ARPA-E Overview and Fuel Cell Activities

Eric Rohlfing, Deputy Director for Technology

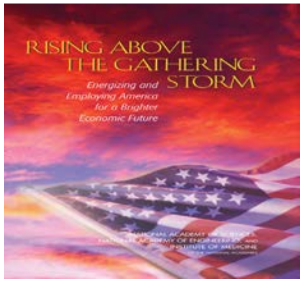
DOE Hydrogen and Fuel Cell Technical Advisory
Committee Meeting
October 27, 2015

Outline

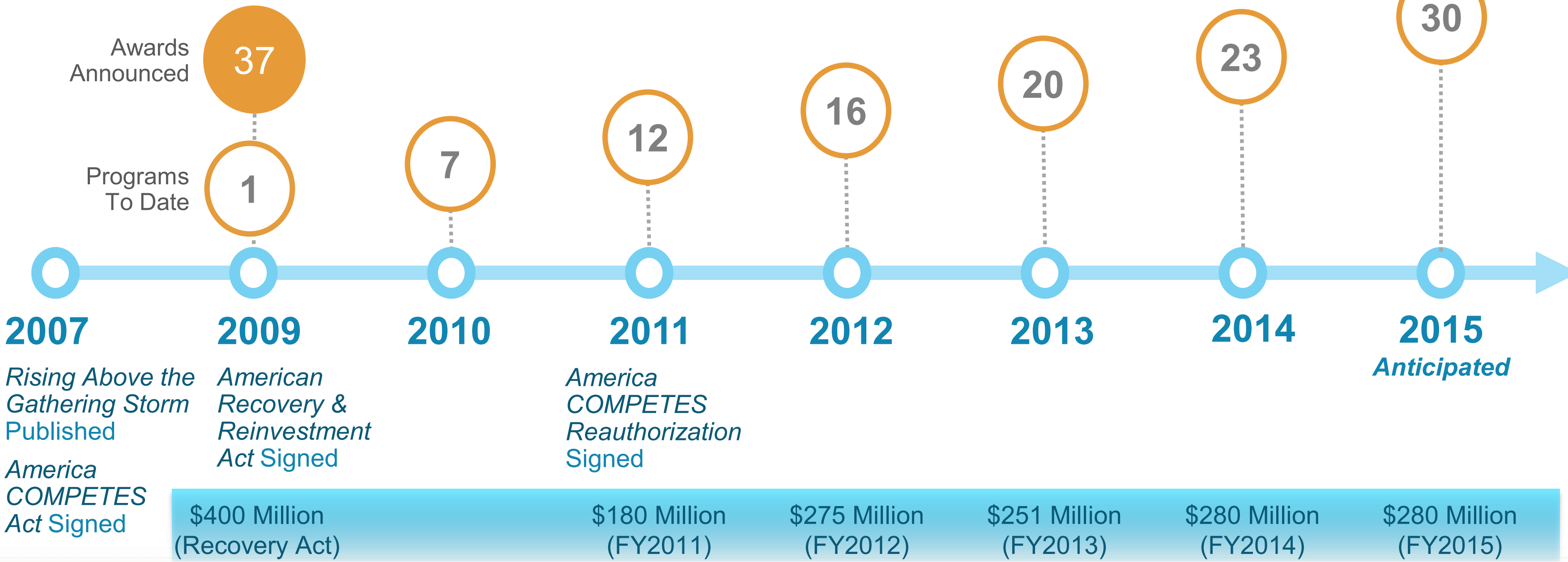
- ARPA-E overview
- The REBELS (intermediate temperature fuel cell) program
- A recent workshop on renewable transportation fuels

ARPA-E's History

In 2007, The National Academies recommended Congress establish an Advanced Research Projects Agency within the U.S. Department of Energy



…"The new agency proposed herein [ARPA-E] is patterned after that model [of DARPA] and would sponsor creative, out-of-the-box, transformational, generic energy research in those areas where industry by itself cannot or will not undertake such sponsorship, where risks and potential payoffs are high, and where success could provide dramatic benefits for the nation."…



DARPA – Defense Advanced Research Projects Agency

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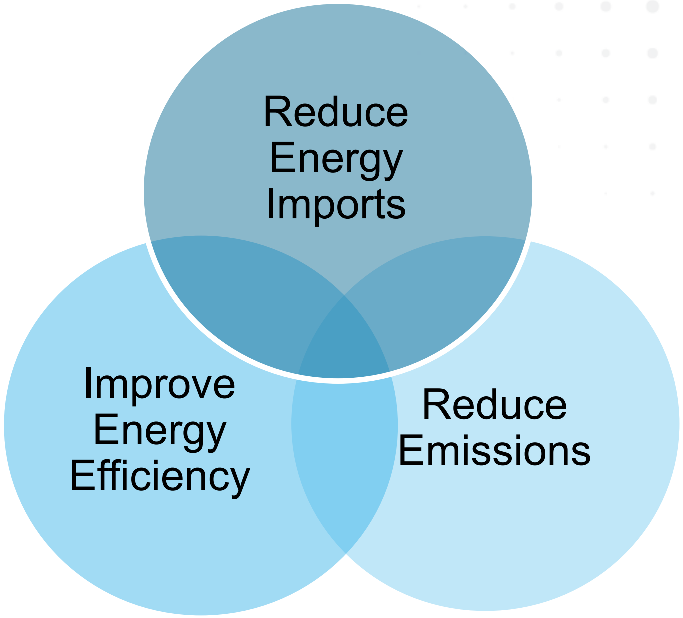
ARPA-E Authorizing Legislation

Mission: To overcome long-term and high-risk technological barriers in the development of energy technologies



Goals: Ensure America's

- Economic Security
- Energy Security
- Technological Lead in Advanced Energy Technologies

Means:

- Identify and promote revolutionary advances in fundamental and applied sciences
- Translate scientific discoveries and cutting-edge inventions into technological innovations
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical and financial uncertainty

Built on DARPA foundation, but still evolving…

ARPA-E Additions

Fellows as creative resource

Fully in-house contracting

Tech-to-market focus

Majority cooperative agreements

Institutional independence

High risk / return R&D

Substantial involvement in tech management

Empowered program directors

Flat organization

Internal program pitches / scrubs

Special hiring authority with term limits

DARPA-like Foundation

Unique to DARPA:

Staged prototype demonstrations

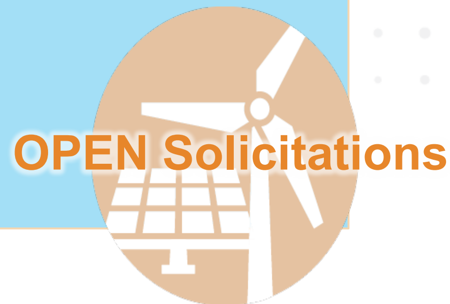
Large-scale systems integration

Primary "customer" (DoD)

Programs

OPEN programs support the development of potentially disruptive new technologies across the full spectrum of energy applications.

