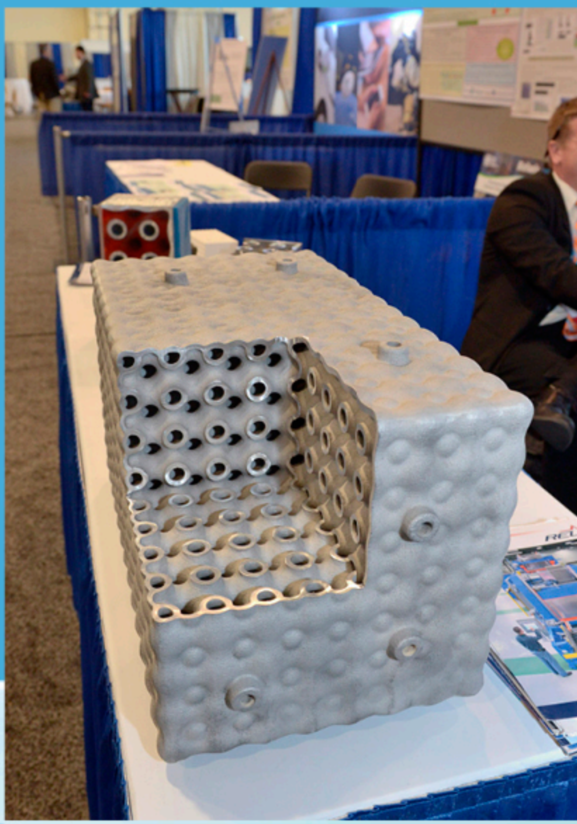
CHANGING WHAT'S POSSIBLE

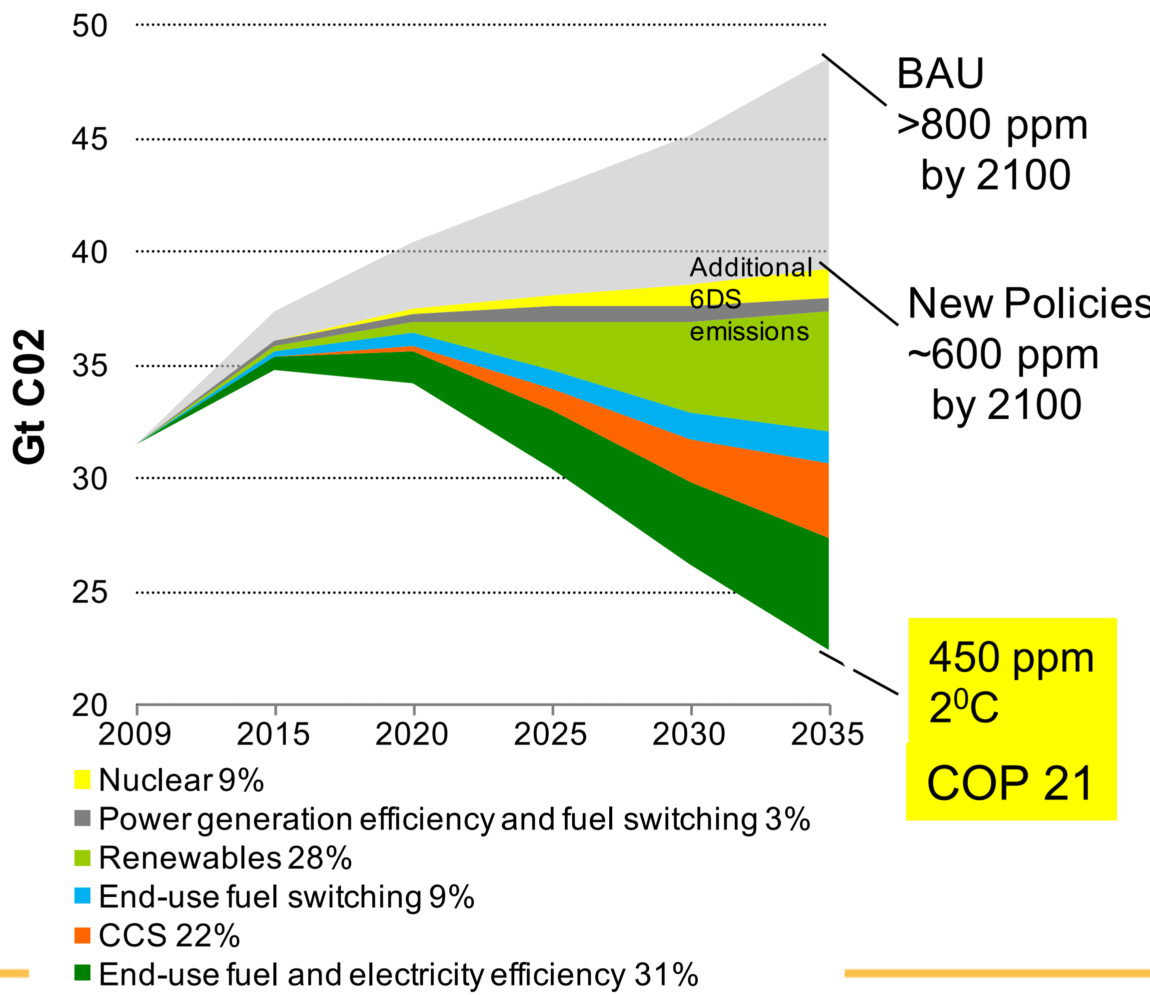


Eric A. Rohlfing
Deputy Director for Technology

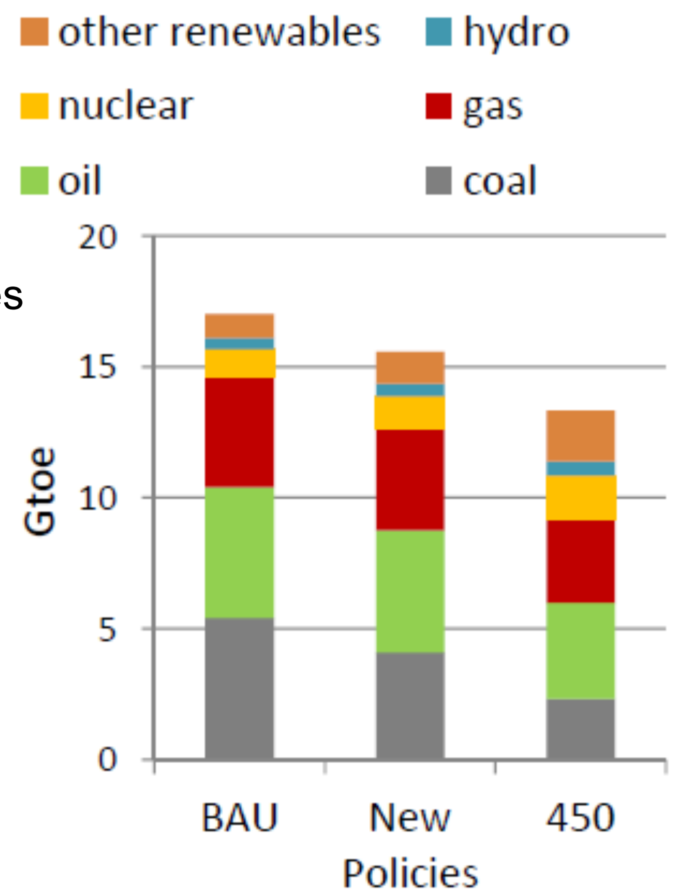
http://www.arpa-e.energy.gov/

Alternative Climate Futures

Contributions to reductions in IEA scenarios:



Scenarios: energy mix in 2035



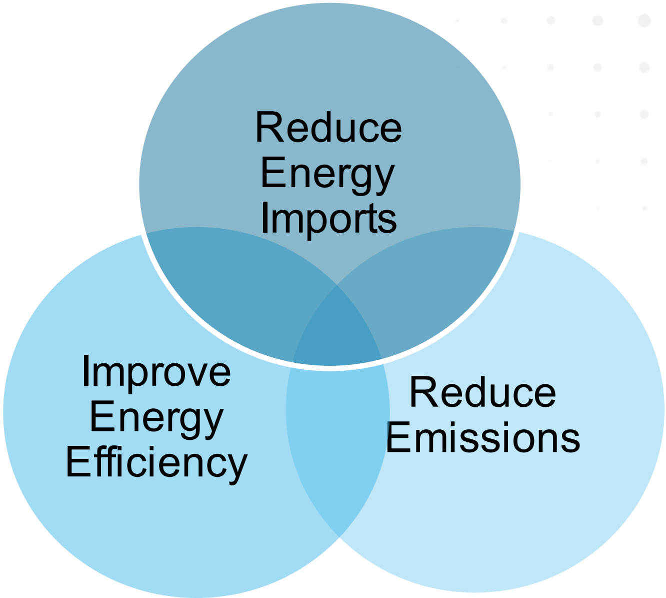
Source: IEA
World Energy Outlook 2011

ARPA-E

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

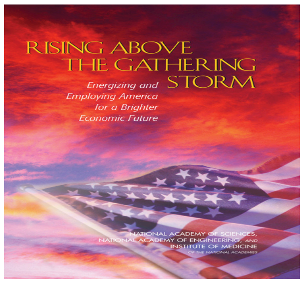


Means:

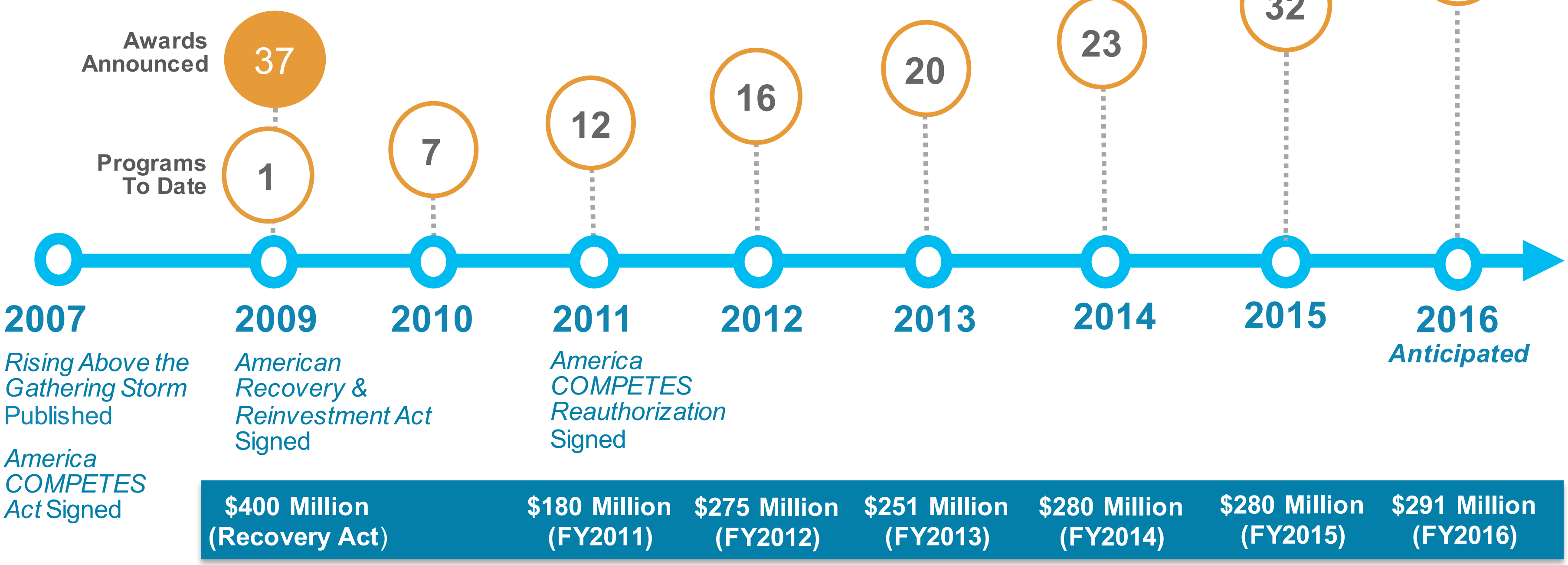
- Identify and promote revolutionary advances in fundamental and applied sciences
- Translate scientific discoveries and cutting-edge inventions into technological innovations
- Accelerate transformational technological advances in areas that industry by itself is not likely to undertake because of technical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

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."…



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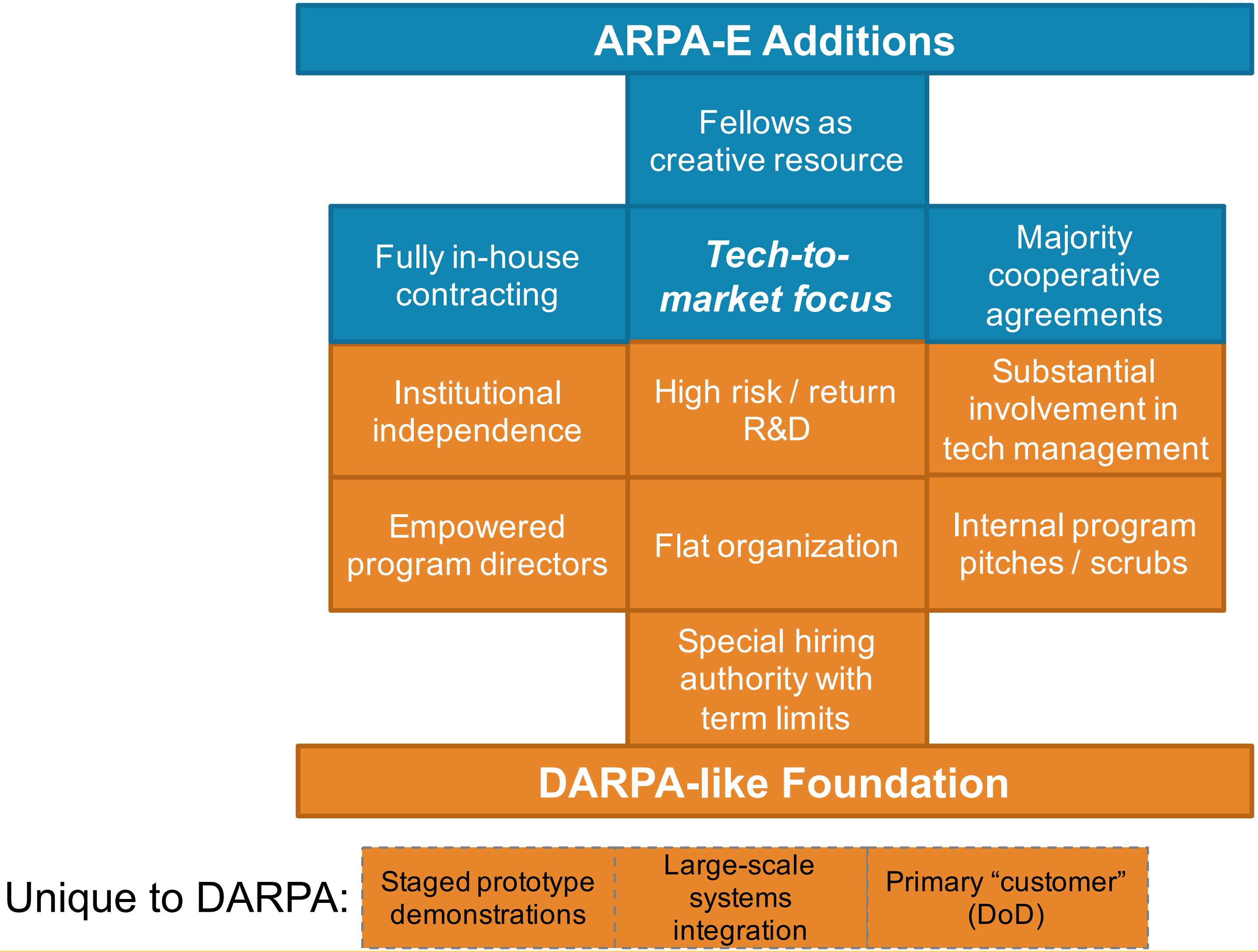
Built on DARPA foundation, but still evolving…



