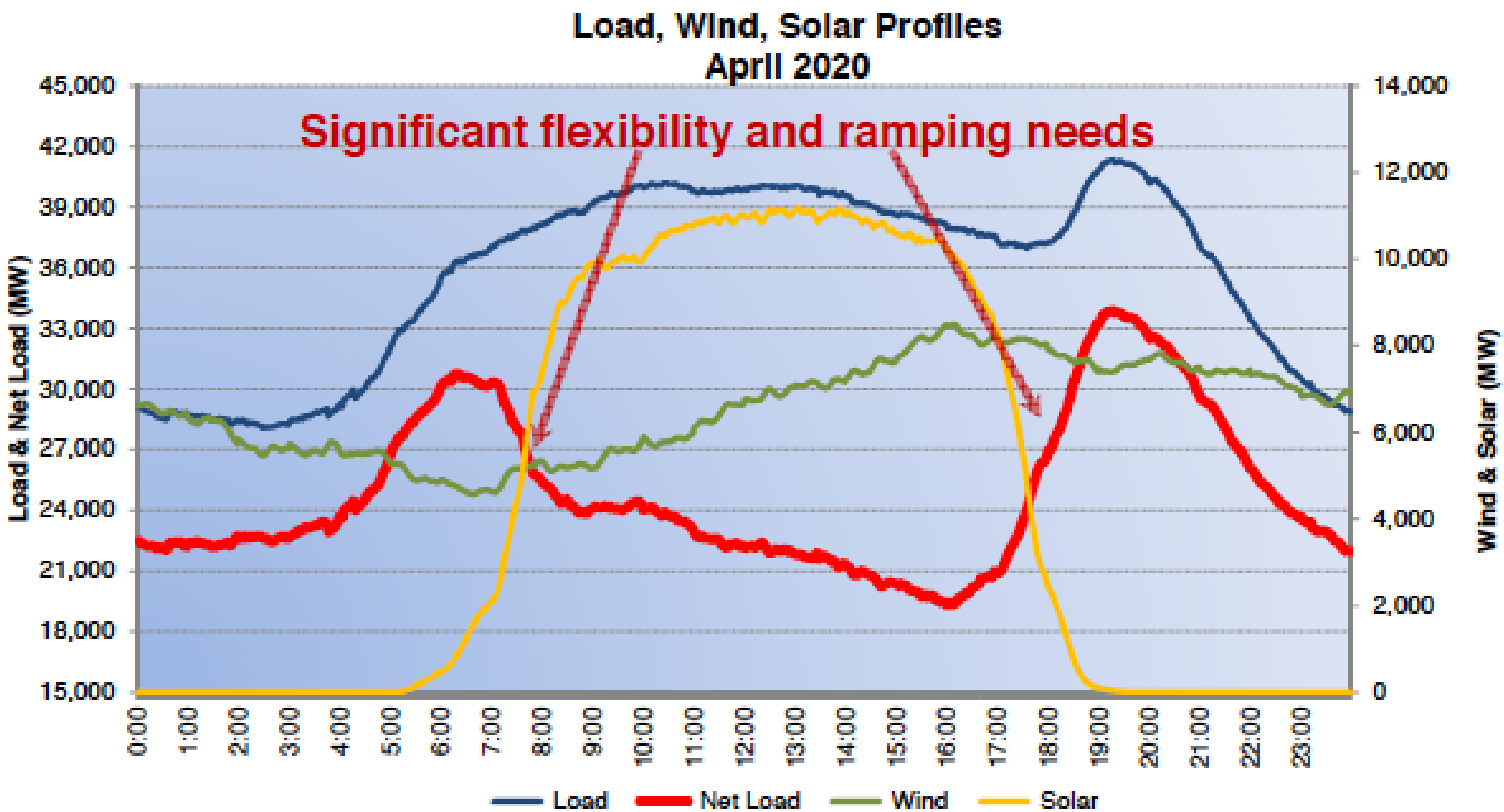
The Value of Distributed Generation (DG)



Early movers: Verizon, Microsoft, Google, Big Box Stores, etc.

