ADVANCED RESEARCH PROJECTS AGENCY (ARPA-E)

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NIChE Workshop on Large Scale Energy Storage
NIST – Gaithersburg, MD
September 16, 2010

www.arpa-e.energy.gov

Overview of ARPA-E as an Agency

Overview of (GRIDS) as a Program

Technology Readiness as Benchmark

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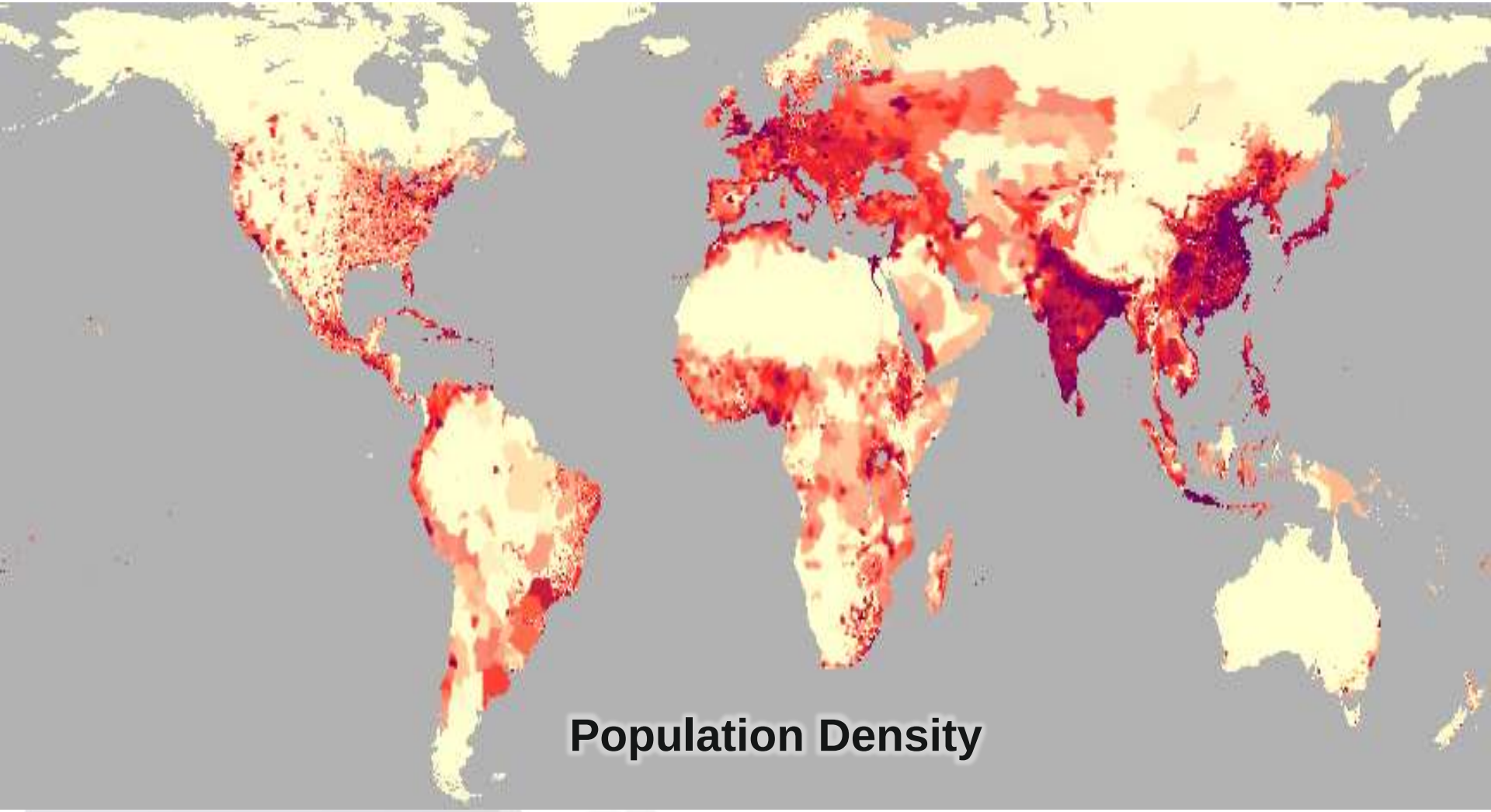