- Complement focused programs
- Support innovative "one off" projects
- Provide a "snapshot" of energy R&D

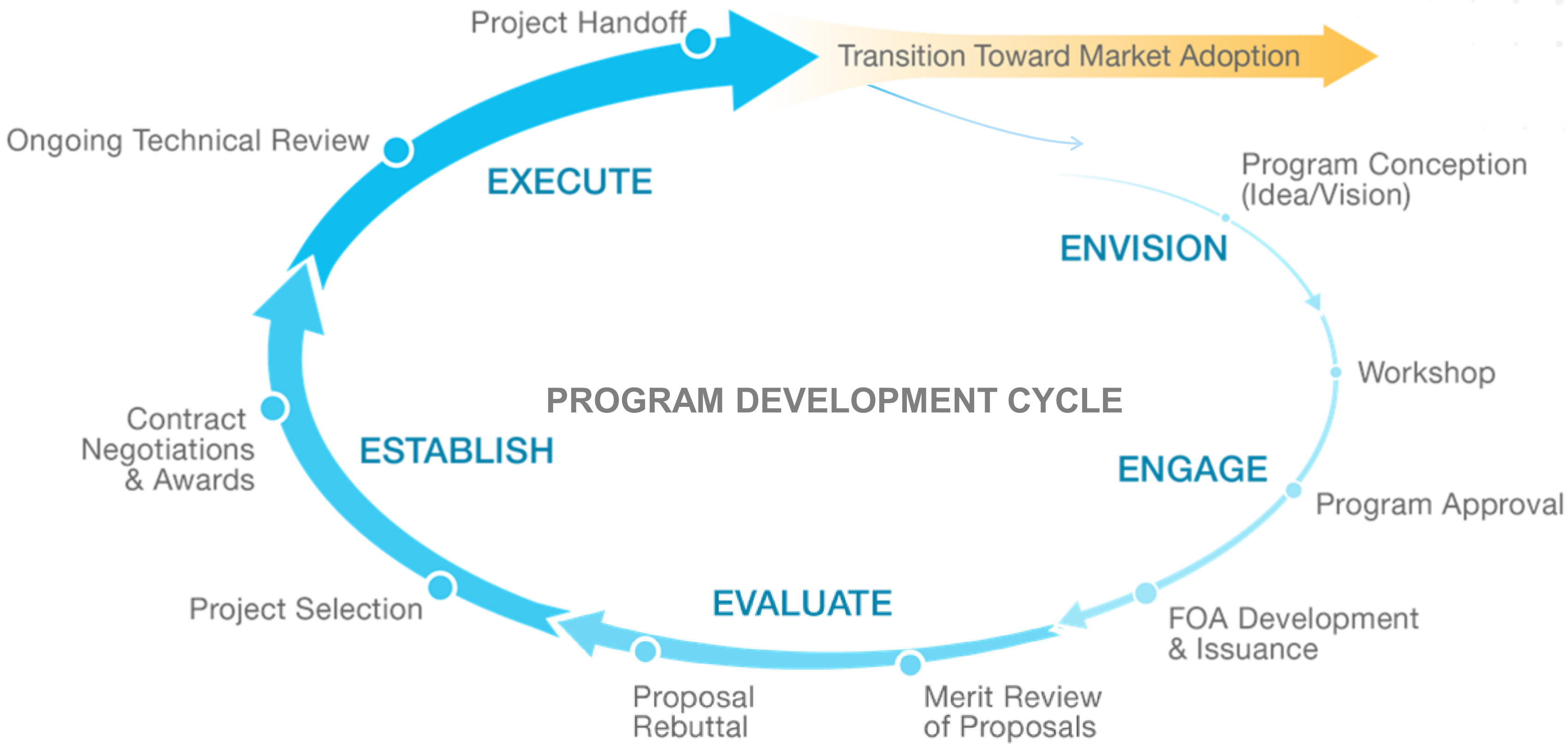


Focused programs prioritize R&D topics by their potential to make a significant difference in ARPA-E's mission space.

- Size of the potential impact
- Technical opportunities for transformation
- Portfolio of projects with different approaches

Developing ARPA-E Focused Programs

ARPA-E Program Directors



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ARPA-E Program Framing Questions

What is the problem to be **solved**?

If successful, how will the proposed program impact one or more of **ARPA-E's mission areas**?

What is the current state of R&D? How is the proposed program a **transformative and disruptive approach**?

How does the program **complement R&D efforts** in other DOE programs, federal agencies, and the private sector?

Why is now the **right time** to solve this problem?

What are the **program goals** and how will progress towards those goals be measured?

What happens at the conclusion of the program? What are the **barriers to commercialization** and how might these problems be overcome?

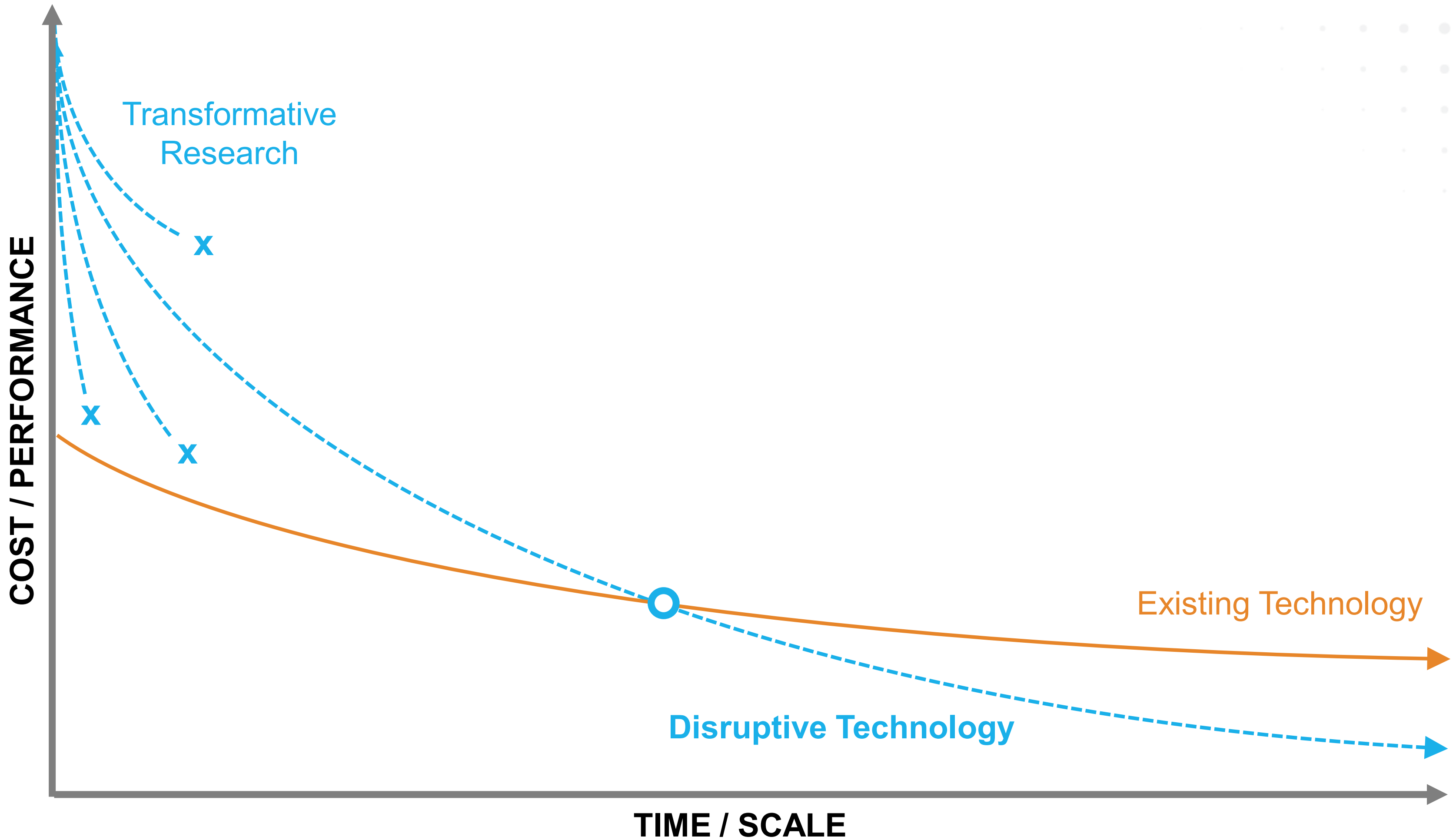
What **research communities** need to be brought together?

Adapted from the DARPA Heilmeier questions

If it works…

will it matter?