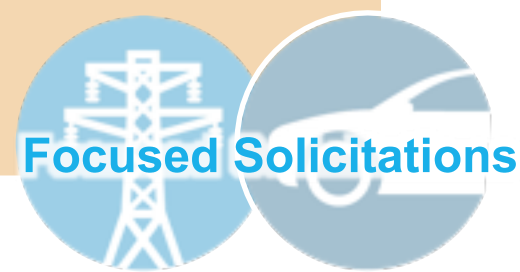
Programs

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

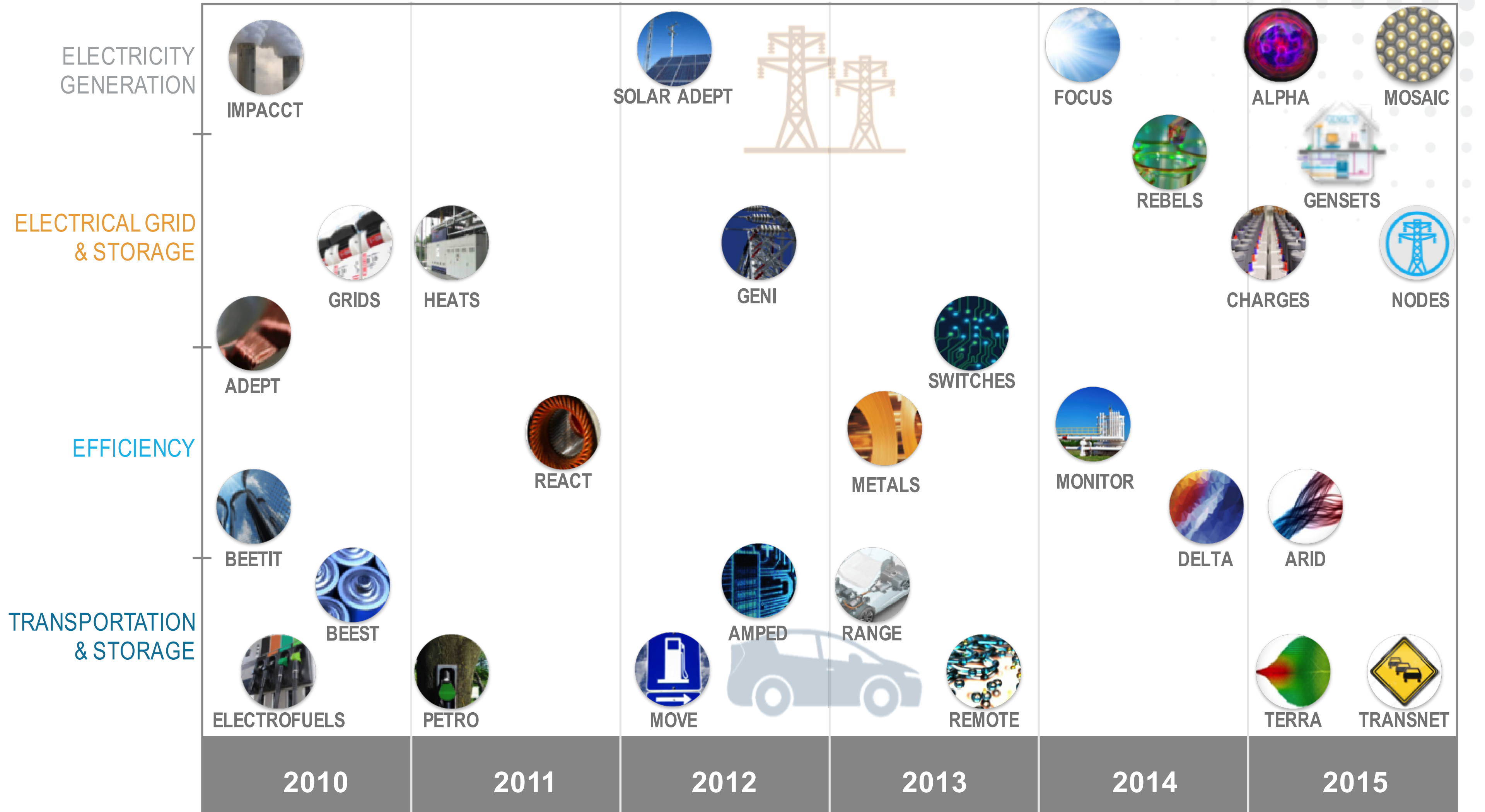
- Complement focused programs
- Support innovative “one off” projects
- Provide a “snapshot” of energy R&D

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



ARPA-E Program Portfolio



OPEN 2009
36 projects

OPEN 2012
66 projects

OPEN 2015
41 projects

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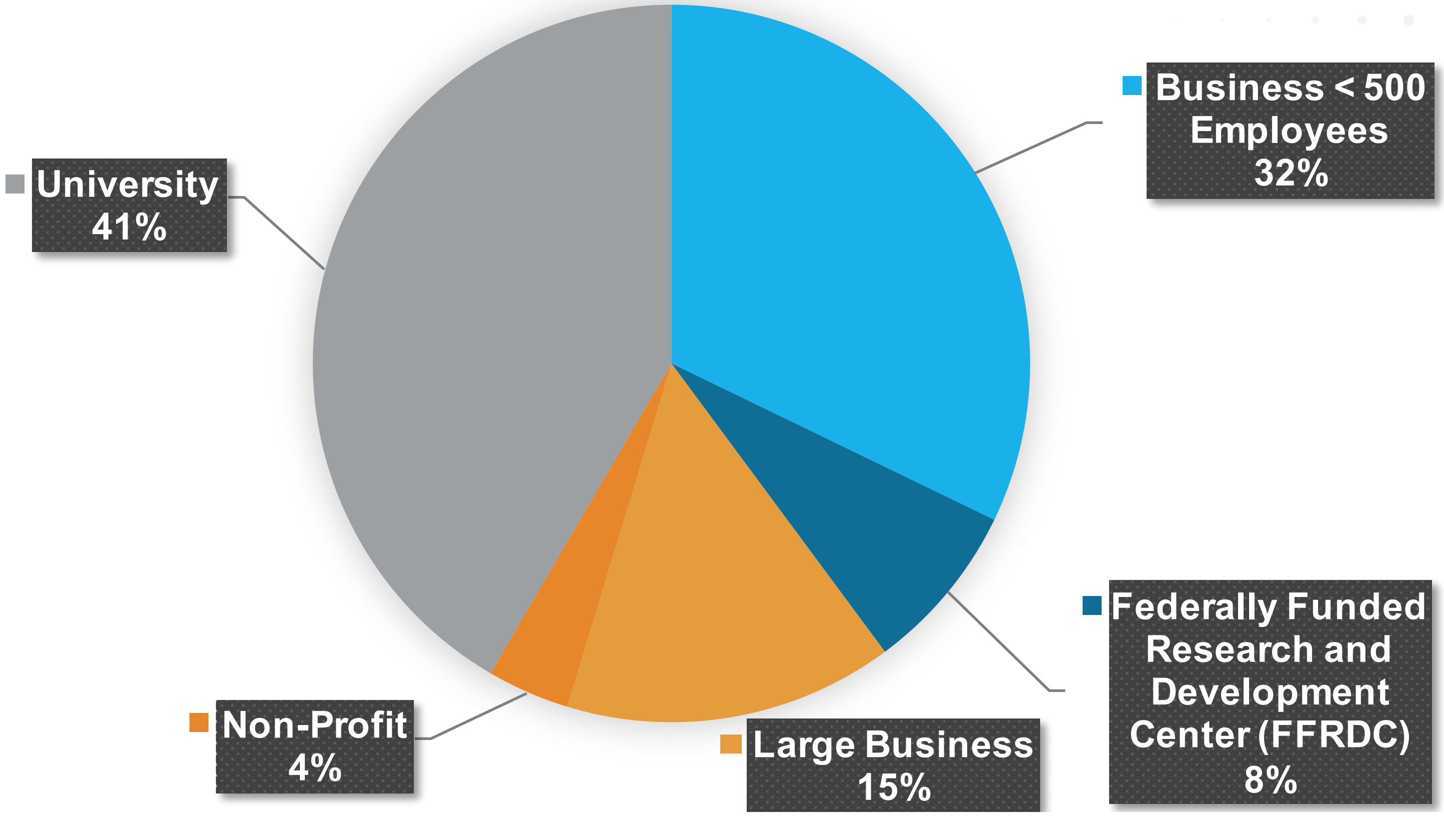
ARPA-E Project Portfolio by Lead Organization



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

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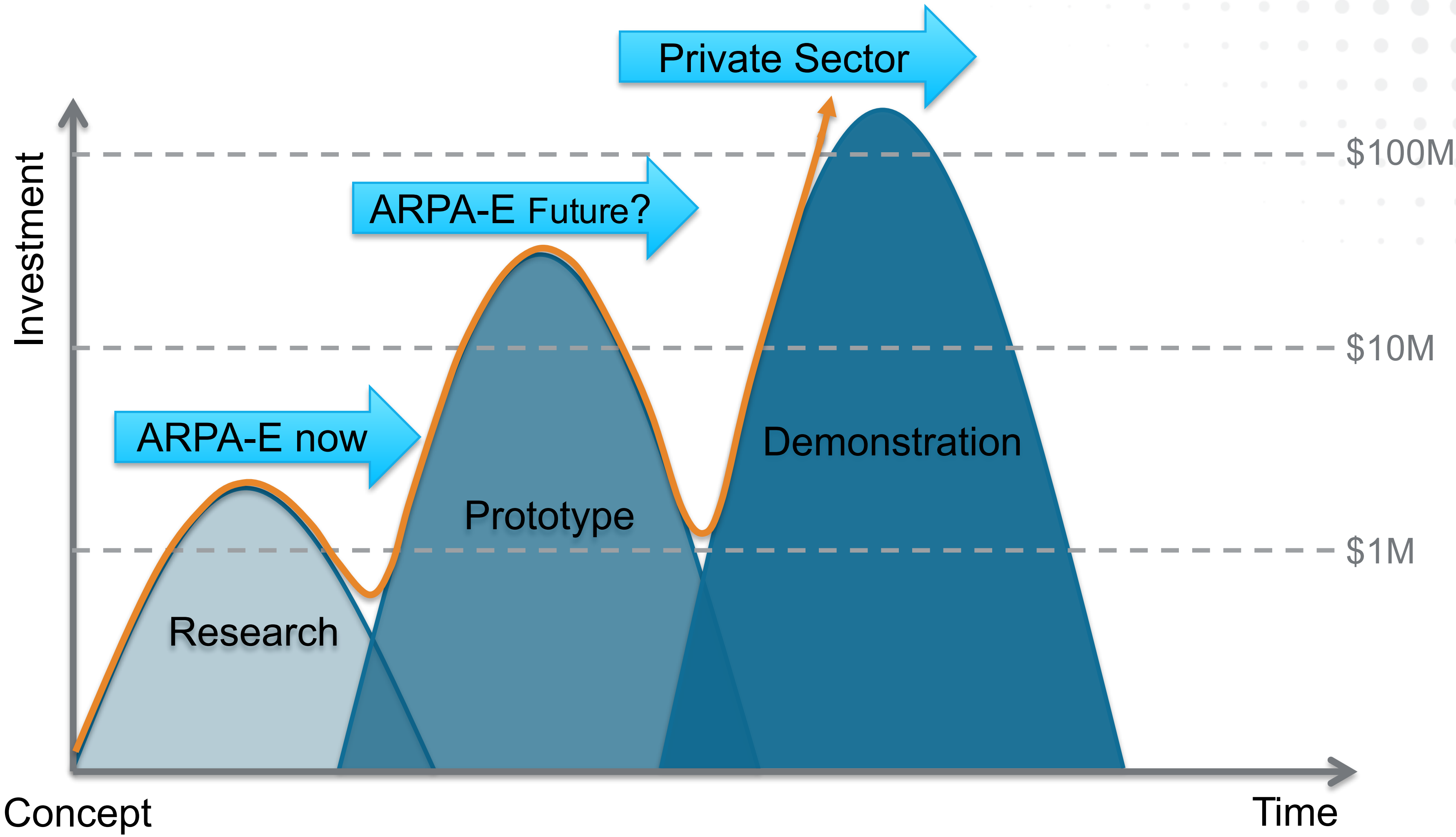
Measuring the transition to the market

Since 2009 ARPA-E has invested approximately $1.3 billion in more than 475 projects through 30 focused programs and three OPEN solicitations.

- 45 ARPA-E projects have attracted more than $1.25 billion in private-sector follow-on funding.
- 36 projects have formed new companies to commercialize their technologies.
- 60 projects have partnered with other parts of DOE or other government agencies to further advance their technologies.