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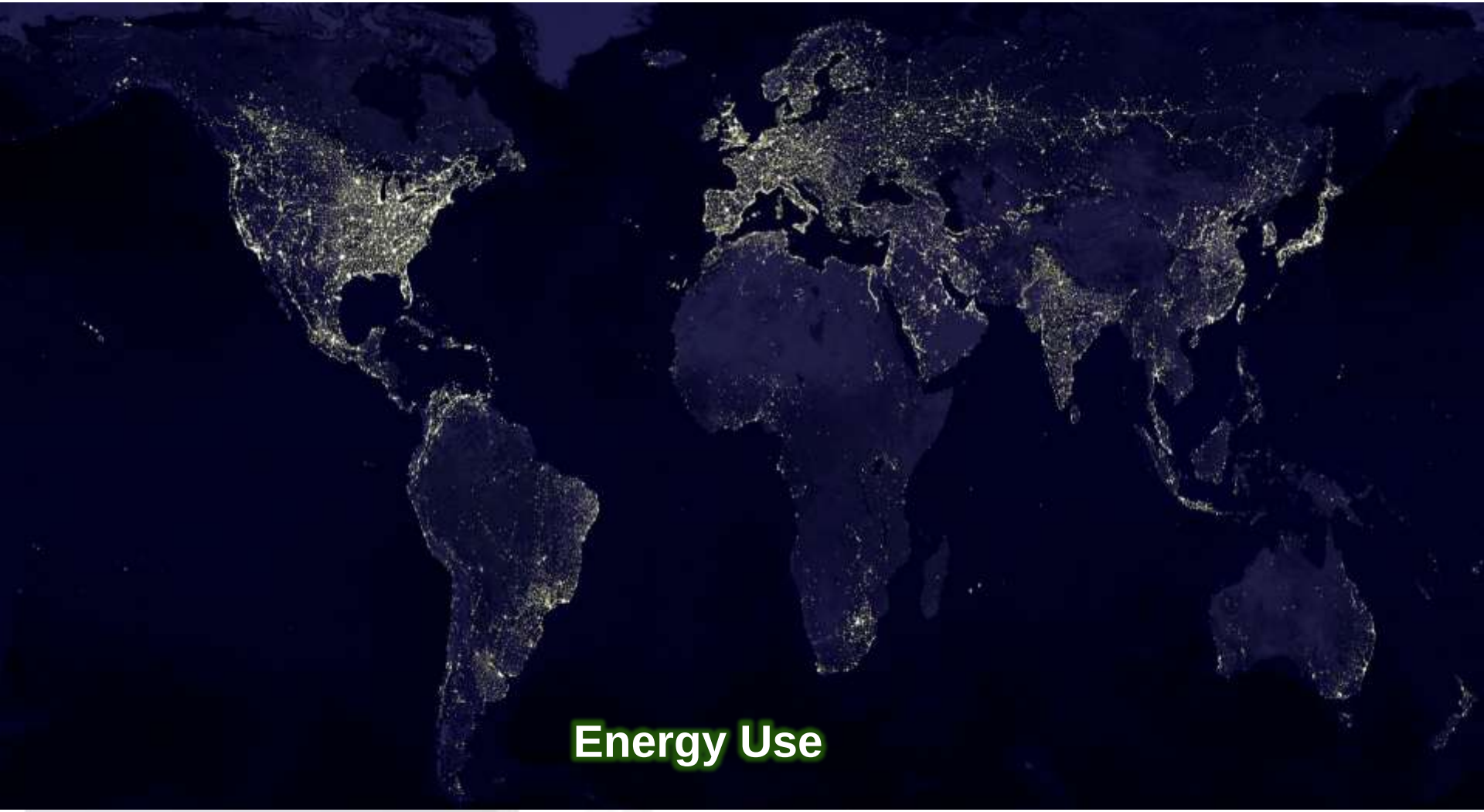

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Population and consumption don’t always correlate

Innovation Pace And Scale Needed In Energy Technologies…

20th Century Game-Changers

100 years

- Artificial Fertilizers
- Green Revolution
- Transistor
- Airplanes
- Electrification
- Polio Vaccination
- Antibiotics
- Nuclear Energy
- Integrated Circuits
- Fiber Optic Communication
- Wireless Communication
- Internet

20 years

Imagine all of this happening in the next 20 years…

Identify and support today's Haber, Bosch, Borlaug, Bardeen, Shockley, Brattain, Salk, Wright brothers, Kilby, Noyce, Gates, Jobs, Page, Brin of the energy field

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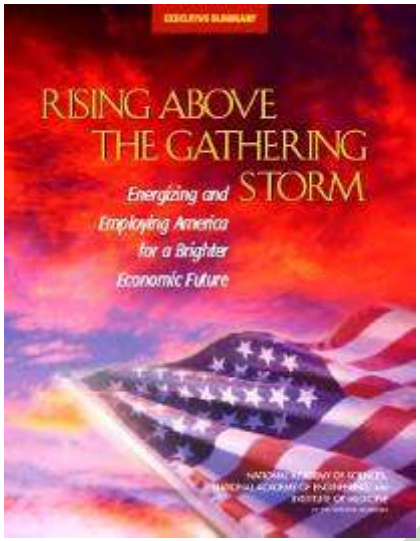
ARPA-E: Applying The ARPA Model To Energy