Transformative R&D to disruptive technology



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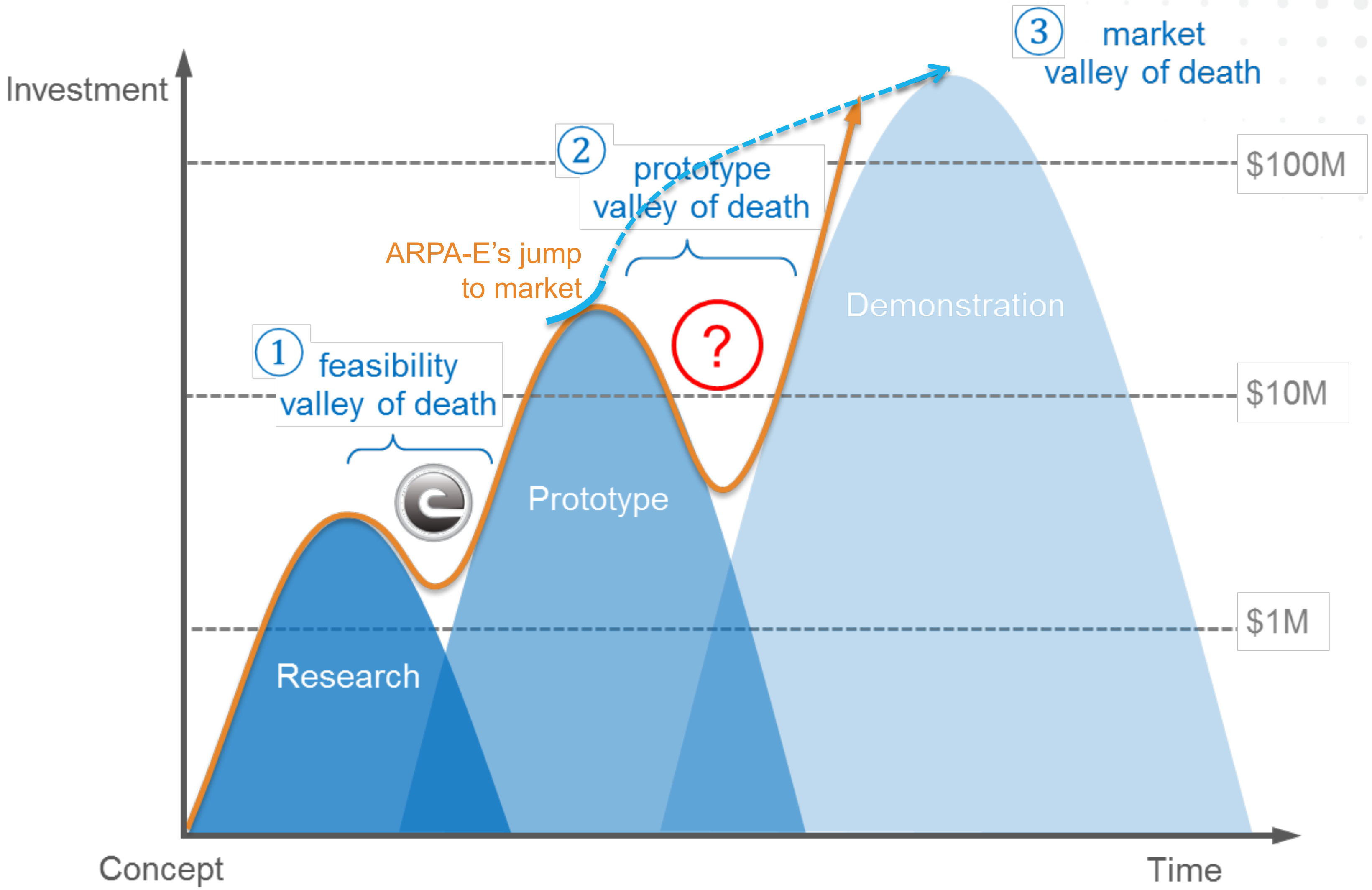
Energy Technology "Valleys of Death"



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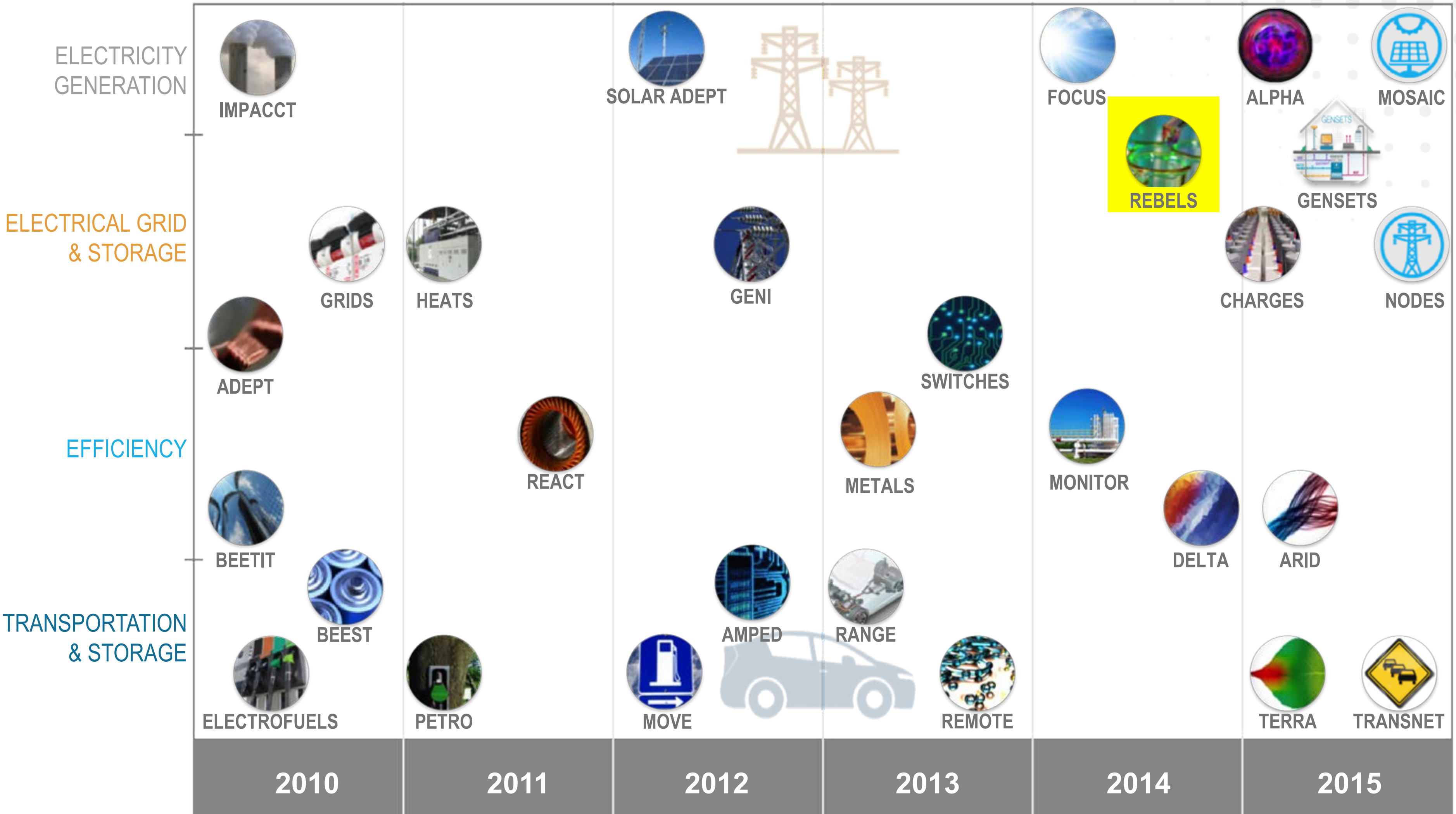
The ARPA-E Portfolio