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

Impact of PV, Wind on Baseload



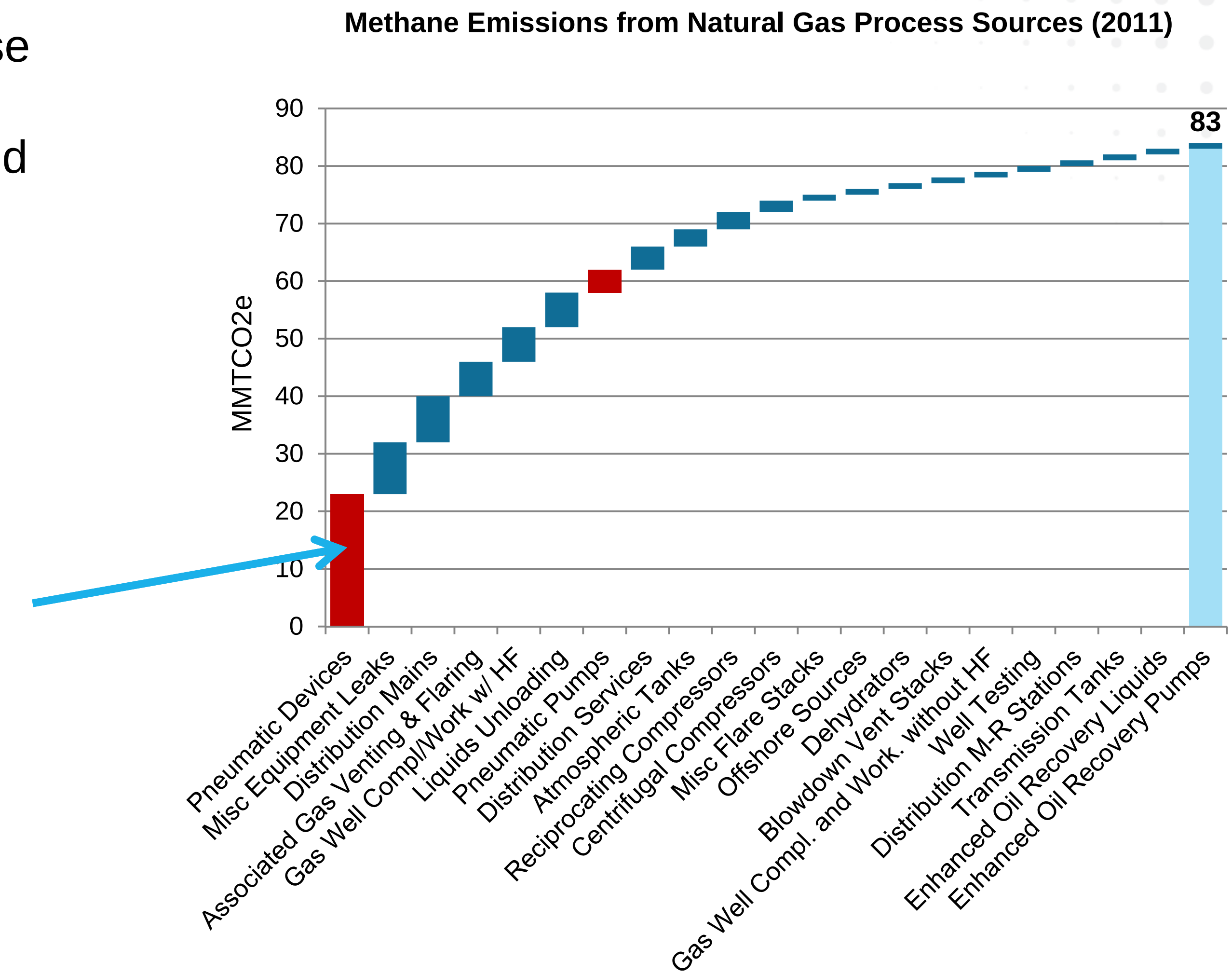
Decrease in base load requires significant reserves to offset high ramps

Mark Rothleder, CAISO, "Operational Flexibility Analysis," presented at the CPUC Operational Flexibility Workshop, June 4, 2012