2006
Rising Above the Gathering Storm
(National Academies)

2007
America COMPETES Act

American Recovery and Reinvestment Act of 2009 (Recovery Act)

$400M appropriated for ARPA-E
President Obama launches ARPA-E in a speech at NAS on April 27, 2009

ARPA-E's Distinct Culture

- Excellence
- Openness
- Integrity
- Speed
- Metrics Driven
- Flat and Nimble

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Fulfilling ARPA-E's Mission

- **Find and fund high-risk, high-impact projects**
- **Identify and promote revolutionary advances in fundamental sciences**
- **Accelerate transformational technologies or create new technologies where none currently exist**
- **Translate scientific discoveries and cutting-edge inventions into technological innovations**
- **Bridge gaps in the energy innovation pipeline**

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The ARPA Model: Different By Design

- ARPA-E is modeled after the first Advanced Research Projects Agency (ARPA), now known as DARPA, at the Department of Defense

- DARPA was explicitly chartered to be different, so it could do fundamentally different things than had been done by other military service research and development organizations
  - Did not have labs
  - Did not focus on existing military requirements
  - Separate from any other operational or organizational elements

- Using this model, DARPA has enjoyed 50 years of success

Revolutionary Ideas Developed By DARPA

The Internet

GPS

Stealth Technology

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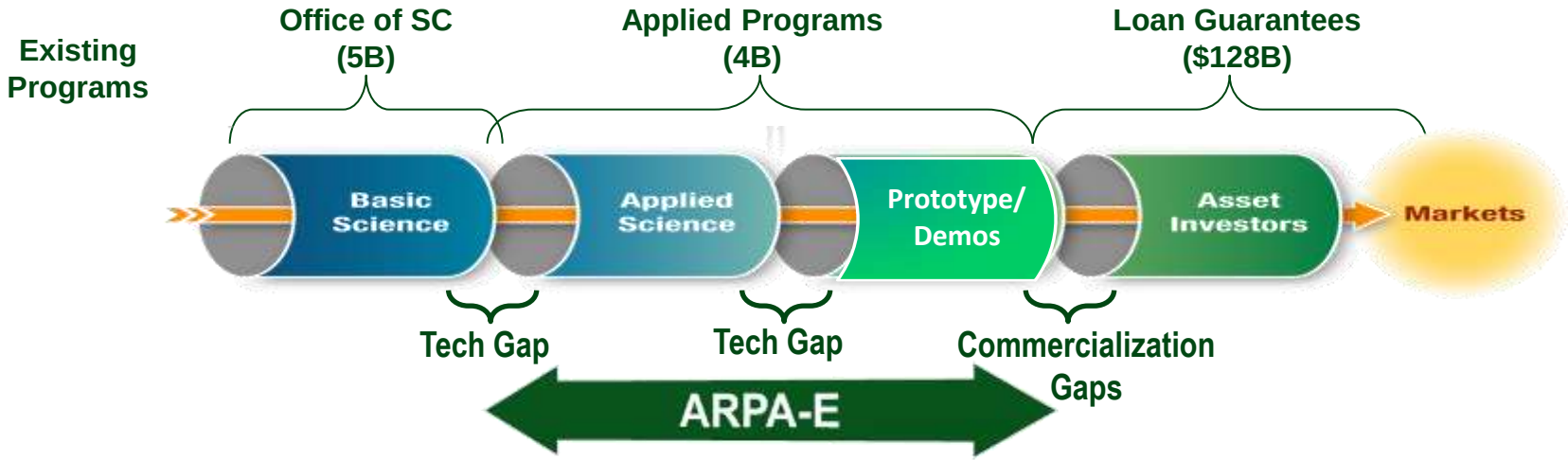
ARPA-E was created with a vision to bridge gaps in the energy innovation pipeline



what ARPA-E will do

- Seek high impact science and engineering projects
- Invest in the best ideas and teams
- Will tolerate and manage high technical risk
- Accelerate translation from science to markets
- Proof of concept and prototyping