OPEN 2009
36 projects

OPEN 2012
66 projects

OPEN 2015
?? projects

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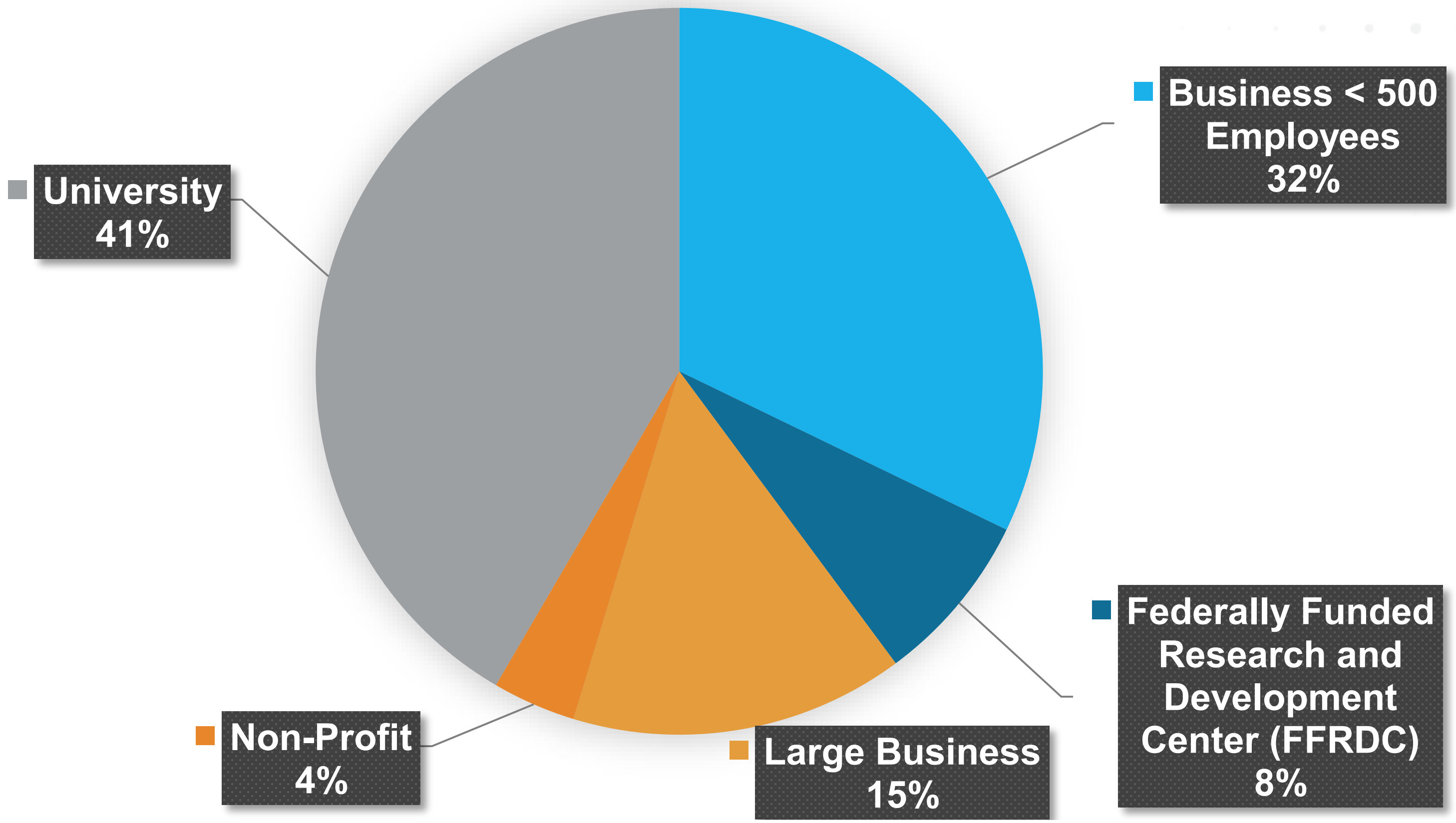
ARPA-E Project Portfolio by Lead Organization

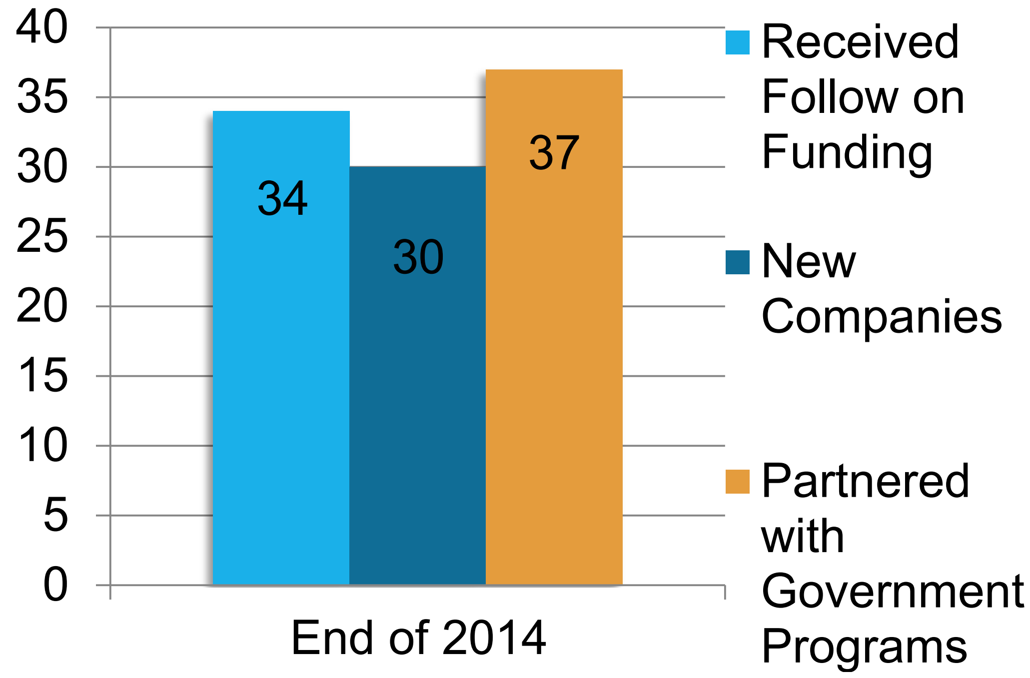


ARPA-E supports multi-institutional teams with substantial involvement from the private sector:
74% of projects involve more than one institution
79% of projects include the private sector, as leads or partners

Measuring the transition to the market

Since 2009 ARPA-E has invested approximately $1.1 billion in more than 400 projects through 23 focused programs and two OPEN solicitations.

34 ARPA-E projects have attracted more than $850 million in private-sector follow-on funding.



What Makes an ARPA-E Project?

IMPACT

- High impact on ARPA-E mission areas
- Credible path to market
- Large commercial application

TRANSFORM

- Challenges what is possible
- Disrupts existing learning curves
- Leaps beyond today's technologies

BRIDGE

- Translates science into breakthrough technology
- Not researched or funded elsewhere
- Catalyzes new interest and investment

TEAM

- Comprised of best-in-class people
- Cross-disciplinary skill sets
- Translation oriented

Outline

- ARPA-E overview
- REBELS: Reliable Electricity Based on Electrochemical Systems

  Originating program director: John Lemmon

  Current program directors: Grigorii Soloveichik and Paul Albertus
- A recent workshop on renewable transportation fuels