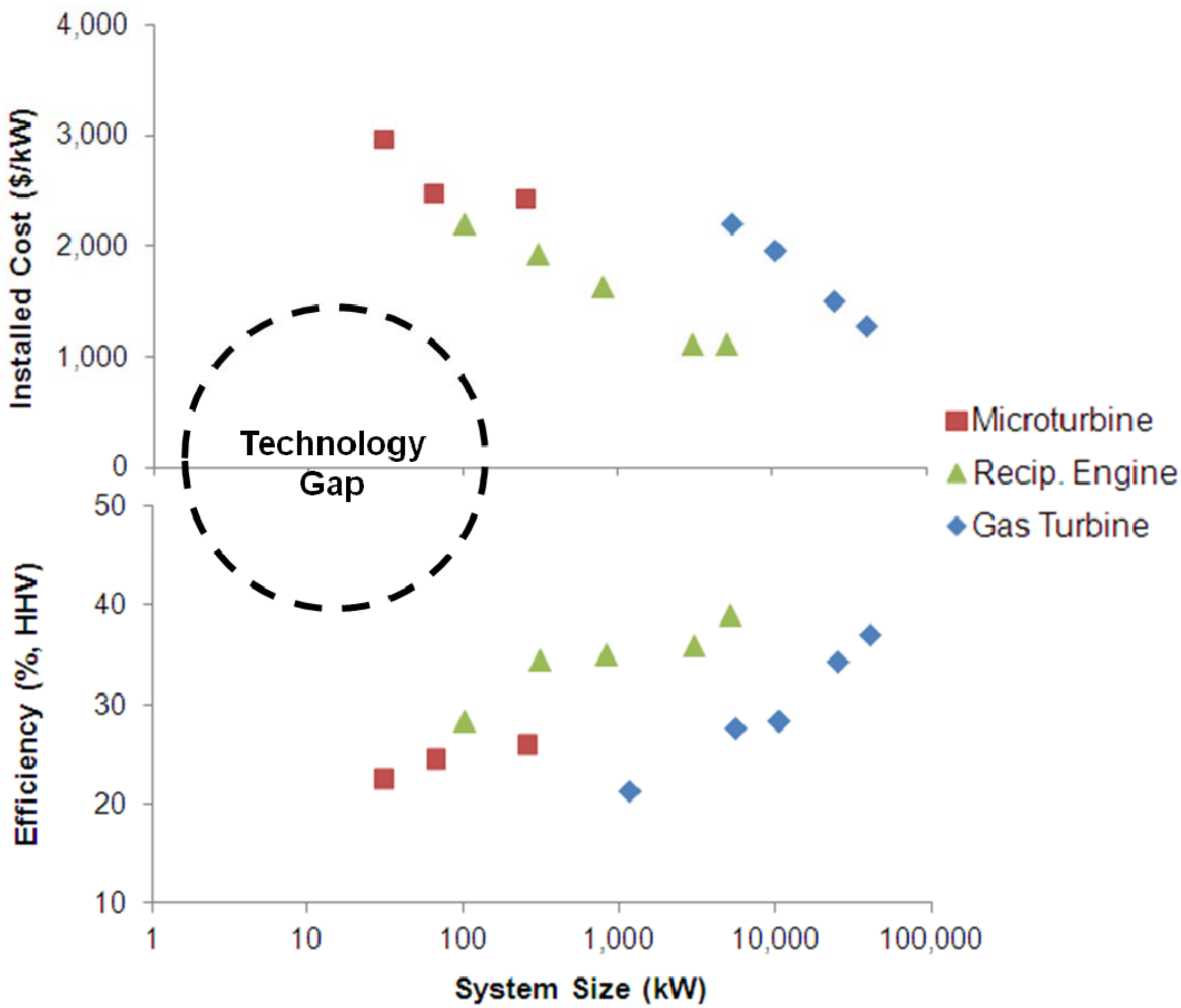
Small DG Opportunity: Remote NG Wellpads

Pneumatic devices use NG pressure to drive pumps, regulators, and valves & then vent it

Results in 20%-35% of methane emissions from the NG production sector



Small DG Prime Movers



Maintenance Intervals (hrs)	
Gas Turbine	4,000-8,000
Microturbine	5,000-8,000
Recip. Engine	1,000-2,000
Fuel Cells	20,000 – 40,000+

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Source: Catalog of CHP Technologies, EPA CHP partnership (2008); DNV KEMA Report to ARPA-E (2013)

Existing Fuel Cell Research Thrusts

Temperature (ºC)

800

600

400

200

SOFC

Power density

Fuel flexibility

Seals, interconnects

Thermal cycling

Stack lifetime

SECA focus

PEM

Rapid start

Simpler materials integration

Pure hydrogen only

Expensive catalysts

Complex system

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

Build a community of FC, solid state materials and C-H bond catalysis scientist and technology developers.