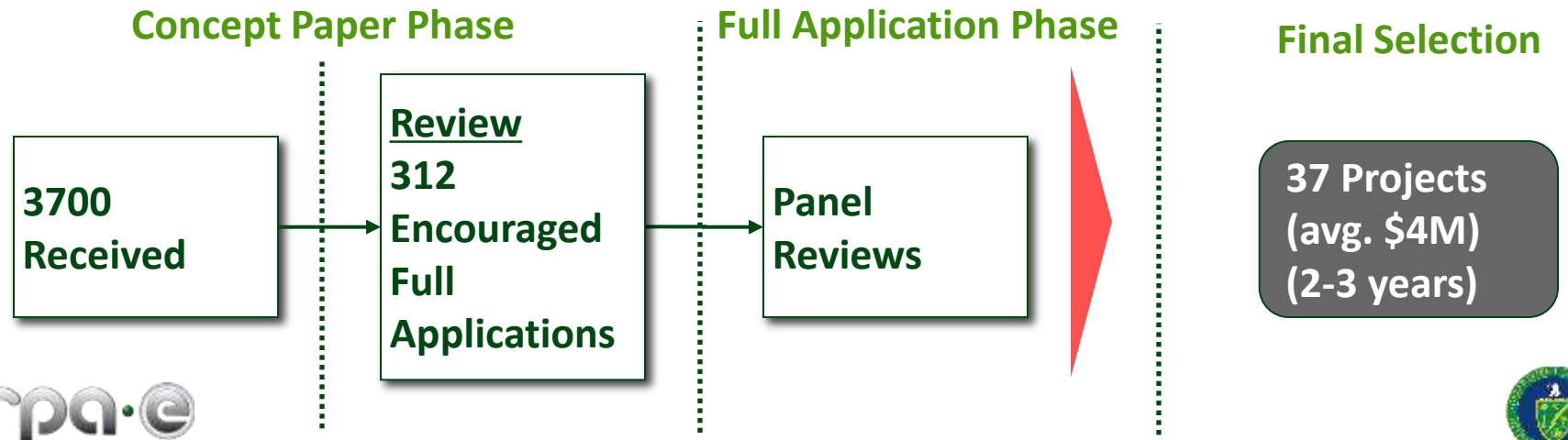
what ARPA-E *NOT* will do

- Incremental improvements
- Basic research
- Long term projects or block grants
- Large-scale demonstration projects

FOA Round 1

- ARPA-E's First Funding Opportunity
  - Announced April 2009, Selections Oct 2009
  - 3,700 proposals to 37 project selections ($151M)

- As ARPA-E's inaugural program, this funding opportunity was open to all energy ideas and technologies, but focused on applicants who already had well-formed research and development plans for potentially high-impact concepts or new technologies



FOA-1 Projects Span 10 Areas

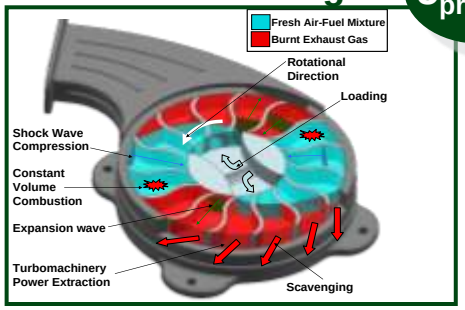
Energy Storage
6 projects

Biomass Energy
5 projects

Carbon Capture
5 projects

Solar Fuels
5 projects

Vehicle Technologies
5 projects



Renewable Power
4 projects

Building Efficiency
3 projects

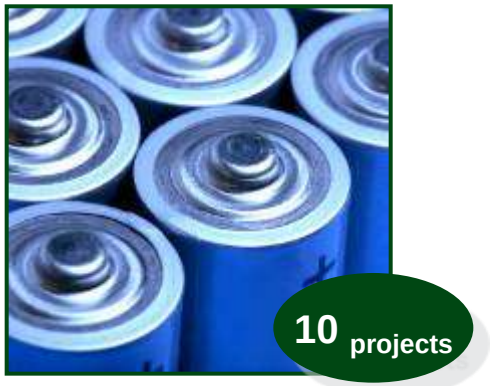
Waste Heat Capture
2 projects

Conventional Energy
1 project

Water
1 project

FOA-2: Funding for 3 Program Areas

Batteries for Electrical Energy Storage in Transportation (BEEST)



Developing a new generation of energy-dense, low-cost battery technologies for plug-in and hybrid electric vehicles

Could give electric vehicles the range, performance, lifetime, and cost required to shift transportation energy from oil to the U.S. electric grid

Electrofuels

Exploring using microorganisms to harness energy and convert carbon dioxide into liquid fuels

Theoretically, this could be10 times more efficient than current approaches

Innovative Materials & Processes for Advanced Carbon Capture Technologies (IMPAACT)

Revolutionizing technologies that prevent carbon dioxide produced by coal-fired power plants from entering the atmosphere

Could dramatically reduce the amount of carbon dioxide emissions that contribute to global warming

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FOA-3: Funding for 3 Program Areas

Agile Delivery of Electrical Power Technology (ADEPT)

Exploring materials that will increase performance and lower costs of computers and other electronics

Could reduce energy consumption by up to 30 percent – or 12 percent of total U.S. energy consumption