Stationary Power Today

Strengths

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

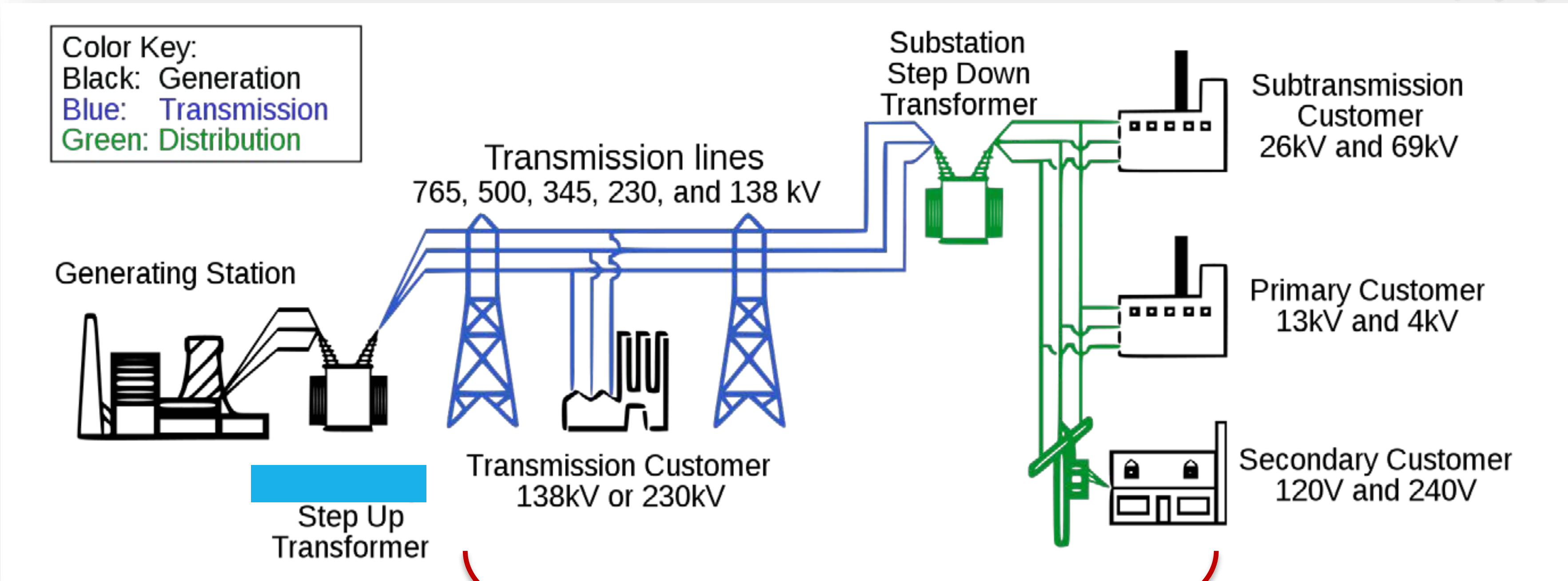
Weaknesses

- 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: emissions improvement over coal but weaknesses need to be addressed

NGCC – Natural gas conversion company; HHV – High heating values; T&D – Transmission & delivery; CCS – Carbon capture and storage

Energy Loss in Today's Grid



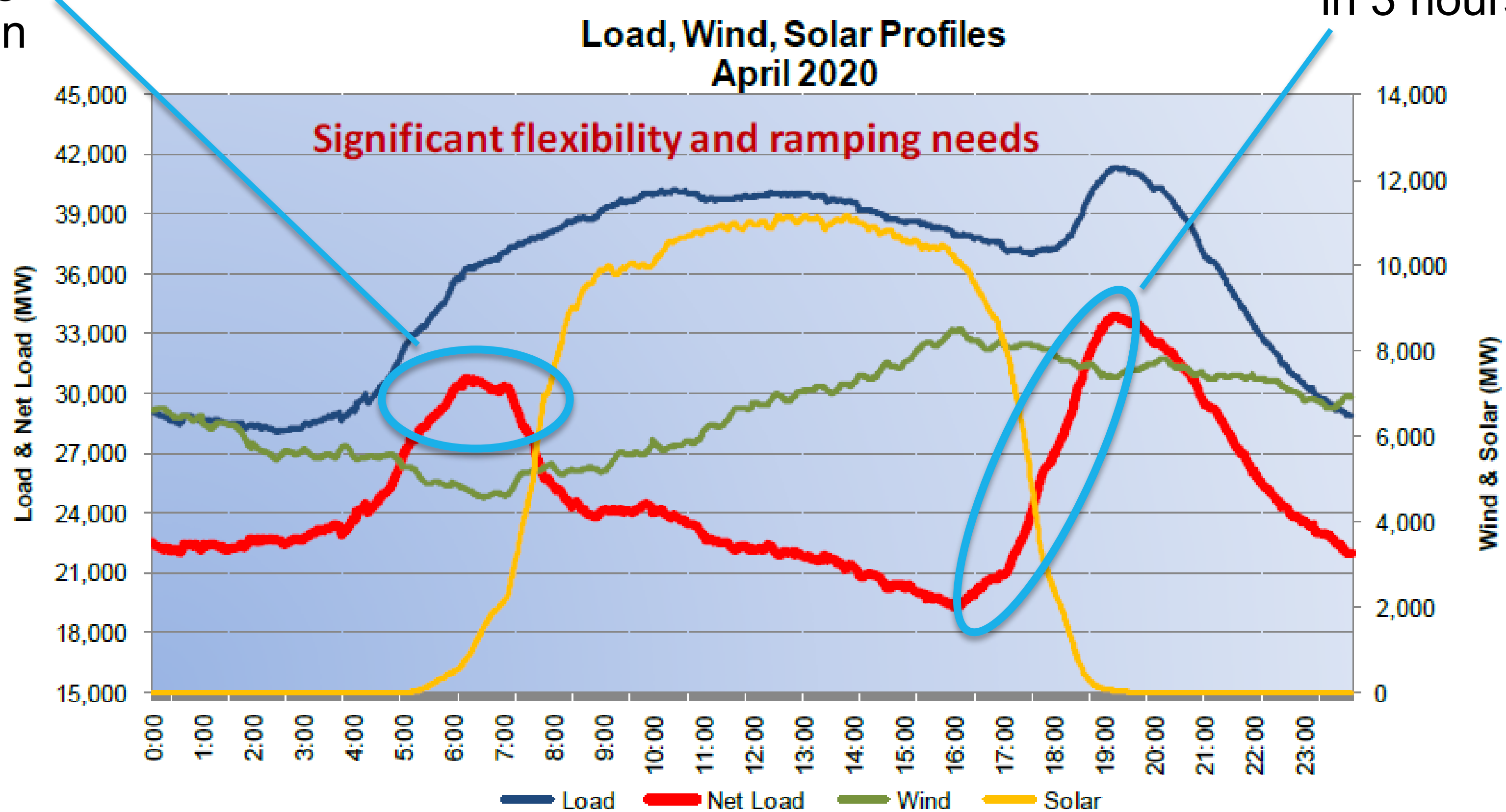
U.S. transmission & distribution losses are roughly 6-8%