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

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REBELS Program Vision

A new temperature range (roughly 200-500 C) will enable new chemistries, materials, & functionalities:

1 ITFC

Efficient, reliable small power systems

- Entry markets valuing reliability, including DoD
- Low cost CHP: higher efficiency, less CO_2

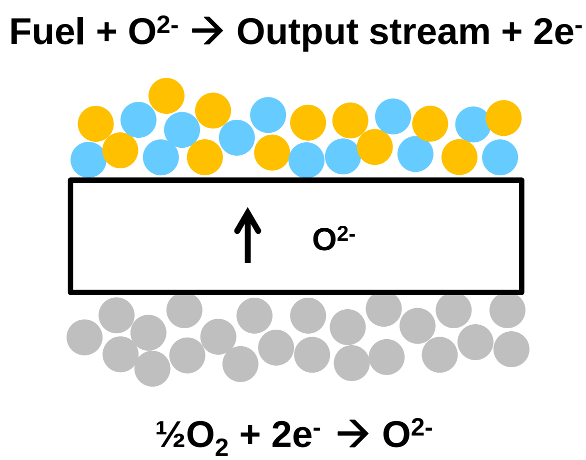
2 Fuel Cell + Additional Functionality

Fuel cell with integrated battery mode for faster response to transients

3 Fuel Cell + Additional Functionality

Fuel cell with ability to convert natural gas to liquid fuels

Category 1: ITFC



Fuel cannot be H_2; mostly focusing on CH_4

Final Deliverable: 100 W, 5 cell stack

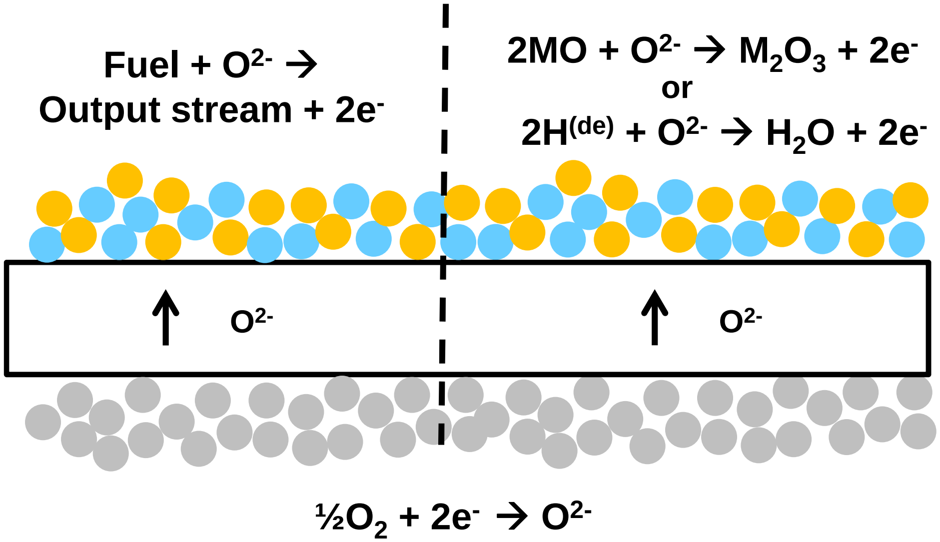
ID	Category	Value
1.1	Desired operating temperature range	200-500 °C
1.2	Current density at 70% of Nernst voltage	> 200 mA/cm^2
1.3	Electrical efficiency at rated power	>50%
1.4	Startup time	< 10 minutes
1.5	Transient response	< 1 minute
1.6	Minimum stack testing time	1,000 hours
1.7	Power degradation rate	< 0.3% per 1,000 hours
1.8	Platinum group metal (PGM) total loading	< 0.1 mg PGM / cm^2 electrode area

***Oxygen ion conductor is a schematic only; other FC types are equally applicable**

Category 1 Projects

Colorado School of Mines	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: Dynamic Response ITFC