Building Energy Efficiency Through Innovative Thermodevices (BEETIT)

Developing efficient air conditioners and building-cooling technologies that use less energy and release less greenhouse gases

Could reduce emissions and significantly increase the U.S. technological lead in rapidly emerging clean energy industries

Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS)

Developing affordable, large-scale energy storage that enables the widespread use of two key renewable energy sources: wind and solar power

These technologies will position the U.S. to lead the technology and manufacturing of stationary electricity storage infrastructure in the emerging global market

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Attributes Of ARPA-E Projects

High Impact on ARPA-E Mission Areas –

- Reduction in energy imports
- Improvement in energy efficiency
- Reduction in energy-related emissions, including greenhouse gases
- To “ensure” U.S. “technological lead in developing and deploying advanced energy technologies

Disruptive, Innovative Technical Approach –

- ARPA-E is focused on high risk/high reward R&D
- Interested in –
  - New technical approaches that move to entirely new learning curves
  - Fundamentally new areas of research with uncharted white space

Best-in-class People & Teams

- Complementary, cross-discipline skill sets
- Strong interest to bring in new, talented scientists and engineers to energy technology research
- Break down barriers between science and engineering

Strong Impact of ARPA-E Funding Relative to Private Sector –

- Invest in areas too risky for the private sector
- ARPA-E investments de-risk technologies and catalyze follow- on private sector investments

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ARPA-E Metrics Of Success

NOW **3 - 5 YRS** **10+ YRS**

- Follow on investment post ARPA-E award ($)
- Increase in enterprise value of company ($)
- Companies created (#)
- Initiating new technology-business ecosystems
- Accelerated market entry - Products to market (#) / Product sales ($)
- Patents filed and licensed (#)
- Papers published in top journals (#)
- World record-setting "best-in-class" performance (#)
- Help identify mechanisms for scaling innovations

Home Runs

- Domestic and global sales, US market share ($)
- Avoided greenhouse gas emissions (tCO_2 equivalent)
- Reduced oil imports (barrels of oil equiv.)
- Creation of new technology/business or new industry ecosystem (#)
- Jobs created (#)
- Beating current projections and trajectories (Moving McKinsey GHG abatement cost curves, EIA & IPCC projections, etc.)

It is not expected that all selected projects will be successful, but it is expected that at least a few of them will be game-changing

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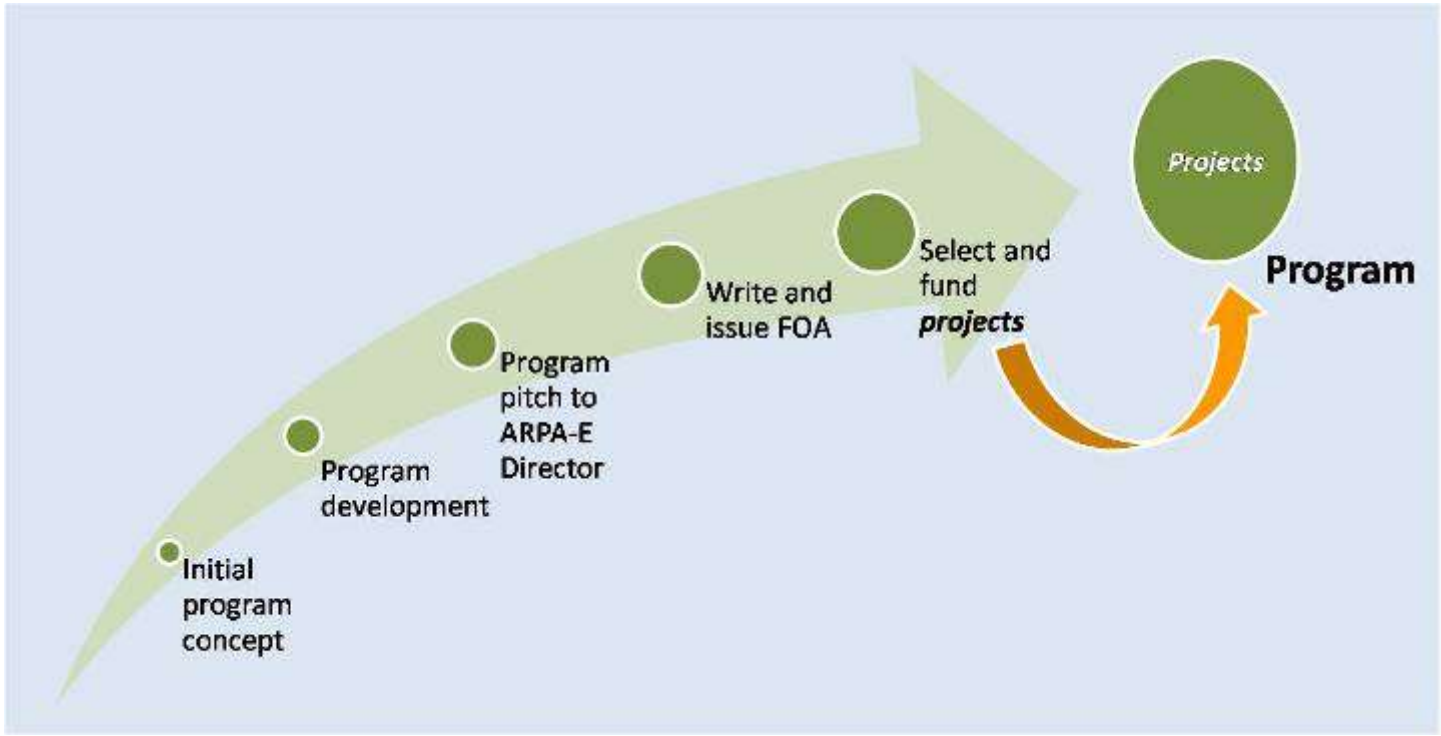
Program And Project Selection