Impact of Increasing Renewables

CA in 2020: 33% power from renewables & retirement of some conventional plants

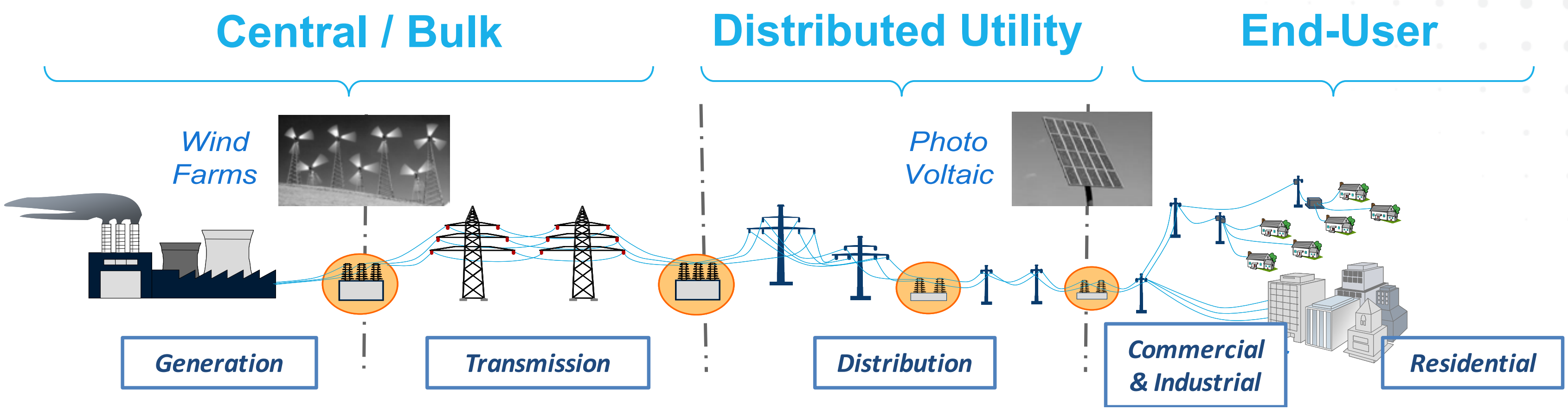
Change in ramping direction

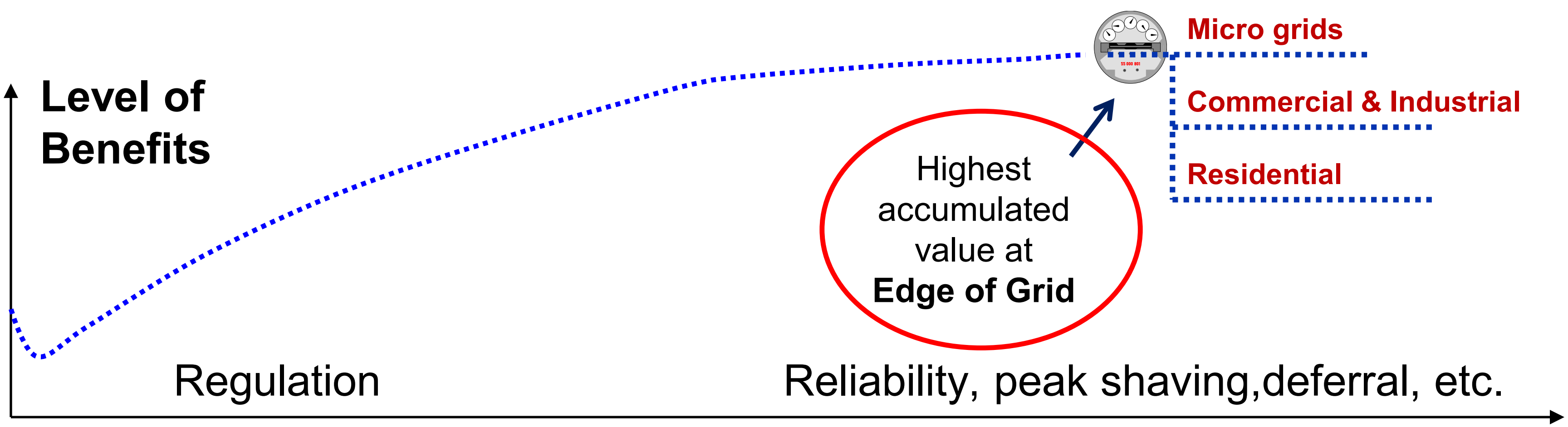
13 GW ramp in 3 hours



http://www.caiso.com/Documents/RevisedStrawProposal_FlexibleRampingProduct_includingFMM-EIM.pdf

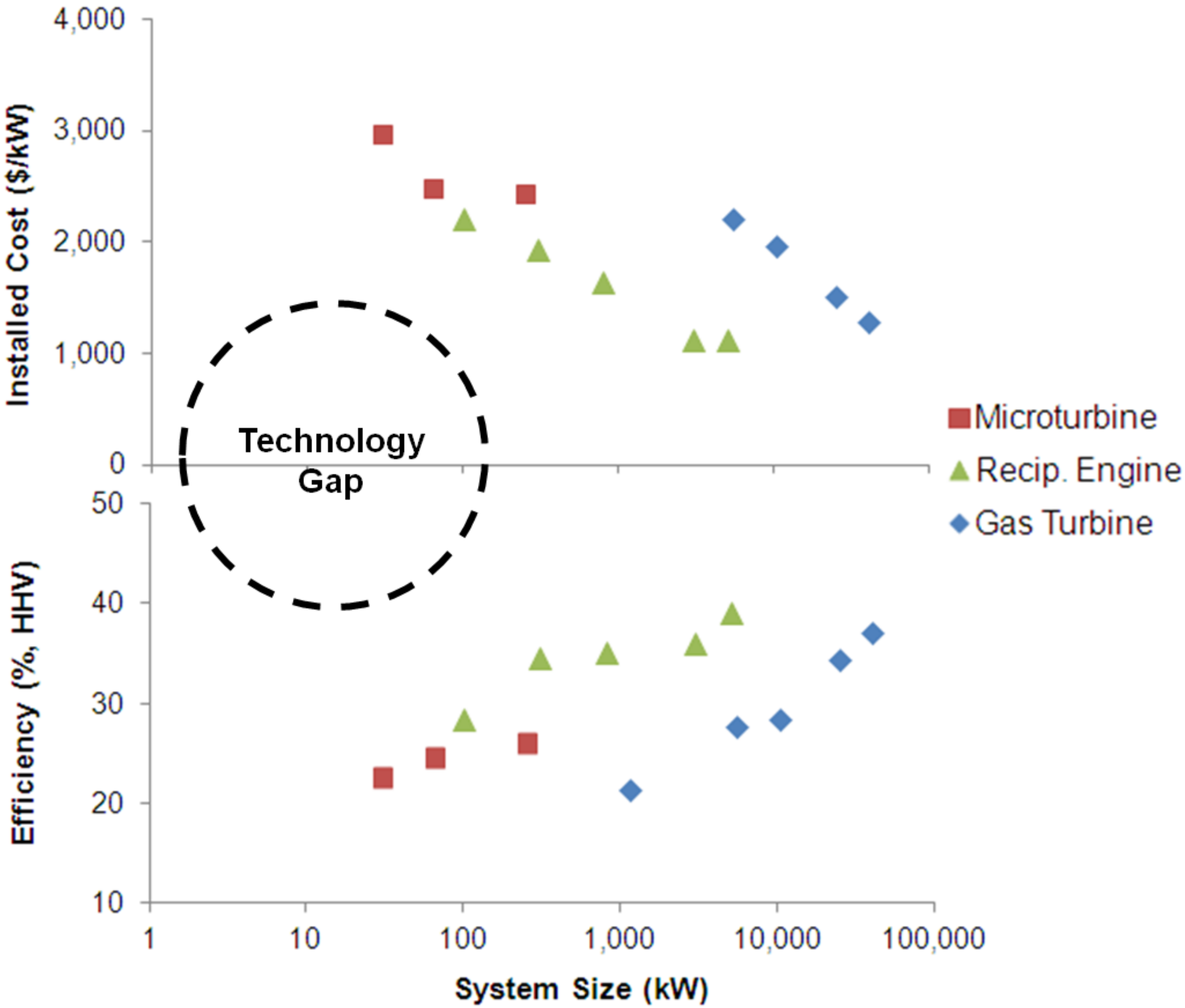
The Value of Distributed Generation (DG)