Energy Technology "Mountains of Opportunity"



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ARPA-E FY 2017 Budget Request

($ millions)	FY 2015 Enacted	FY 2016 Enacted	FY 2017 Request	FY 17 vs FY 16 Delta
ARPA-E Annual Appropriation	280	291	350	+59
ARPA-E Energy Trust (Mandatory)	-	-	150	+150
Total	**280**	**291**	**500**	**+209**

The ARPA-E Trust proposes a total of $1.85 billion in mandatory funds over five years and defines a path toward a $1B/year agency

Appropriations Request ($350 M in FY17)

- Core activities – dynamic portfolio of early stage innovation programs, with strong focus on developing commercial potential
- Release FOAs for 7 - 8 focused programs
- Continue a stand-alone SBIR/STTR program
- Continue IDEAS, a small rolling open FOA
- Commercial readiness support for highly successful projects

ARPA-E Trust ($1.85 B over 5 Years)

- Complement core activities
- New activities to integrate advances from core program into innovative technology systems, accelerating large impacts on the energy system
- Create investable opportunities by reducing technical risk of early stage innovations

ARPA-E is a key component of “Mission Innovation”

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?

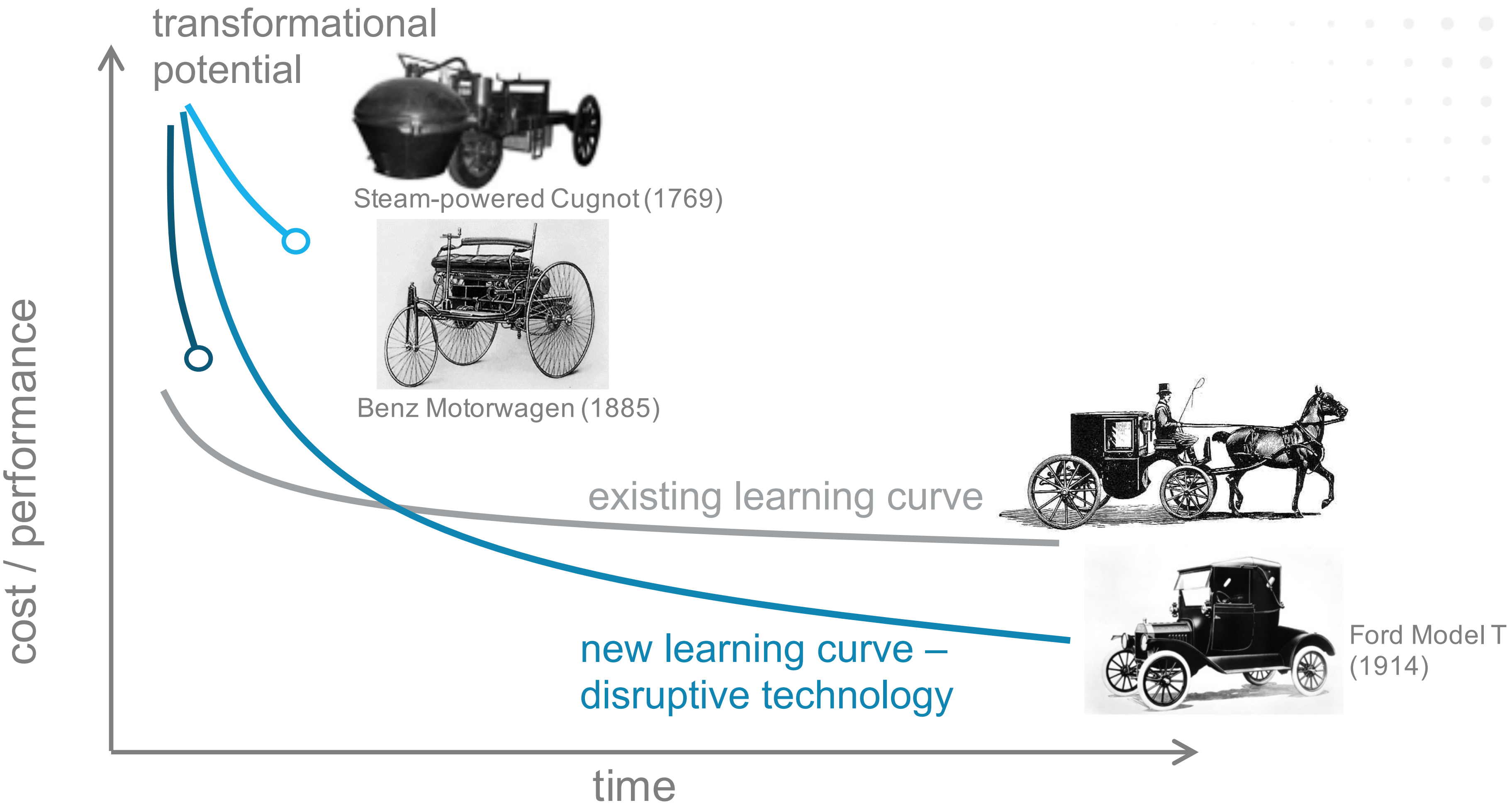
What **research communities** need to be brought together?

Adapted from the DARPA Heilmeier questions

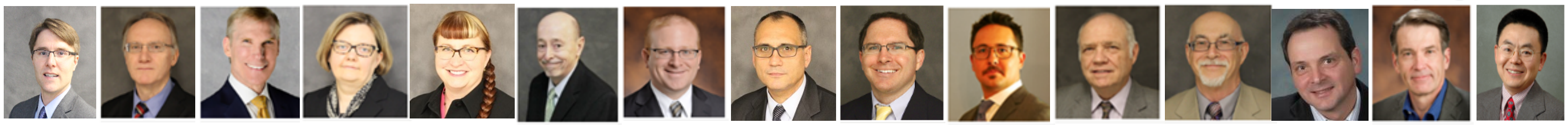
If it works…

will it matter?