- ARPA-E funds universities, startups, established firms, and others

- ARPA-E solicits projects to fund by issuing a competitive funding opportunity announcement (FOA) for each future program area



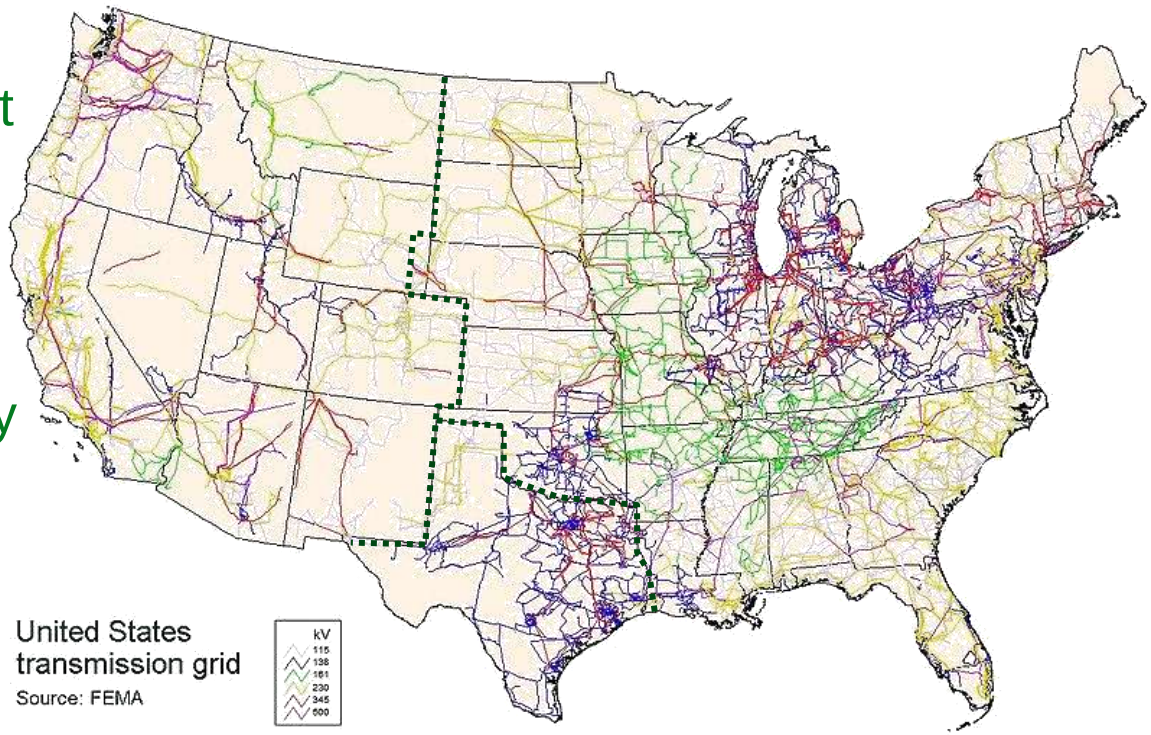
Overview of ARPA-E as an Agency

Overview of (GRIDS) as a Program

Technology Readiness as Benchmark

POWER GRID: LARGE SUPPLY CHAIN WITH NO WAREHOUSE

- Electrification: Premier Engineering Accomplishment of the 20th Century [NAE]
- Harnessing Power: #1 Challenge for 21st Century



ENERGY STORAGE CAN PROVIDE A VARIETY OF BENEFITS

Generation - Supply Side

- Renewables Integration
- Rate Optimization
- Price Arbitrage / Peak Shaving
- Capacity Value
- Cycling Cost Management
- Ancillary Services