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

Gap in Small DG Prime Movers



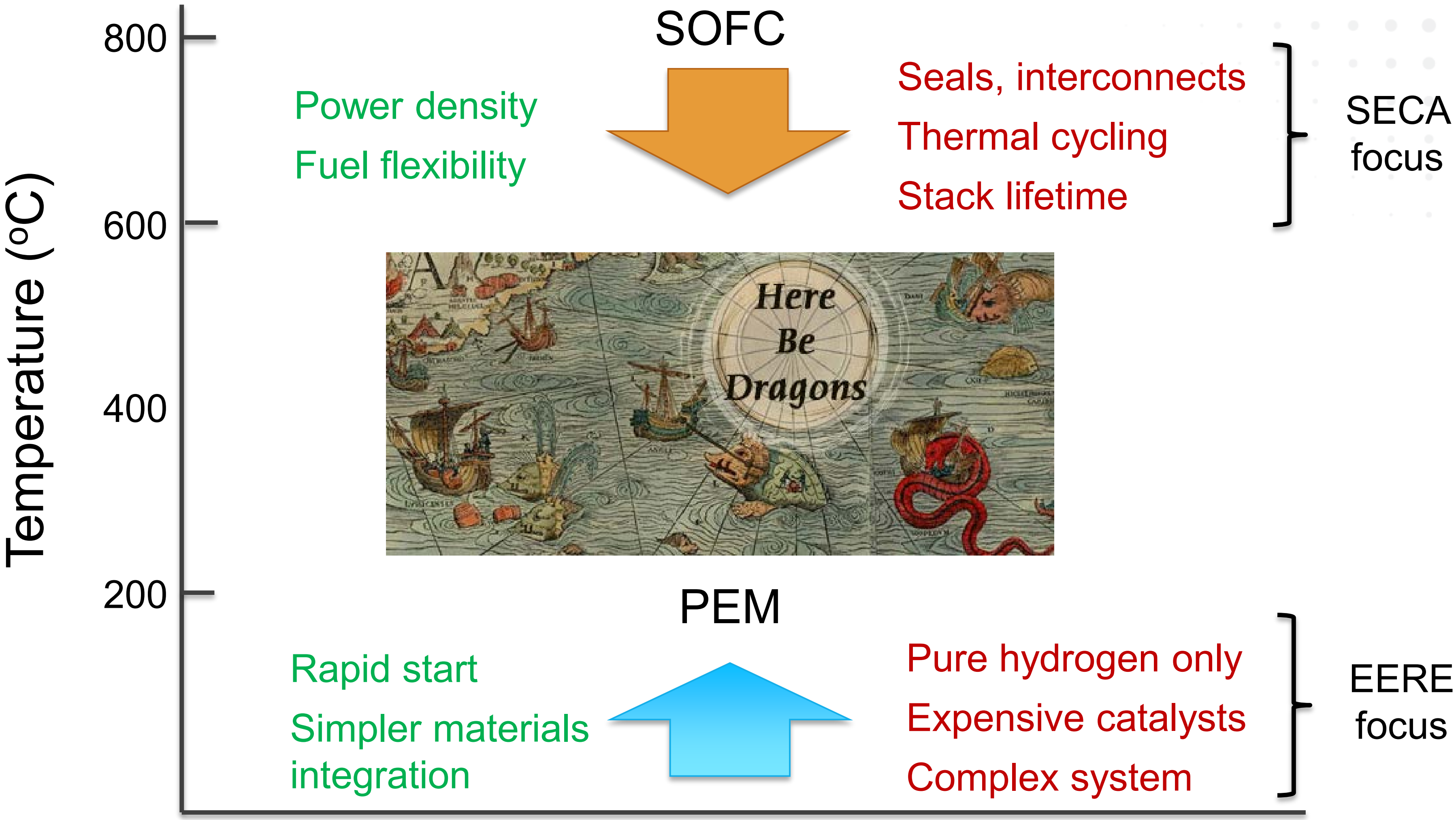
Maintenance Intervals (hrs)	
Gas Turbine	4,000-8,000
Microturbine	5,000-8,000
Recip. Engine	1,000-2,000

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)

Existing Fuel Cell Research Thrusts



New Materials Enable 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

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

CHP -- Combined heat and power

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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**

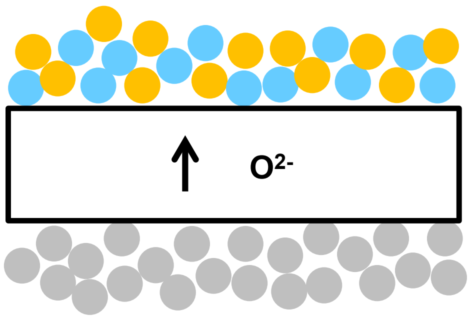
Fuel cell with integrated battery mode for faster response to transients

3. **Fuel Cell + Additional Functionality**

Fuel cell with ability to convert natural gas to liquid fuels

Category 1: ITFC

Fuel + O^{2-} → Output stream + $2e^-$



$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$

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

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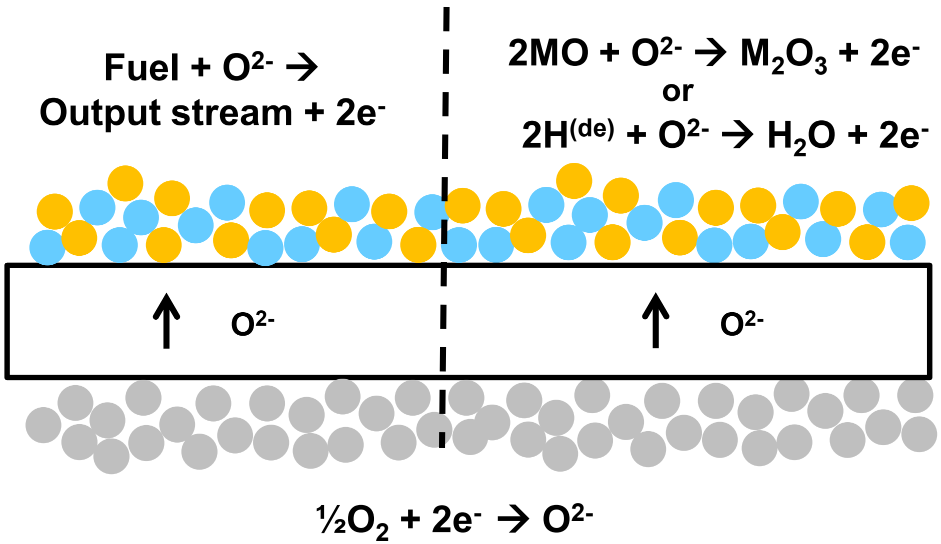
***Oxygen ion conductor is a schematic only; other FC types are equally applicable**

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: 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**

Category 2 Projects

Si Energy Systems, LLC — An Allied Minds Company

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

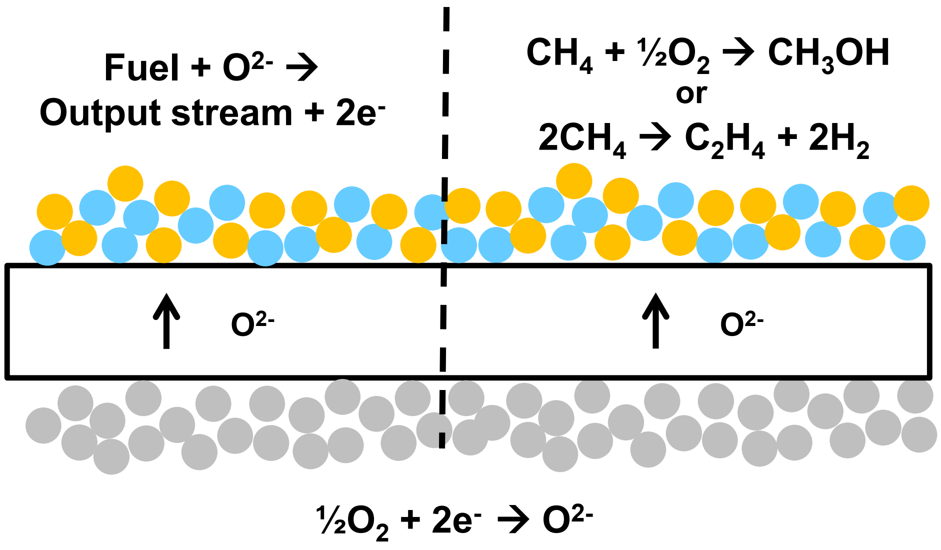
University of South Carolina

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)

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

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

Outline

- ARPA-E overview
- The REBELS (intermediate temperature fuel cell) program
- “Bridging Renewable Electricity with Transportation Fuels”
  ARPA-E workshop, August 27-28, Denver, CO
  Grigorii Soloveichik, Program Director