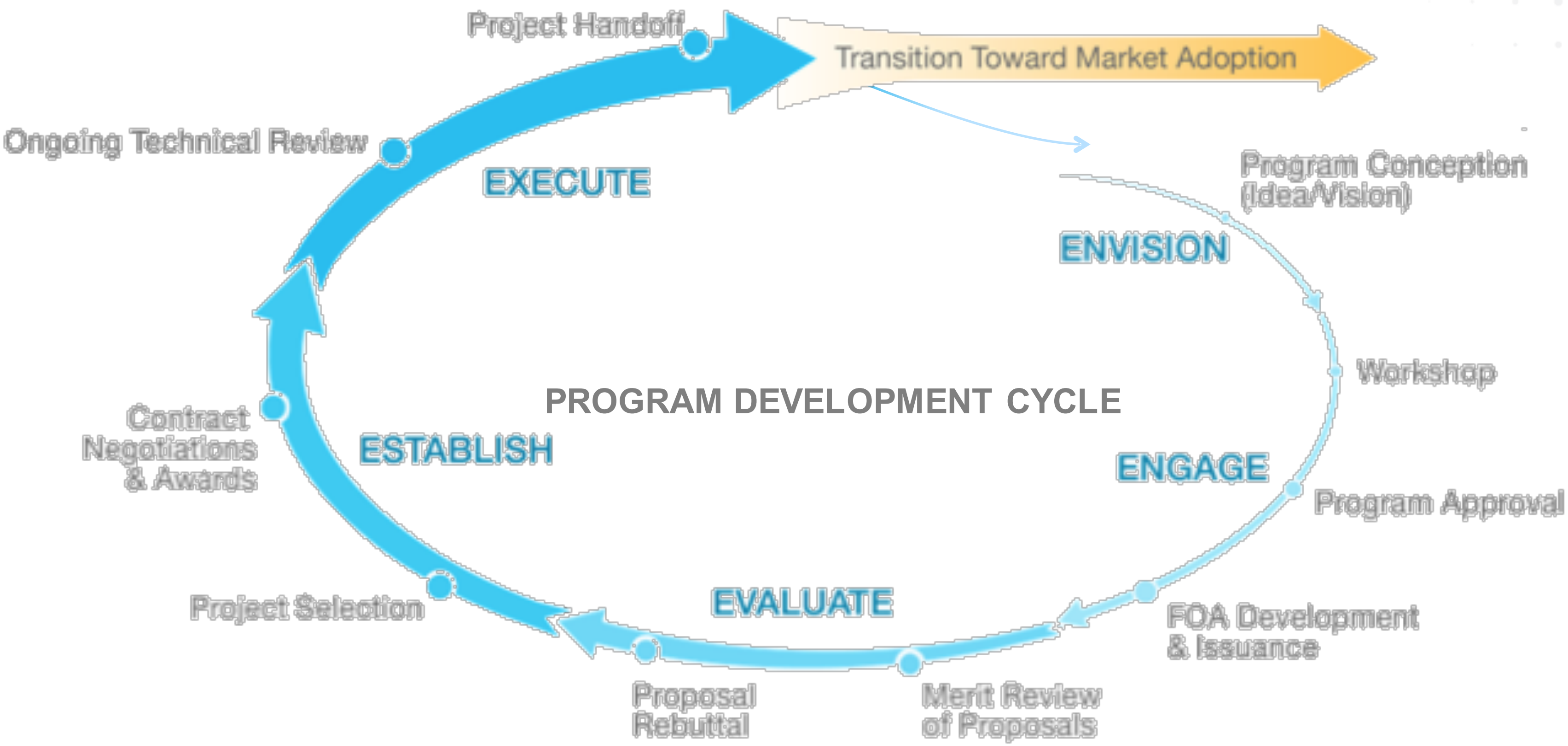
ARPA-E goal: Disruptive technologies



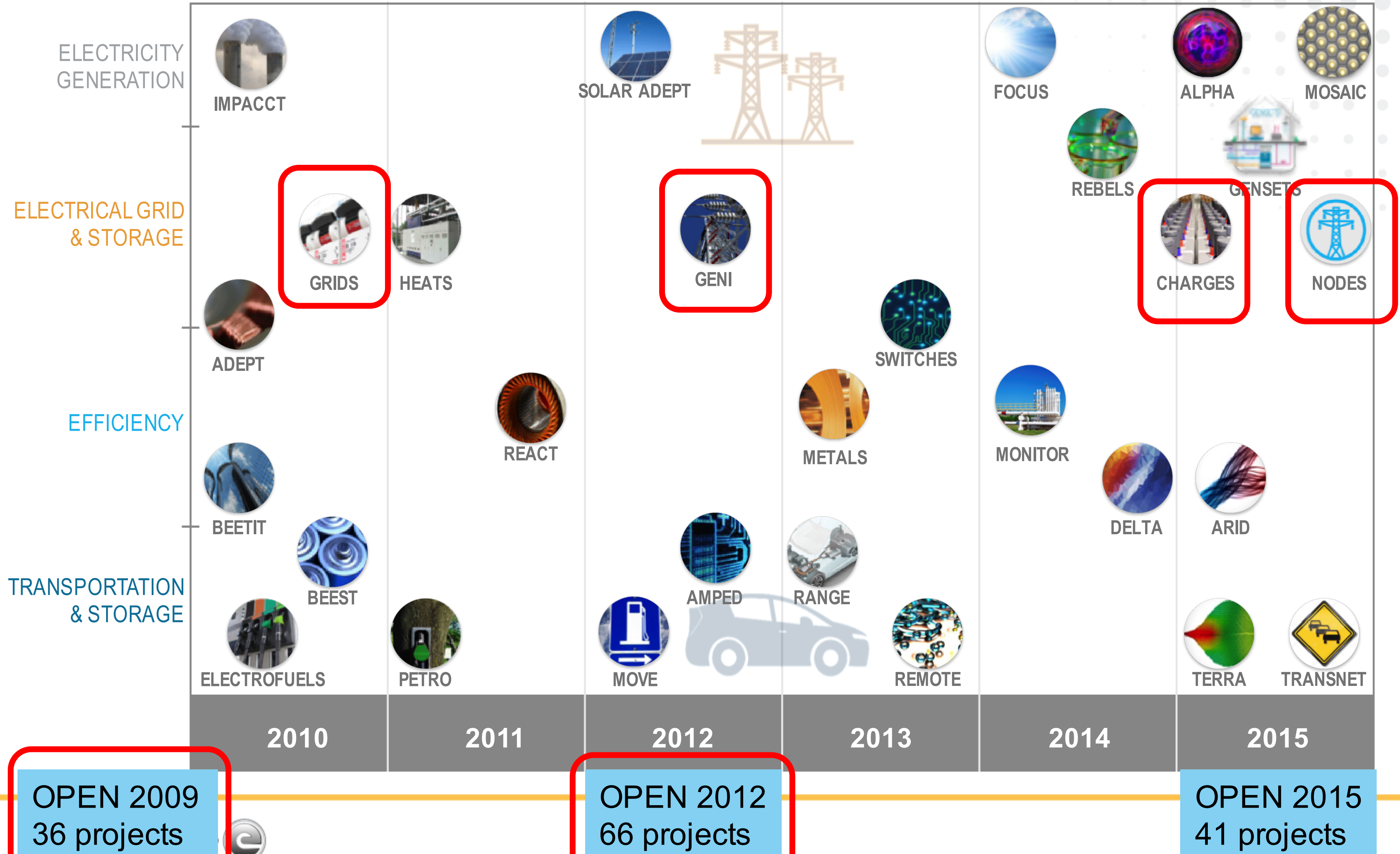
Developing ARPA-E Focused Programs



ARPA-E Program Directors

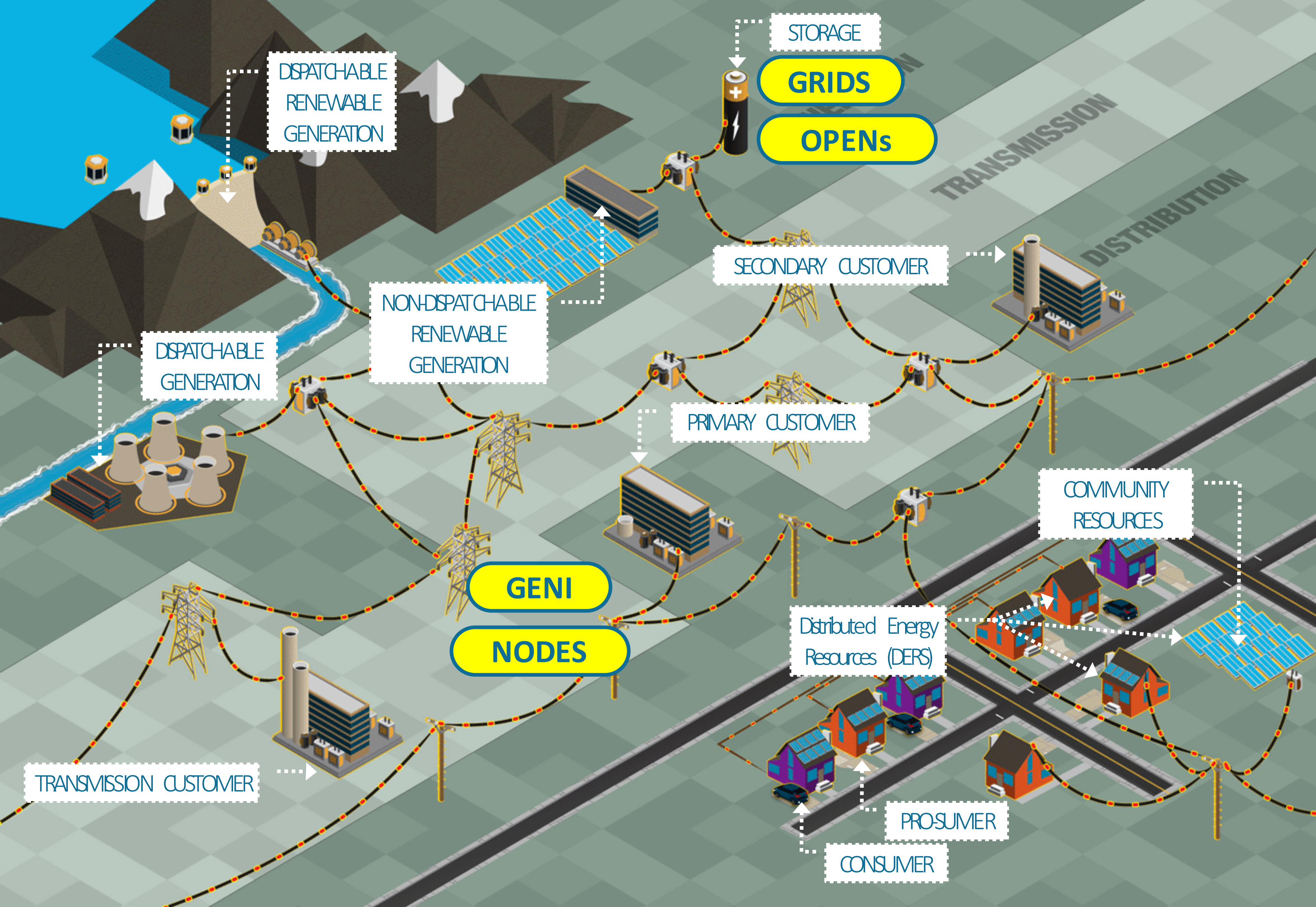


Changing what's possible – the grid

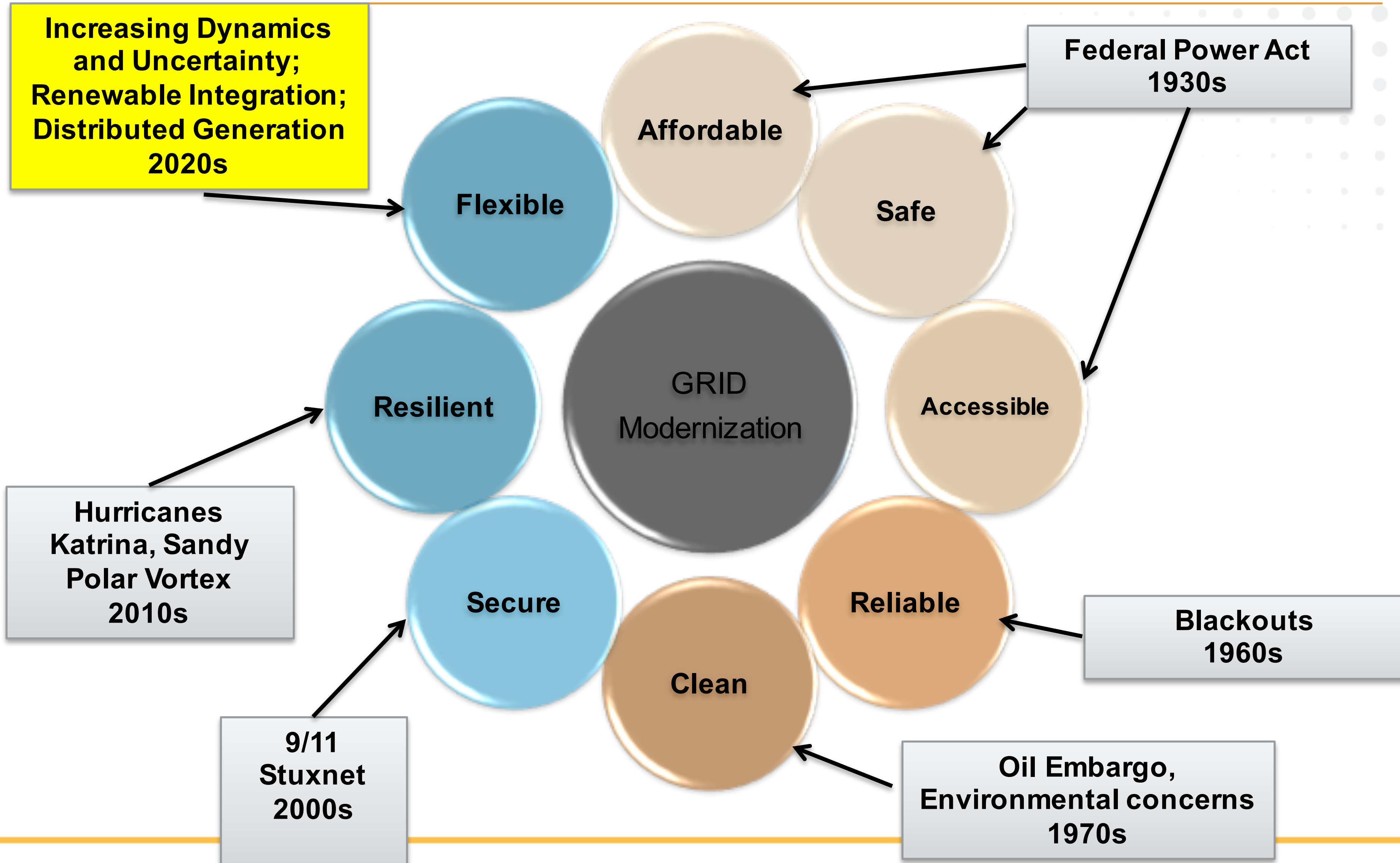


CHANGING WHAT'S POSSIBLE

The Flexible Grid of the Future



Evolution of Electric Grid Requirements

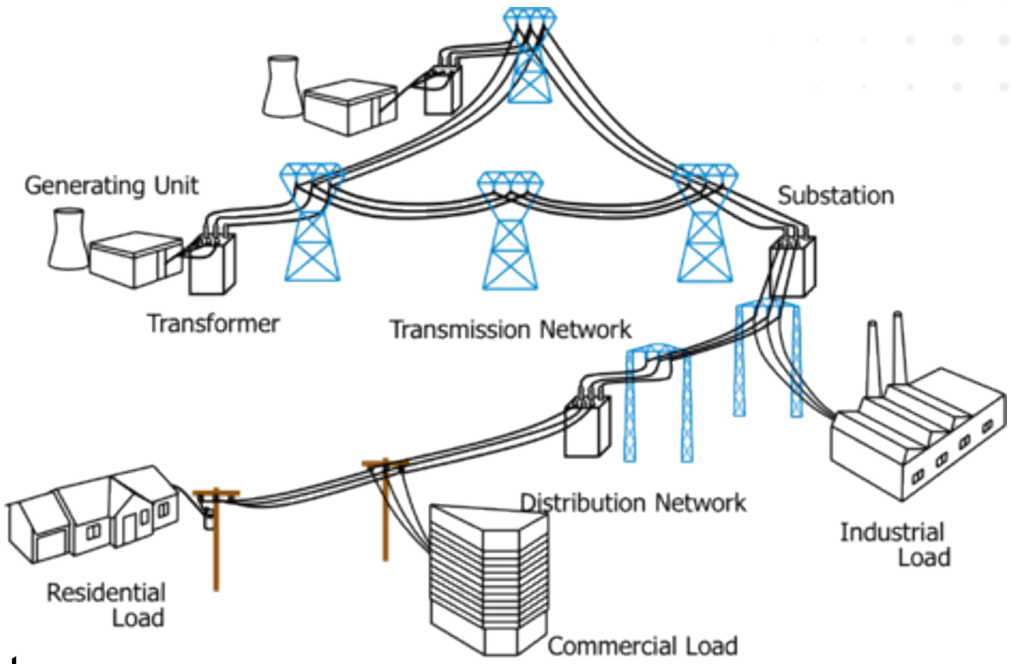


arpa·e CHANGING WHAT'S POSSIBLE

Source: Adapted from DOE Grid Tech Team

New Potential Sources of Network Flexibility

- **Advances in power electronics, computational technologies, and mathematics offer new opportunities for optimizing grid power flows.**



<u>Power Flow Controllers</u>

- AC Power Flow Controllers
- High Voltage DC Systems

<u>Transmission Topology Optimization</u>

- Optimal line switching
- Corrective switching actions

<u>Network Optimization</u>

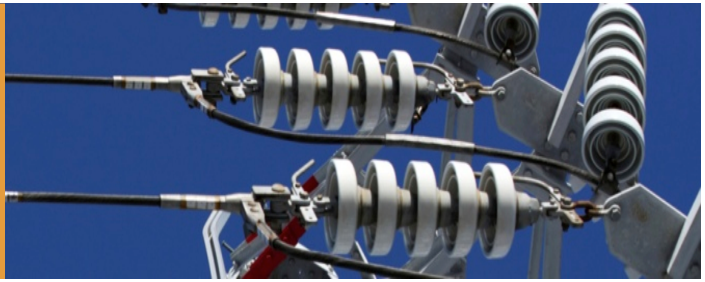
- Scheduling energy flows
- Coordination of diverse storage assets
- Stochastic optimization of generation

<u>Responsive Demands</u>

- Scheduling large loads (eg. industrial)
- Mobilize large numbers of small assets

GENI Program

Green Electricity Network Integration



Goals

- Enable 40% variable generation penetration
- > 10x reduction in power flow control hardware (target < $0.04/W)
- > 4x reduction in HVDC terminal/line cost relative to state-of-the-art

Duration	2012-2015
Projects	15
Total Investment	$39 Million

Tim Heidel
Program Director

Project Categories

- Power Flow Controllers
  - Power flow controllers for meshed AC grids.
  - Multi-terminal HVDC network technologies.
- Grid Optimization
  - Optimization of power grid operation; incorporation of uncertainty into operations; distributed control and increasing customer optimization.

Distributed Series Reactors

PI: Frank Kreikebaum, Smart Wires

SMART WIRES
REIMAGINE THE GRID

- Functions as a current limiter to divert current from overloaded lines to underutilized ones
- Increases line impedance on demand by injecting the magnetizing inductance of a Single-Turn Transformer
- Status
  - 100 units deployed on TVA transmission grid
  - Raised $46M in venture capital funding
  - Mass manufactured, interoperable devices at low cost, using COTS components,
  - Integration into broader utility ecosystem (EMS, IT, cybersecurity, planning, operations, asset management)

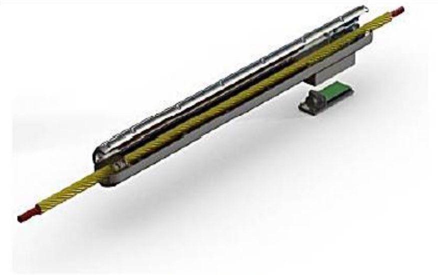


Figure 1

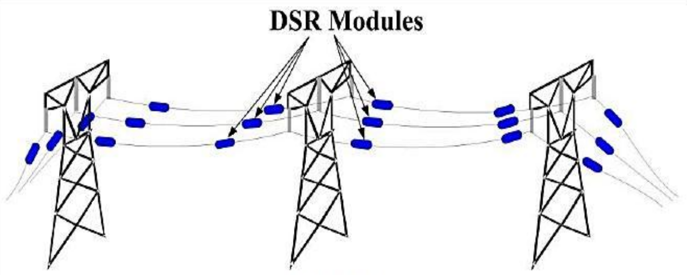


Figure 2

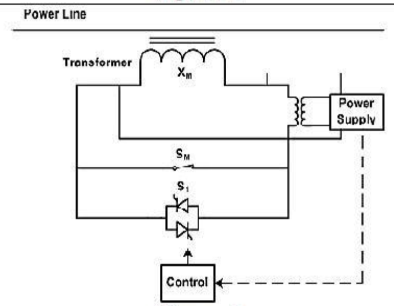


Figure 3

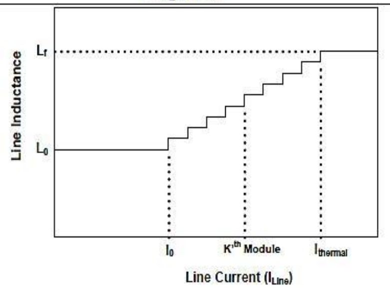


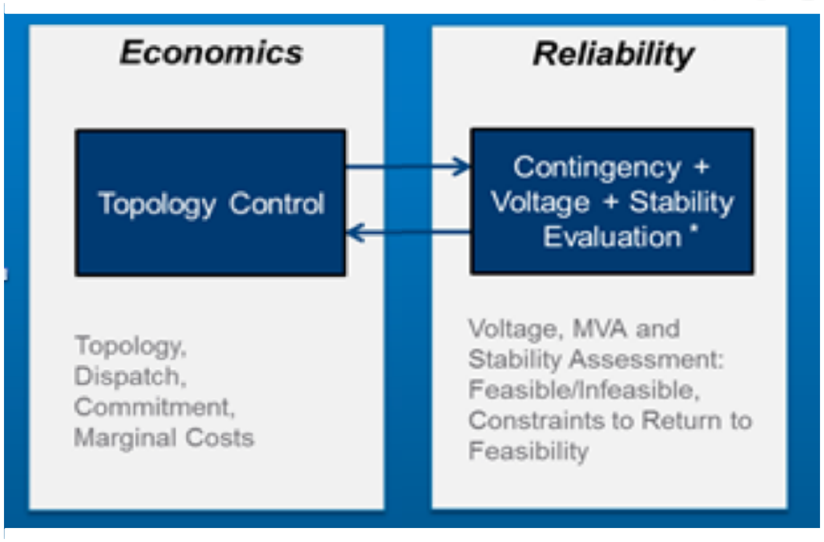
Figure 4

arpa·e CHANGING WHAT'S POSSIBLE · Carnegie Mellon University · INNOVENTOR "The Original Idea People" · newpotato TECHNOLOGIES · Georgia Tech NEETRAC National Electric Energy Testing, Research and Applications Center · edd · PowerWorld Corporation The Visual Approach to Analyzing Power Systems