Delivery – Transmission and Distribution

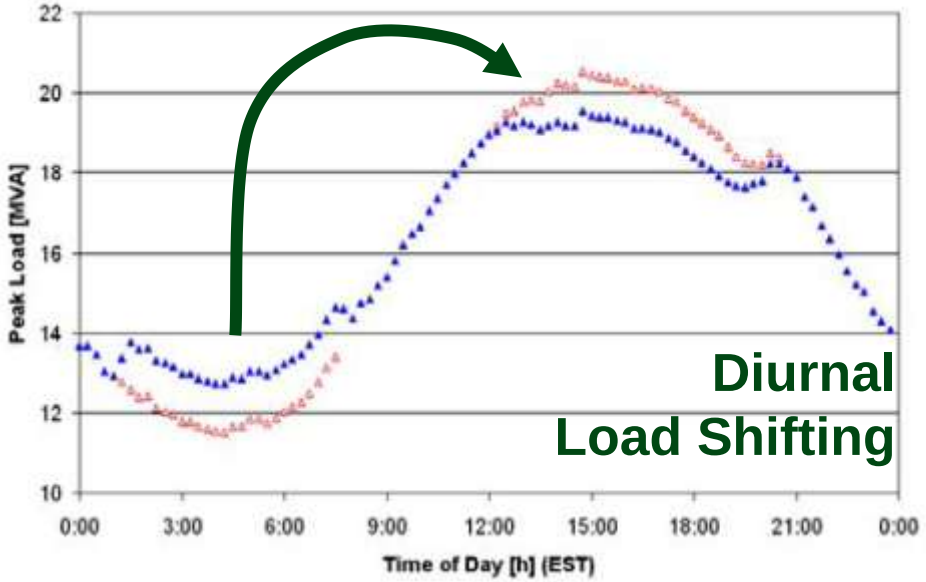
- T&D Network Investment Deferral
- T&D Component Life Extension
- Transmission Access / Congestion Charge Management
- T&D Asset Utilization
- Reliability
- Power Quality

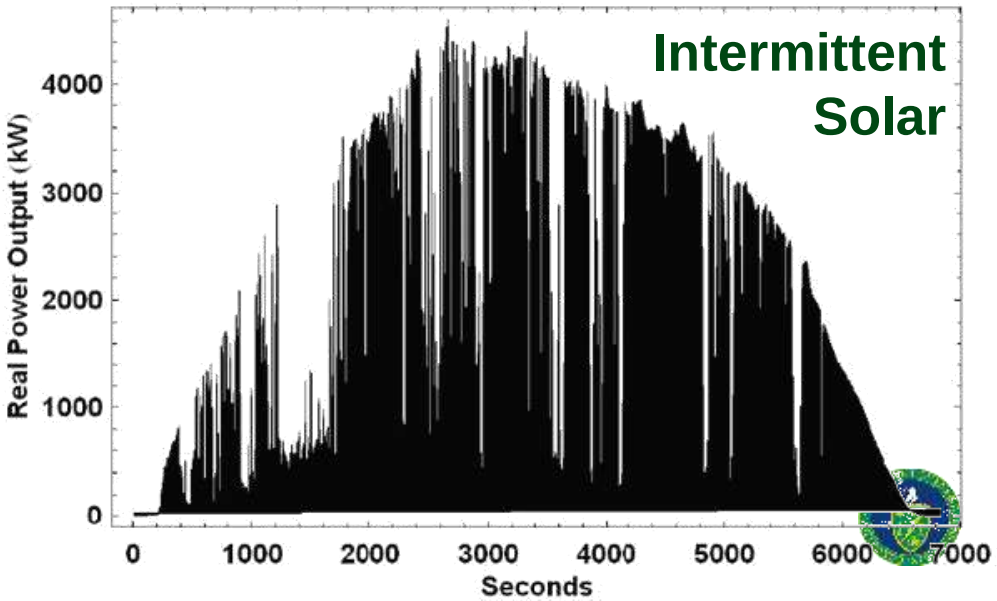
STORAGE AND RENEWABLES

Timing Matters

1 cycle to 1 minute:
frequency / voltage

1 minute to hours:
power / energy





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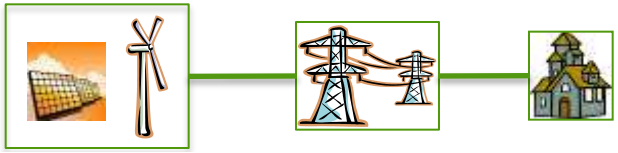
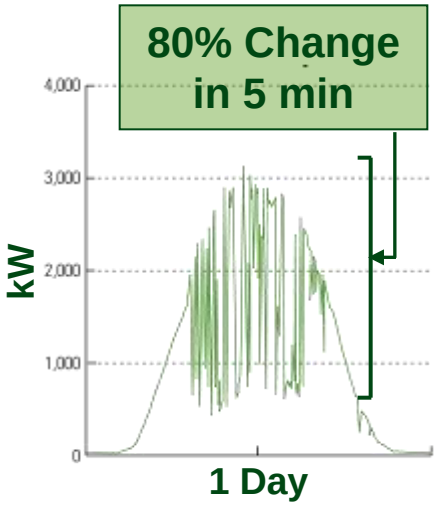
GRID-SCALE RAMPABLE INTERMITTENT DISPATCHABLE STORAGE (GRIDS)