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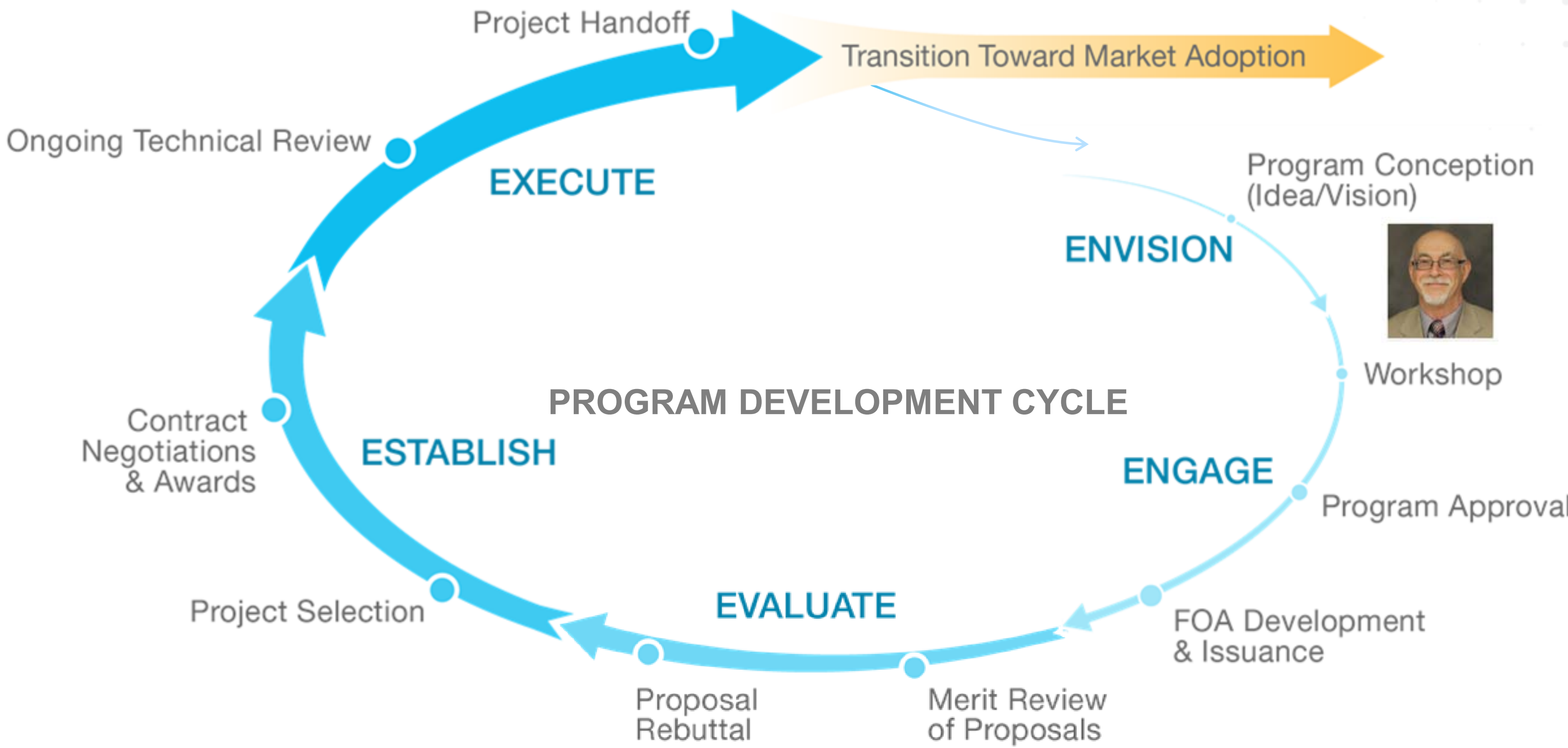
Developing ARPA-E Focused Programs

ARPA-E Program Directors

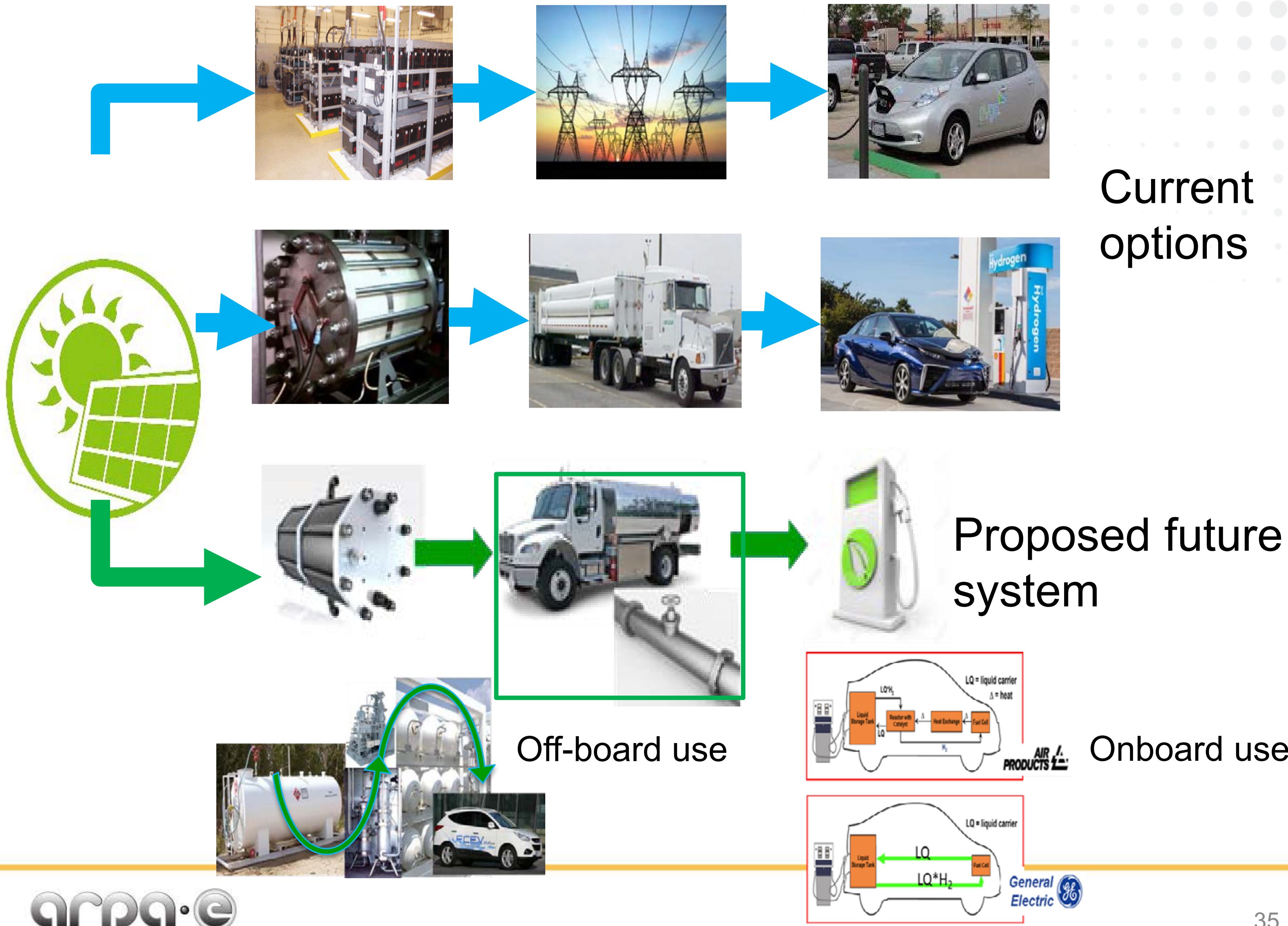


Thesis: replace fossil fuels with zero-emission rechargeable fuels

- Make more effective use of intermittent, renewable resources in remote locations by converting energy into a liquid fuel that is readily transported

- Enable the use of existing infrastructure via:
  - energy conversion into hydrogen-rich liquid fuels,
  - transportation of liquids, and
  - energy generation at the end point using direct (combustion or electrochemical) or indirect (via intermediate hydrogen extraction) oxidation

Energy delivery from remote renewable production



Possible program targets

- Develop **scalable**, **preferably direct** electrochemical or photochemical conversion of renewable energy to high energy density **liquid** hydrogenated fuels via water splitting
- Develop cost effective methods for **direct** (electrochemical) and **indirect** (thermal) extraction of hydrogen and demonstrate their use in fuel cells
- Enable the use of existing liquid fuel **infrastructure** (with minimal modifications) for energy transmission and storage and zero-carbon stationary and mobile applications

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February 29 – March 2, 2016
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just outside Washington, D.C.