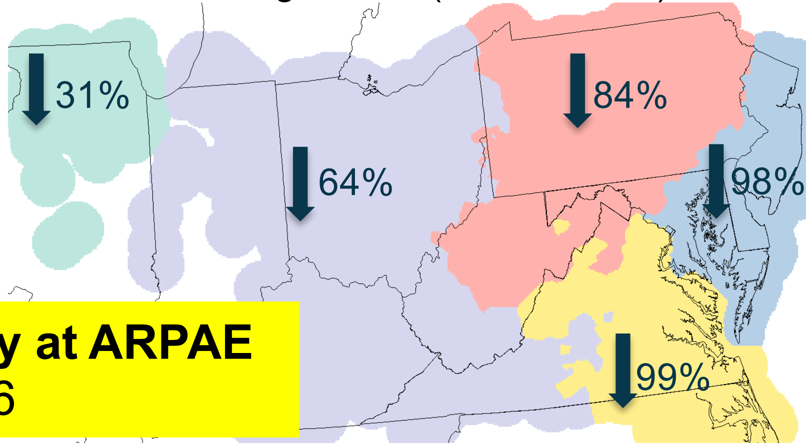
BU: Transmission Topology Control Algorithms

PI: Pablo Ruiz, Boston University

- Algorithms optimize transmission topology (line switching) in real time
- Practical solution times reached (below 5 minutes in PJM)
- Collaborated with PJM to demonstrate in simulation :
  - Savings of over 50% of Cost of Congestion (> $100 million/year under 2010 conditions)
  - Renewable curtailments reduced on average by 40% in high-renewables case
- Status
  - Team has won small-scale consulting contracts and has spun out a company, New Grid, Inc.
  - Largest customer (PJM) has issued RFP for topology optimization services



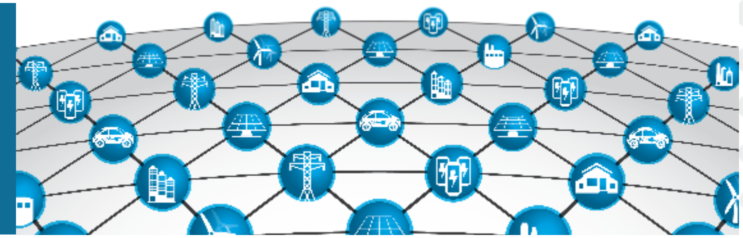
Renewable curtailment reductions with Topology Control Algorithms (Winter Week)



Doing the Hard Math to Unlock Grid Flexibility at ARPAE
Greentech Media | Jeff St. John | March 11, 2016

NODES

Network Optimized Distributed Energy Systems



Mission

Reliably manage dynamic changes in the grid by leveraging flexible load and Distributed Energy Resources' (DERs) capability to provide ancillary services to the electric grid at different time scales.

Sonja Glavaski
Program Director

Goals

- Enable renewables penetration at > 50%
- Improve overall grid efficiency and reliability
- Reduce CO_2 emissions (renewables↑, reserves↓)
- Increase penetration of Distributed Generation (DG)

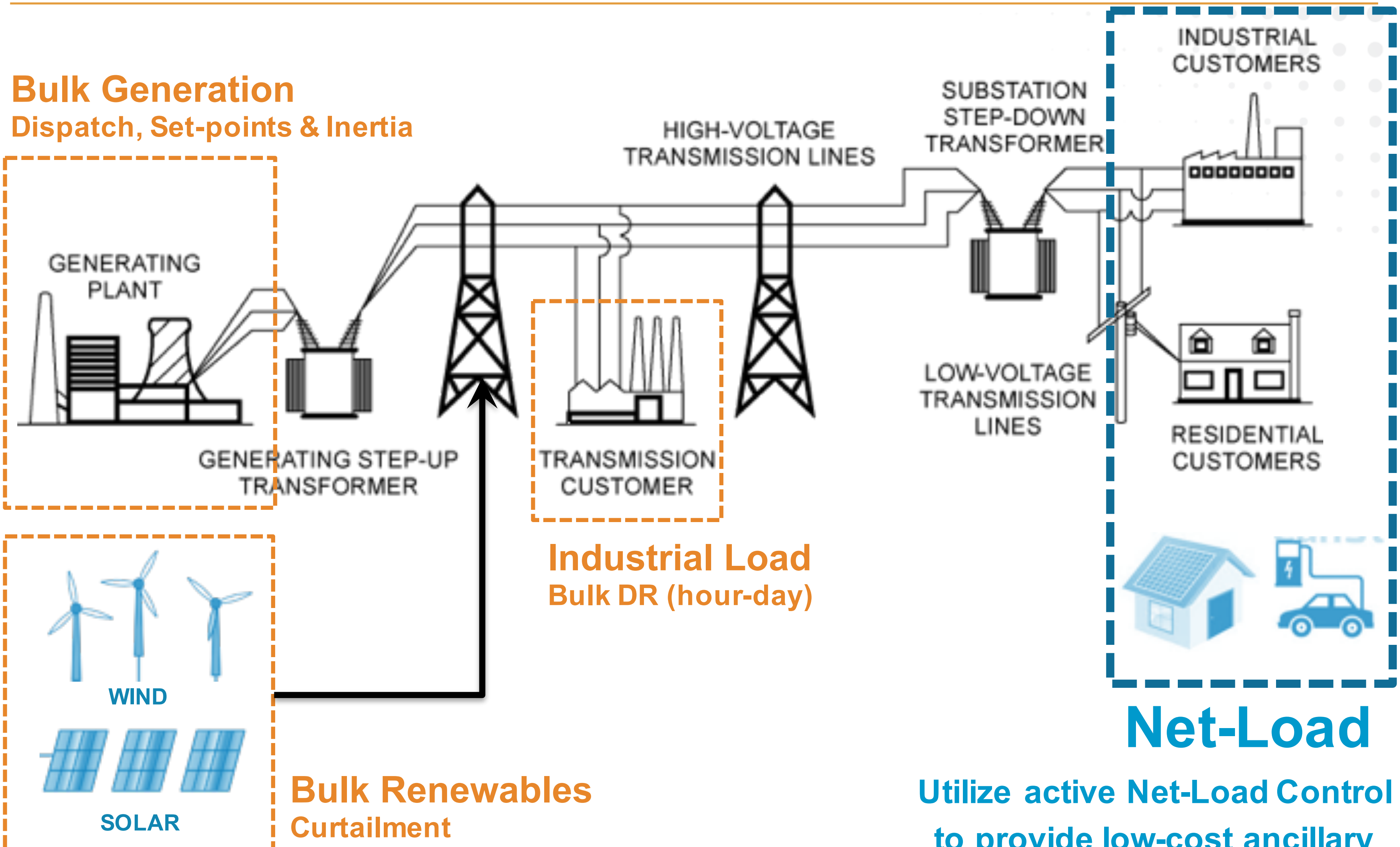
Technical Challenges

- Dispatching both bulk and distributed generation
- Proactively shaping load over different time scales
- Coordinating consumers and generation operation
- Distributed management of heterogeneous resources
- Guaranteeing customers' QoS

Year	2015
Projects	12
Anticipated Investment	$33 Million

Project Categories	Response Time	Ramp Time	Duration
C1: Synthetic Frequency Reserves	< 2 sec	< 8 sec	> 30 sec
C2: Synthetic Regulating Reserves	< 5 sec	< 5 min	> 30 min
C3: Synthetic Ramping Reserves	< 10 min	< 30 min	> 3 hr

What do we want to control?



Utilize active Net-Load Control to provide low-cost ancillary services at different time-scales

GRIDS

GRID-SCALE ENERGY STORAGE

Program Director: Dr. Eric Rohlfing; Dr. Patrick McGrath Tech-to-Market Advisor: Sue Babinec Year: 2010

Technical Challenge: Develop technologies that can provide the dispatchable power duration, low-cost, and life-cycle reliability of pumped hydroelectric, but provide scalability and siting for ubiquitous deployment across the grid.

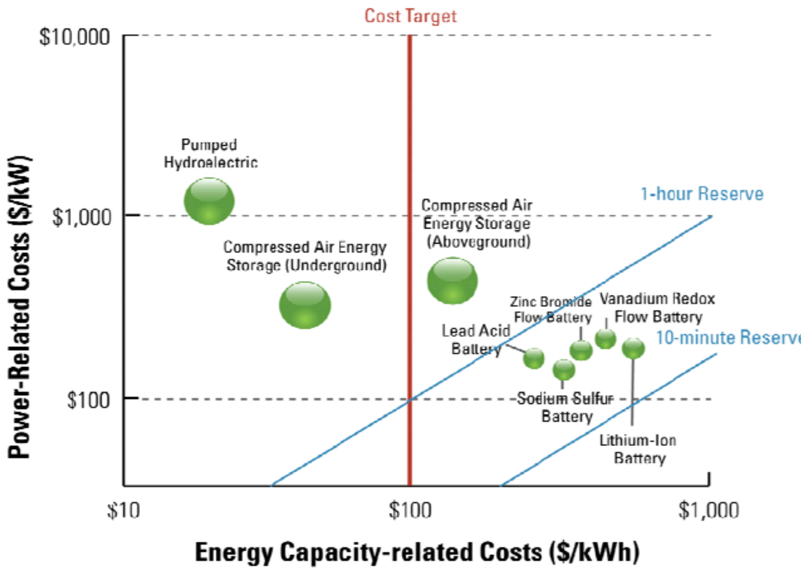
Goals

- System Capital cost < $100/kWh
- Round trip storage efficiency > 80%
- Lifetime > 5000 cycles and 10 years

Technology Categories

- Electrochemical systems based on low-cost materials
- Novel approaches to compressed air storage
- New approaches to flow batteries
- Low-cost flywheel technologies
- Unique, high-risk technical concepts

2010 technology costs (capital)



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Diverse Technical Opportunities for Storage

Multiple ARPA-E Programs

OPEN 2009:	6 projects
GRIDS:	12 projects
SBIR:	5 projects
OPEN 2012:	10 projects

SMES
ABB
TYRC

Flywheel
BOEING
Beacon POWER

Flow Cells
HARVARD
24M
United Technologies Research Center
TELEDYNE TECHNOLOGIES Everywhereyoulook
TreadStone
Proton ENERGY SYSTEMS
CASE WESTERN RESERVE UNIVERSITY
PRIMUS POWER
ITN ENERGY SYSTEMS INC.
BERKELEY LAB
USC
ESS
GENERAL ATOMICS AND AFFILIATED COMPANIES
TVN SYSTEMS Energy to Power the 21st Century

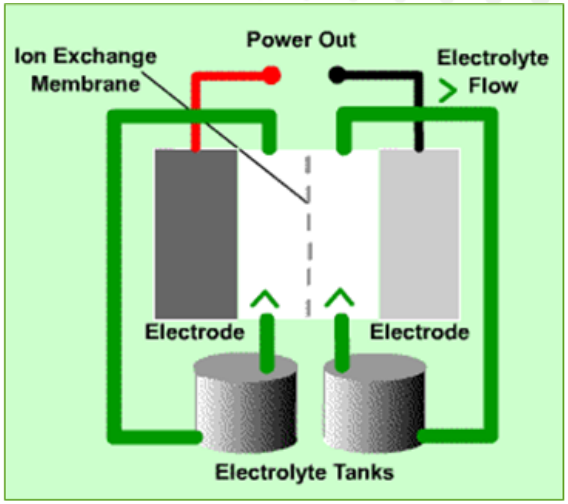
E-C Cells
CUNY
UMBC
UNLV
AMBRI
EaglePicher Technologies, LLC
FLUIDIC ENERGY
Alveo
MSRI
POLYPLUS
Georgia Tech

CAES
GENERAL COMPRESSION expanding clean power

Example: Primus Power

CEO: Tom Stepien

- Flow Cell Energy Storage
  - Zn-Br cell chemistry
  - Modular 280 kW Energy Pods
  - Successful tests at NREL
- Demonstration underway at Miramar Marine Corps Air Station.
  - 250-kilowatt, 1-megawatt-hour flow battery
  - Purpose to reduce mid-afternoon utility premiums and supply full power to one building for 2-3 days
- Status
  - Over $55M in venture funding
  - Strategic agreement with Samruk Energy (Kazakhstan) to supply 1,250 batteries.



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Raytheon

SANMINA

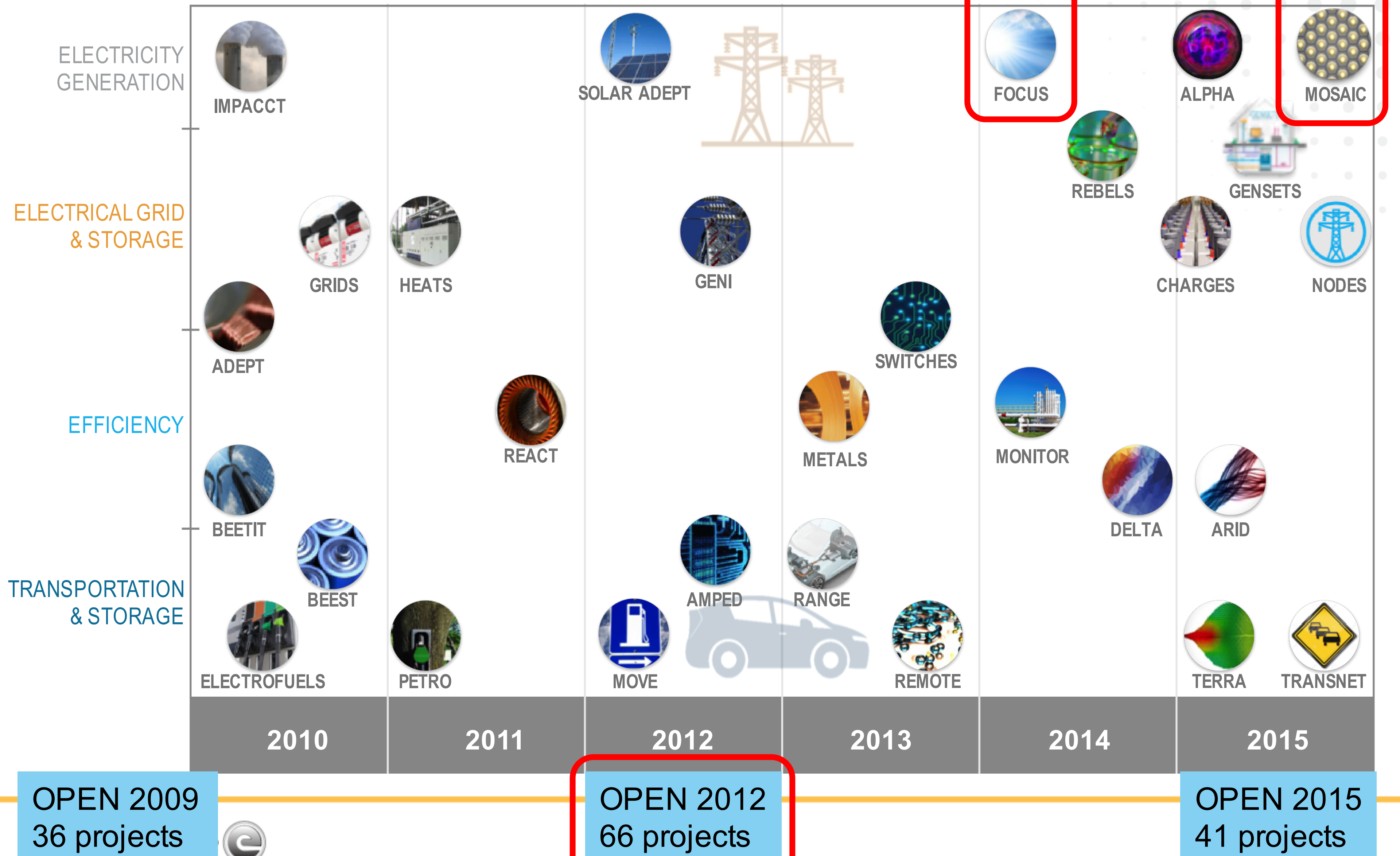
Innovation for the Future of the Power System