Q. Van Overmeer, et al., Nano Lett. 12 (2012) 3756-3760

Fuel can be H_2 or a hydrocarbon

Final Deliverable: 1 cell

ID	Category	Value
2.1	Desired operating temperature	200-500 °C
2.2	Current density at 70% of Nernst voltage	> 200 mA/cm^2
2.3	Minimum stack testing time	100 hours
2.4	PGM total loading	< 0.1 mg PGM / cm^2 electrode area
2.5	Battery response time	< 1 second
2.6	Time at rated power	15 minutes
2.7	Battery cycling degradation	80% of loaded capacity retained after 30 cycles
2.8	Battery mode recharge time	< 1 hour
2.9	Self-discharge rate	< 5% of loaded capacity after 12 hours
2.10	Mode switching temperature	To be specified by the applicant

***Oxygen ion conductor is a schematic only; other FC types are equally applicable**

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Category 2 Projects

Si Energy Systems, LLC — An Allied Minds Company

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

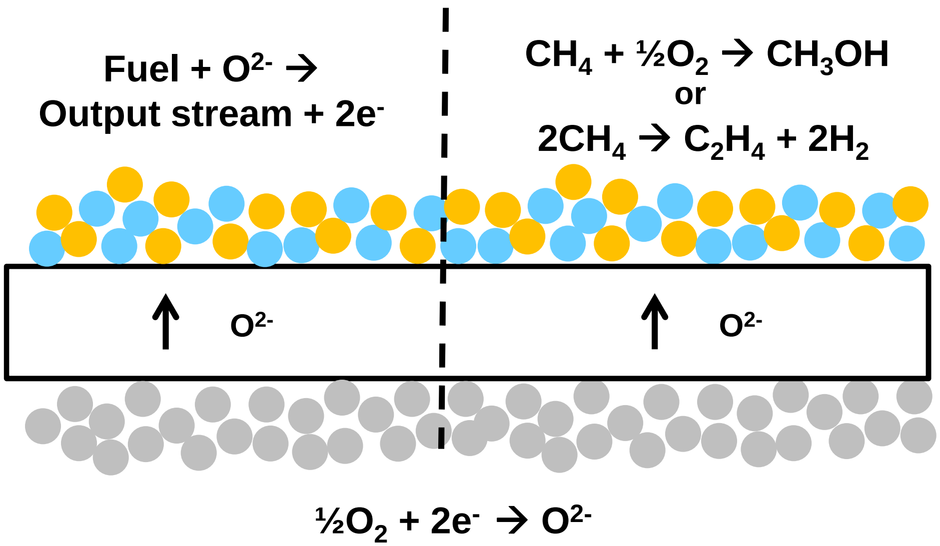
University of South Carolina

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: ITFC with Fuel Production



Fuel can be any hydrocarbon

Final Deliverable: 1 cell

ID	Category	Value
3.1	Desired operating temperature	200-500 °C
3.2	Current density at 70% of Nernst voltage	> 200 mA/cm^2
3.3	Continuous cell operations	> 100 hours
3.4	Minimum cell area	> 100 cm^2
3.5	Current density (during fuel production)	> 100 mA/cm^2
3.6	Cell cost per rate of product output	< $100,000/bpd
3.7	Process intensity	> 0.1 bpd/ft^3
3.8	Product yield	> 50 %
3.9	Carbon efficiency	> 50%
3.10	Desired product(s)	To be specified by applicant
3.11	Volumetric product output per cell	To be specified by applicant (L/day)

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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

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ARPA-E / SECA Coordination

- Common awardees; SECA-funded work has provided the basis for several REBELS projects
- Materials are different, as well as some of the balance-of-plant considerations
- Goal is for REBELS projects to demonstrate key technical points
  - Good electrochemical performance from 200-500 C
  - Efficient fuel processing < 650 C
  - Potential for 10 year stack lifetime

Key Goal: Create new FC type technologies – life after ARPA-E

Summary

- Combination of new materials and DG needs indicated the opportunity for an ARPA-E program
- ARPA-E is excited for all 3 REBELS Categories; contracting process is currently underway
- Important to continue discussions between REBELS and SECA projects going forward