- Clear pathways to improving the reliability of the US power system and simultaneously enabling increased penetration of intermittent and distributed energy sources.
  - Power Flow Control
  - T&D Optimization
  - Responsive Demands
  - Energy Storage

CHARGES: Cycling Hardware to Analyze and Ready Grid-Scale Electricity Storage

- Continuing ARPA-E investments
  - CHARGES
  - NODES
    - *Network Optimized Distributed Energy Systems*
  - GRID DATA
    - *Generating Realistic Information for Development of Distribution and Transmission Algorithms*
  - IONICS
    - *Solid Ionic Conductors for Electrochemical Energy*

Changing what's possible – solar



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FOCUS – Full-Spectrum Optimized Conversion and Utilization of Sunlight

Optimally exploit the full solar spectrum for energy conversion and dispatch solar electricity when the sun is not shining.

Problem Statement

- The value of variable PV electricity falls once widely deployed and electrical storage is too expensive. Concentrating solar power (CSP) provides expensive heat, but stores thermal energy at low cost.

Approach

- Challenge applicants to capture *exergy* of sunlight
- Create 400°C PV to enable capture of waste heat
- Challenge applicants to co-store heat and electricity at high round-trip efficiency

Program Portfolio (solutions)

Kickoff Year	2014
Projects	13
Investment	$34 Million

- Hybrid PV/CSP Hybrid Collectors (9)
- High T solar cells that work for 30 years (3)
- Turbine cycle from ice-cold to hot (1)

Scientific & Technical Challenges

- Keeping the system simple
- High temperature PV that works and is durable
- Inexpensive III-V cells with unusual bandgaps
- Integrating topping PV with thermal fluid
- Low-cost optical dichroics for low concentration
- Small, efficient, inexpensive heat engines

Eric Schiff & Mike Haney
Program Directors

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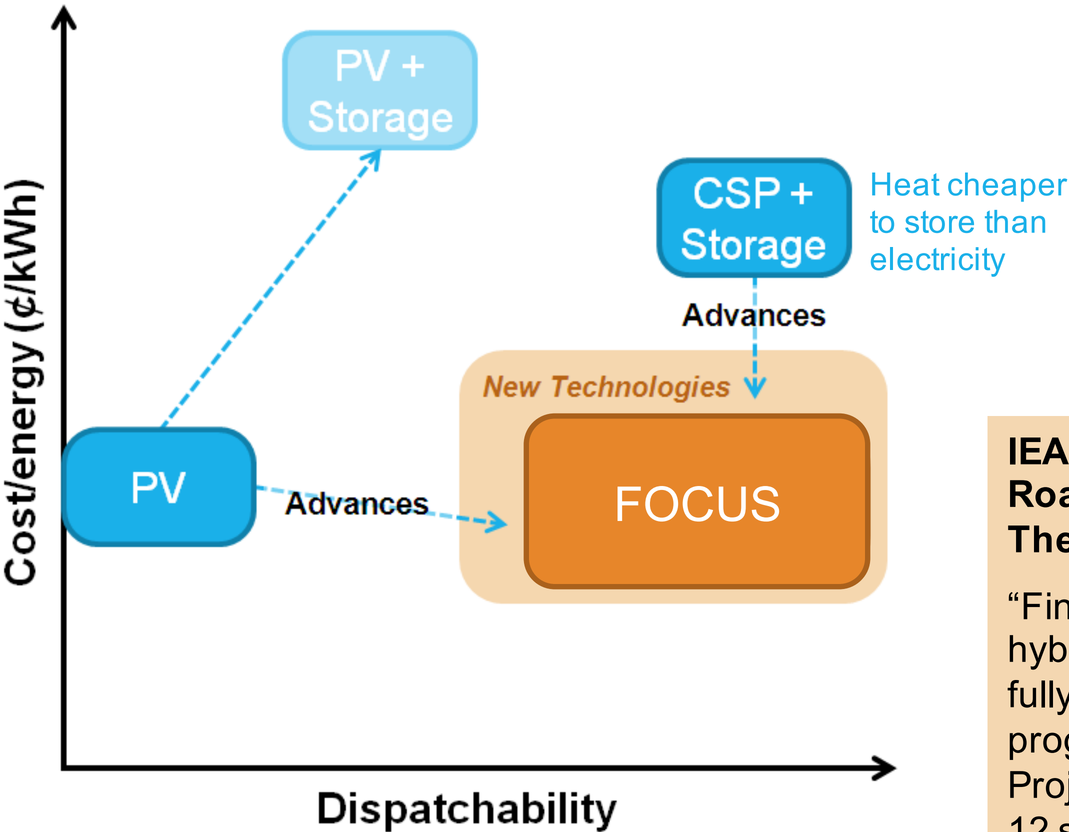
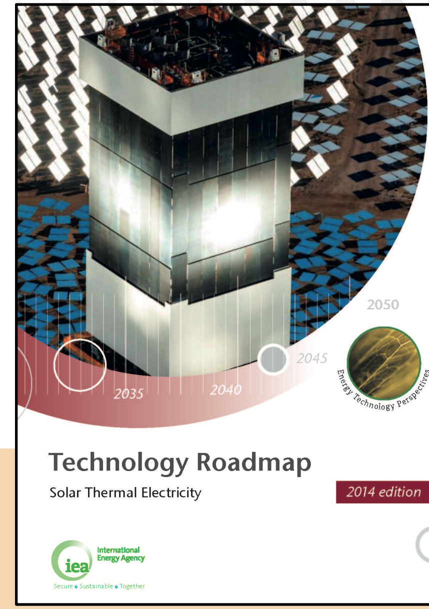
FOCUS Systems Transcend PV & CSP Paradigms





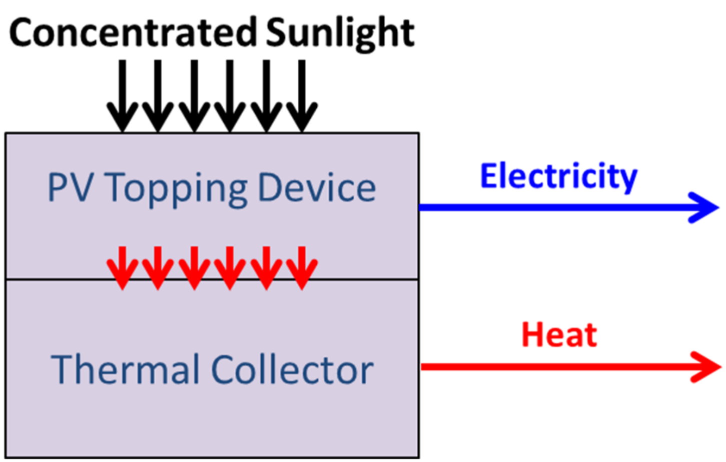
IEA 2014 Technology Roadmap for Solar Thermal Electricity

"Finally, the ultimate evolution could be to hybridise STE technology with PV technology in fully integrated receivers …….The FOCUS programme of the US Advanced Research Projects Agency – Energy (ARPA-E) is supporting 12 such projects (Branz et al, 2014)."

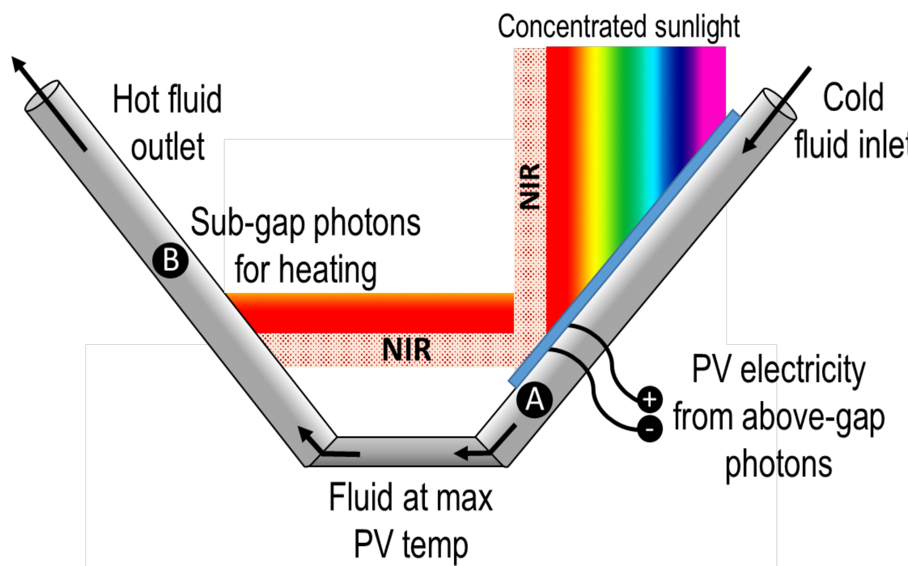
Materials Research Society 2016 Spring Meeting
Session on: Materials and Devices for Full Spectrum Solar Energy Harvesting
Inspired by FOCUS; PD giving invited talk

Options for hybrid collectors

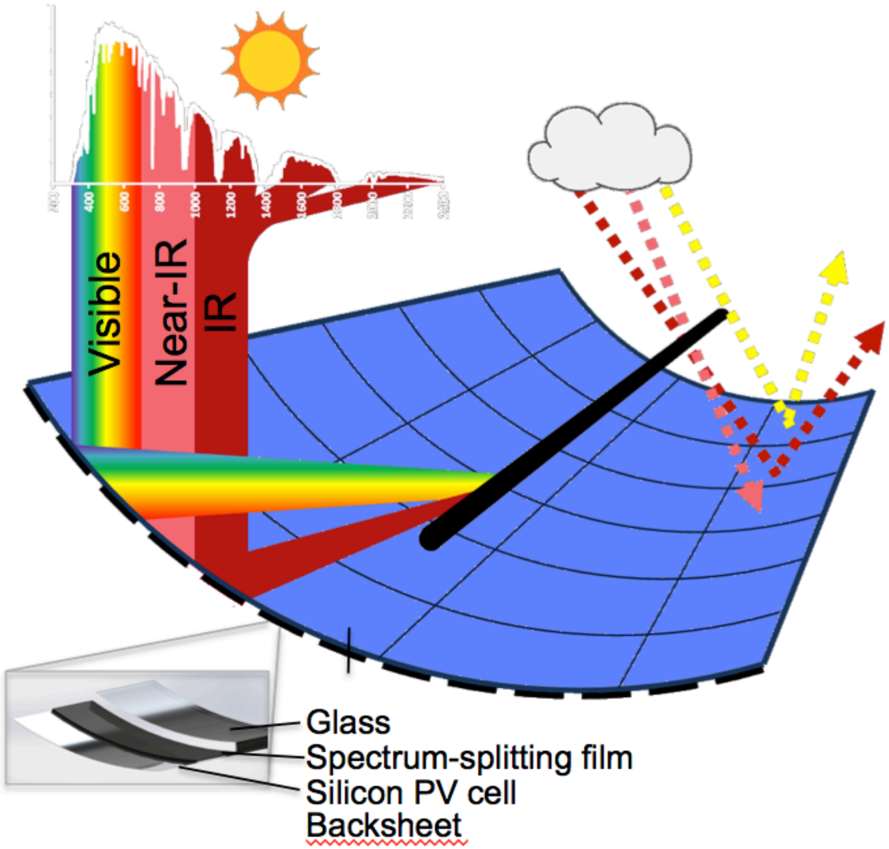
- **Combined cycles:**
  - PV topping cycle
  - Send subgap and thermalization losses to storage, heat engine
  - **Challenge:** high temperature PV

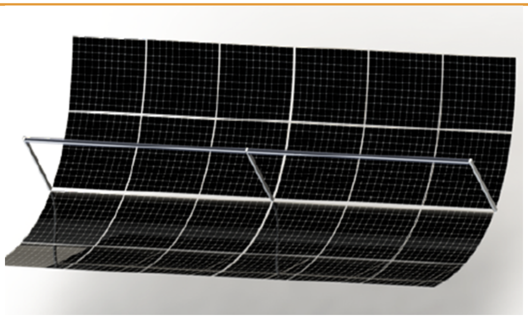


- **Spectral splitting:**
  - Send matched wavelengths to PV
  - UV and IR to thermal cycle
  - (Optional) Capture low-grade heat on PV for preheat



Re-envisioning the solar thermal trough





- Planar Si PV cells and dichroic mirror replace silver mirror
- PV cells convert 1-sun direct and diffuse visible components
- Reflection heats fluid with concentrated direct-beam UV/IR

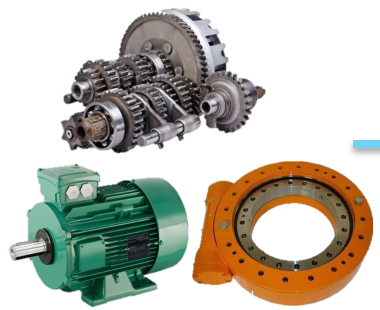
On track for ~50% (relative) gain in trough efficiency

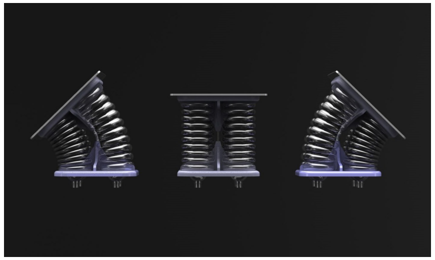
Pneumatic solar tracking

sunfolding

What's old:

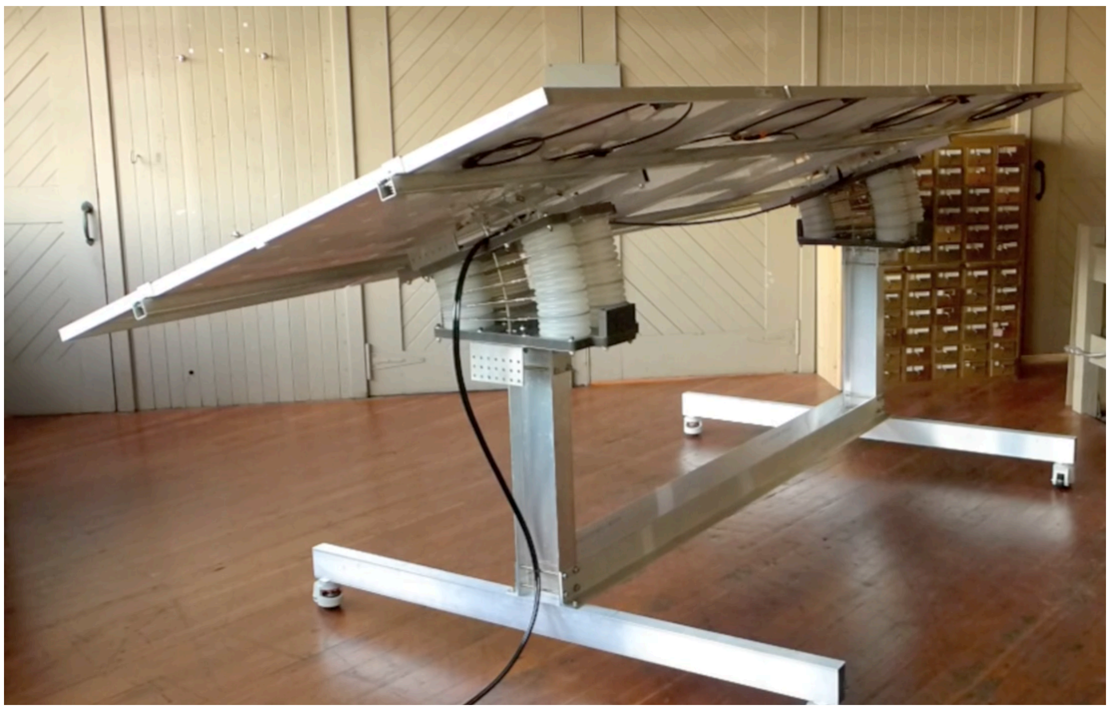
- Electric Motors
- Gears
- Rigid structures
- Top down controls





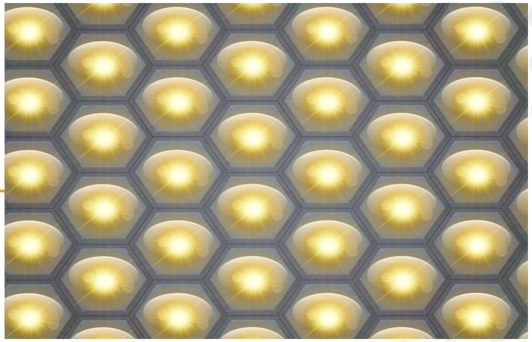
What's New:

- Pneumatics
- Plastics
- Compliant structures
- Distributed actuation



- High strength plastics provide the same strength as steel for 1/3 the cost

MOSAIC (Micro-scale Optimized Solar-cell Arrays with Integrated Concentration)



Motivation

- Low-cost 1-sun flat panel conversion efficiency reaching practical limits.
- Need significant step-change in conversion efficiency to *lower BOS costs to expand the market.*

What's the new idea?

- Bring ***micro-scale*** integration and manufacturing techniques to bear on FP PV.
- Bring together the solar system integration, semi-conductor fabrication, and micro-optics development communities.

Opportunity/Impact

- New learning curve: 50% jump in FP PV efficiency with similar $\$/m^2$ panel costs.
- Make solar more cost effective than other electricity sources in more geographies.

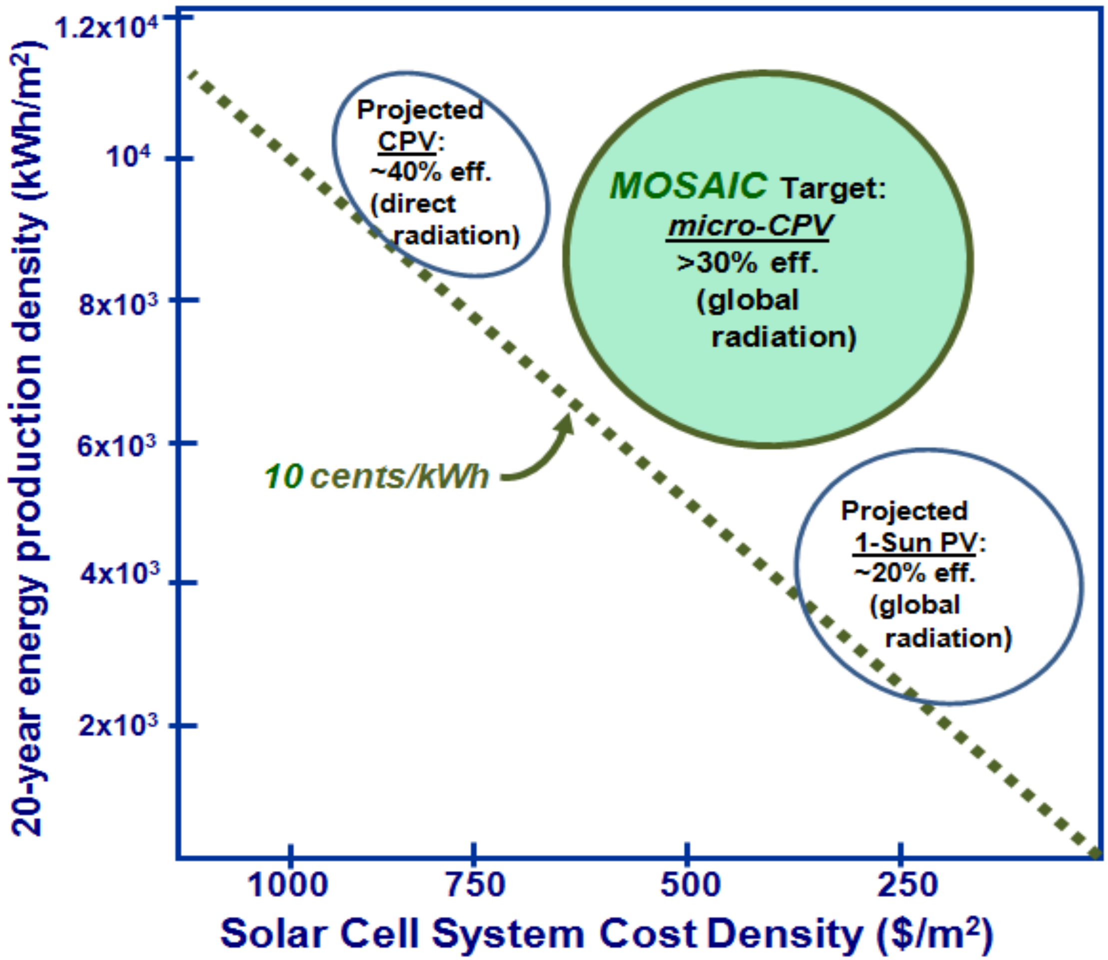
Key technical challenges

- Micro CPV pixilated cell array fabrication, integration, and packaging techniques.
- Micro-scale optics with high performance, robustness, and manufacturing scalability.
- Micro-optical tracking for fixed-tilt applications.
- System fabrication costs commensurate with current FP PV.

Mike Haney
Program Director

Performance/Cost Opportunity for Solar PV

PV system energy harvesting potential vs. cost density



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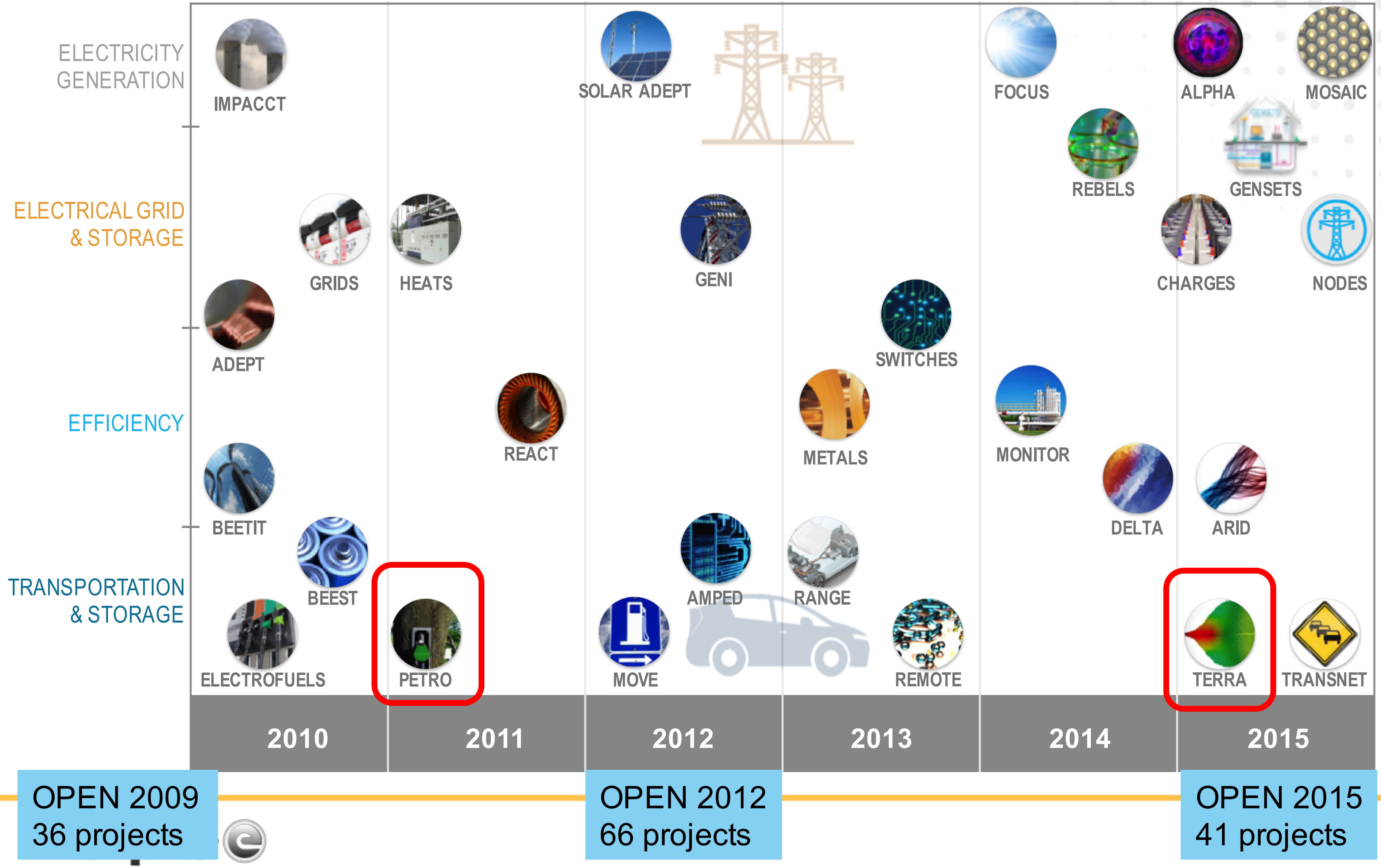
Changing what's possible – biofuels

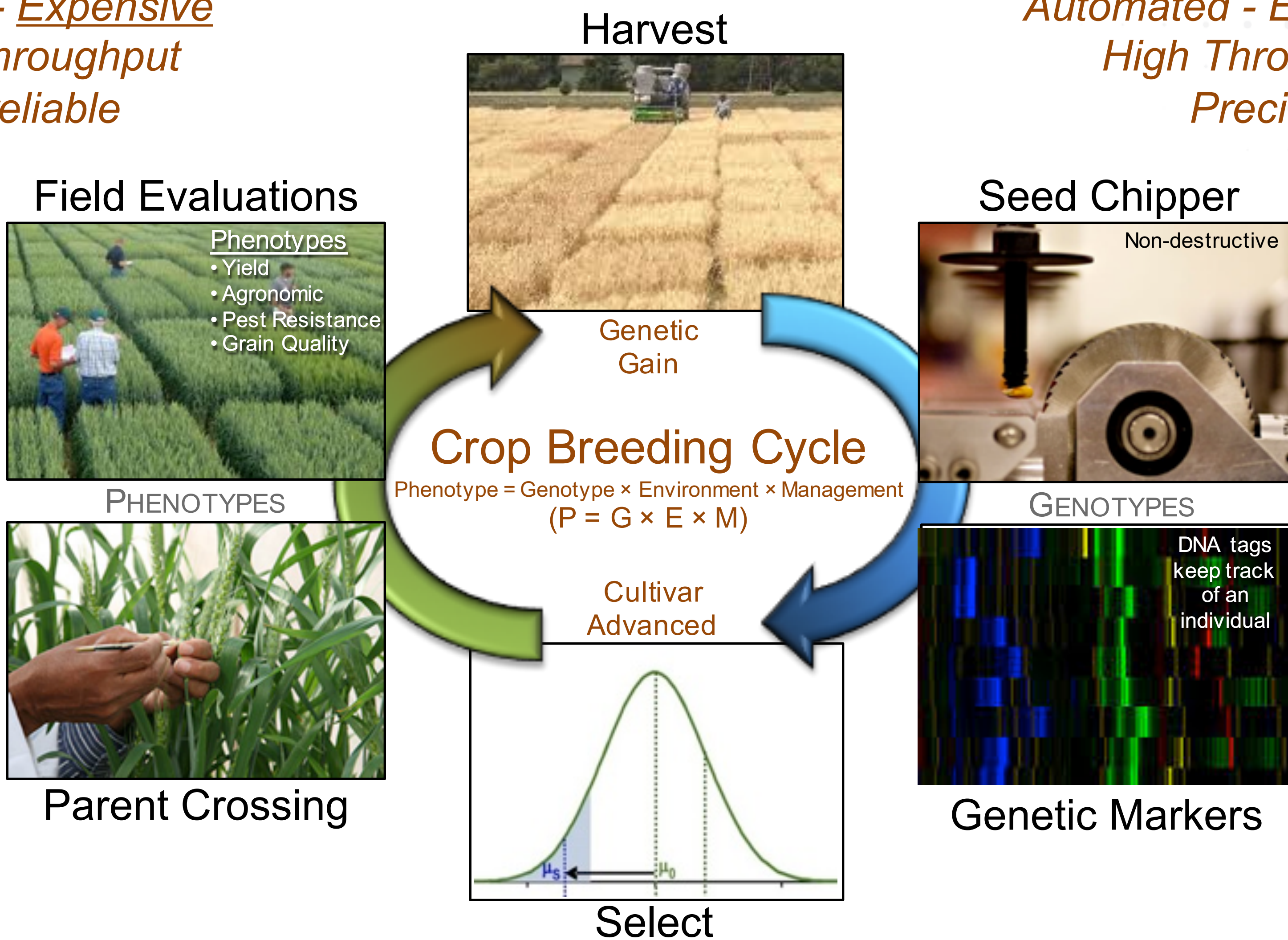


Crop Improvement Process… 8 -10 years / new hybrid

Phenotyping is the Bottleneck for Trait Discovery and Cultivar Development

Manual - <u>Expensive</u>
Low Throughput
Unreliable

Automated - Economical
High Throughput
Precise



Major breeding objectives: yield, composition, disease and insect resistance and tolerance to abiotic stresses.

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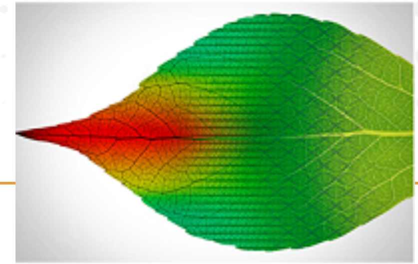
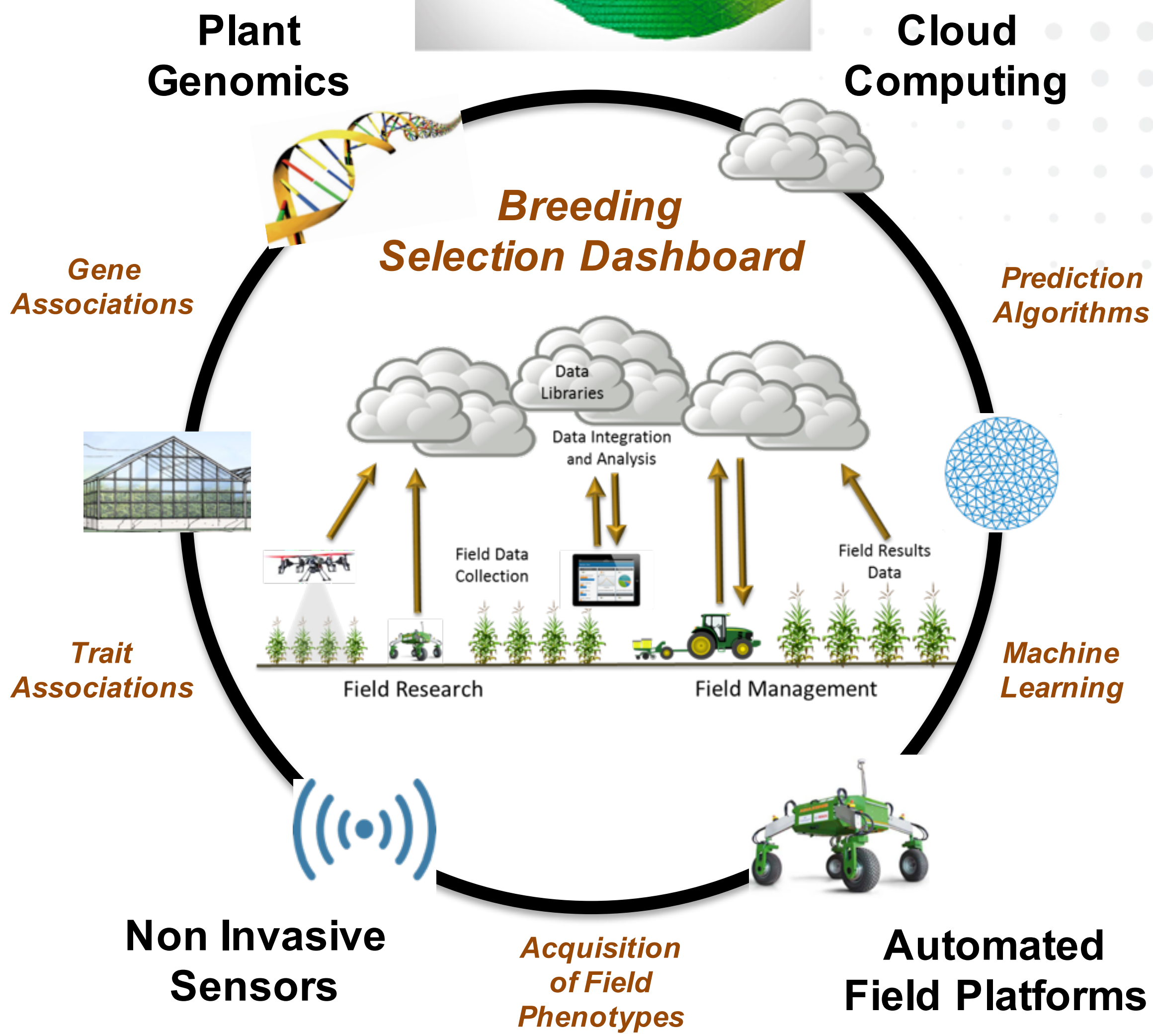
TERRA (Transportation Energy Resources from Renewable Agriculture)



- ARPA-E is funding 6 crop phenotyping projects focused on sorghum at $30M.
- Projects range from 2-4 years, and were contracted in September, 2015.
- ARPA-E purchased and is funding the installation of a state of the art sensing platform (GFE), which will be operated by the public reference team. ($3.5M)



Joe Cornelius
Program Director

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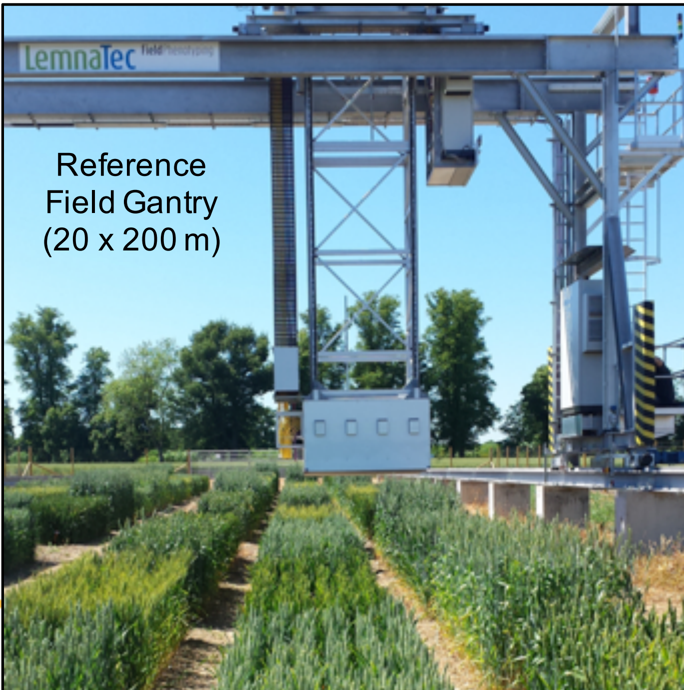
TERRA Robotic Platforms are Diverse and Data Rich

GFE Reference Field Phenotyping Platform
Danforth Center, USDA, UAZ

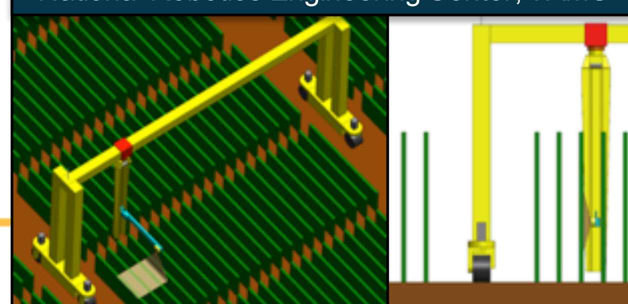


Performance Comparison	Current Breeding Manual	TERRA Ground & Aerial Vehicles
# Breeder Plots	1,000	1,000
# Phenotypes	10's	1000's
Resolution	1 m	1 cm
Bandwidth (nm)	400-700	100-2500
Data Collection	Bytes	Terabytes
Cycle Time	8 hrs	1 min UAV 4 hrs AGV

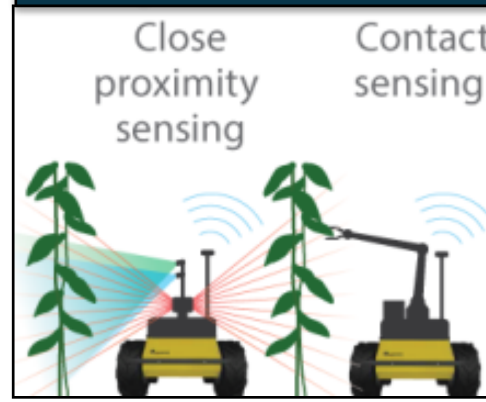
Reference Field Gantry Sensors:

- Hyperspectral i350-2500 nm
- Thermal infrared
- Dedicated NDVI sensor
- Dedicated PRI (photochemical reflectance)
- PAR sensor
- Color sensor
- Height Scanner
- 8 MP RGB down camera
- 2 side looking cameras
- Active reflectance in-field
- Fluorescence
- Environmental temperature, humidity, rainfall, wind, CO_2

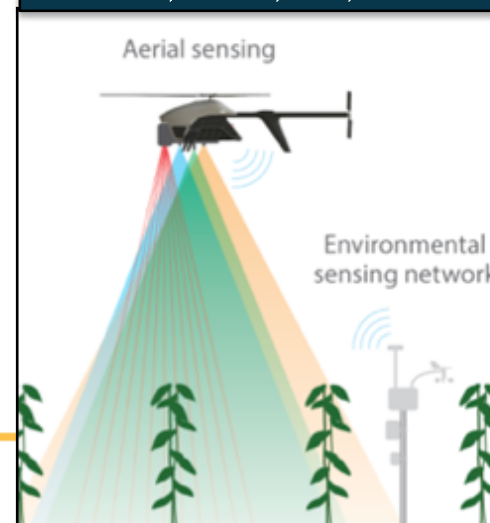
Deployable Gantry Plant Phenotyping Systems
National Robotics Engineering Center, TAMU



Ground Plant Phenotyping Systems
Carnegie Mellon, UIUC, Purdue



Aerial Plant Phenotyping Systems
Near Earth, Purdue, KSU, Blue River



Programs under development in 2016

Title	Summary	Program Director	FOA Date
Solid Ion Conductors for Electrochemical Energy Technologies	Technologies to transform the properties of solid ion conductors for devices using alkaline exchange membranes (e.g., fuel cells and electrolyzers), lithium metal batteries, flow batteries, and other electrochemical energy conversion technologies.	Albertus	Feb 26 CPs due Mar 28
Plant Root Phenotyping for Soil Carbon Sequestration	Technologies that measure structural and functional properties of plant roots and soils that lead to the development of improved root traits. Specifically, traits that reduce atmospheric greenhouse gas concentrations and energy used for crop production by increasing soil carbon storage and improving fertilizer efficiency (N2O emission reduction).	Cornelius	March 2016
Renewable Electricity to Zero-Carbon Liquid Fuels for Transportation and Stationary Energy	New cost- effective and energy-efficient technologies for generation of energy dense liquid fuels from renewable energy, water, air, and biomass, and their conversion to electricity or hydrogen for energy storage or hydrogen FCEVs.	Soloveichik	March 2016
Energy Efficiency Optimization for Connected and Automated Vehicles	Potential improvement in the energy efficiency of each individual vehicle in the automotive fleet, through the improvement of powertrain control and vehicle dynamic control, by utilizing emerging technologies and strategies in sensing, communications, information, control and automation.	Atkinson	March 2016
Energy-efficient Light-wave integrated Technology Enabling Networks that Enhance Datacenters	To overcome the limitations of conventional metal interconnects used for DC server and switch chip input/output (I/O) functions. To achieve this, the high integration density and low energy-per-bit achievable with integrated photonic interconnect and switching technologies will be exploited.	Haney	April 2016

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Top 5 Tips for Writing a Competitive ARPA-E Proposal

1. Read the Funding Opportunity Announcement (FOA) very carefully and several times!
2. Demonstrate the impact potential – if it works, how will it matter?
3. Describe the technology clearly and without excessive jargon
4. Compare to state of art – how will you exceed it?
5. Identify technical challenges and their solutions – we embrace high risk, but you need to tell us what your mitigation strategy is!

Program Directors

ARPA-E is continually recruiting new Program Directors, who serve 3-year terms

ROLES & RESPONSIBILITIES

Program development

- Perform technical deep dive soliciting input from multiple stakeholders in the R&D community
- Present & defend program concept in climate of constructive criticism

Active project management

- Actively manage portfolio projects from merit reviews through project completion
- Extensive "hands-on" work with awardees

Thought leadership

- Represent ARPA-E as a thought leader in the program area

ATTRIBUTES

- R&D experience; intellectual integrity, flexibility, and courage; technical breadth; commitment to energy; communication skills; leadership; and team management
- ***A passion to change our energy future***

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If you are interested please contact me or any ARPA-E program director

Fellows

The ARPA-E Fellowship program is a unique, technical opportunity with a two-year term

ROLES & RESPONSIBILITIES

Identification of high-impact energy technologies

- Perform technical and economic analyses to identify high-impact energy technologies.
- Publish original research papers and reviews.

Program director support

- Help develop future programs through technical analysis, discussions, and workshops.
- Assist with management of current projects, including site visits.

Organizational support

- Review proposals for funding opportunities.
- Contribute to the strategic direction and vision of the agency.

ATTRIBUTES

- Ph.D. in science or engineering; strong analytical and communication skills; ability to work independently and across disciplines; leadership.
- ***A passion to change our energy future***

Spring 2016 Fellowship application open until April 15

Sign up for our newsletter at
www.arpa-e.energy.gov