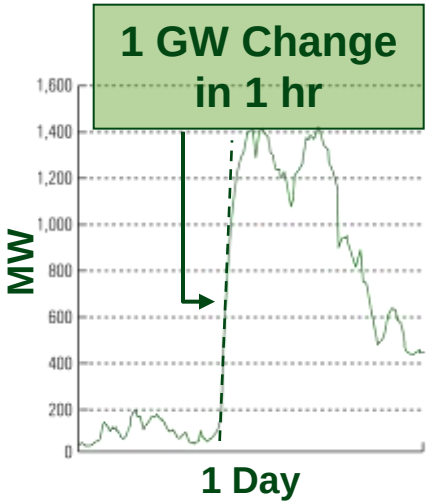
Renewables Today



Solar PV in AZ (TEP)



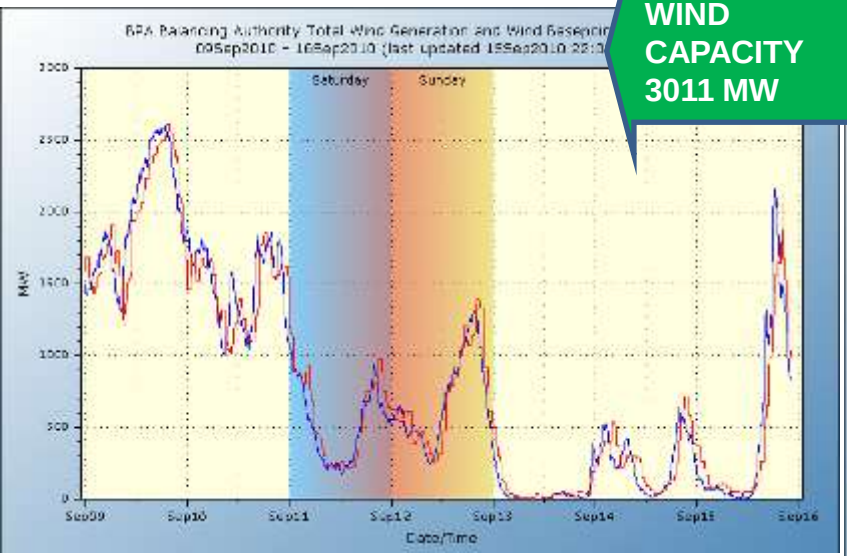
Wind in OR (BPA)



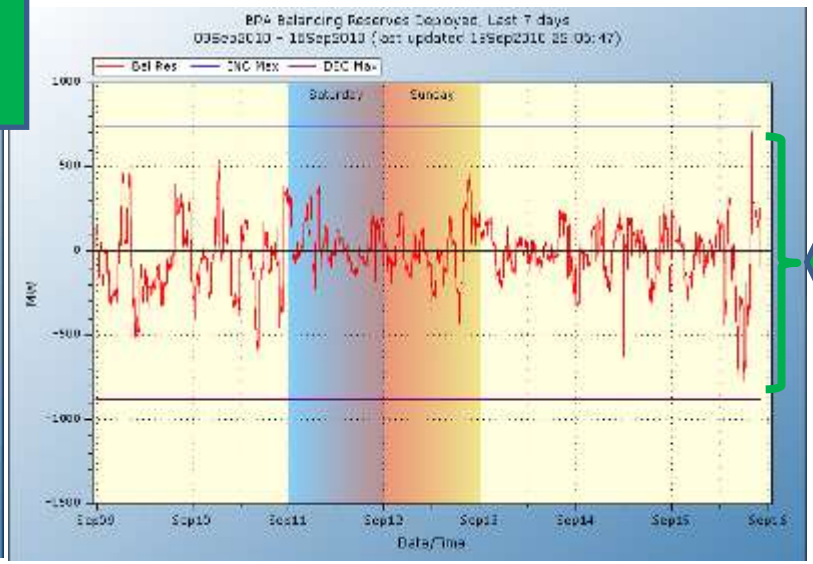
Problem:
Minutes-to-Hours Changes in Power

Goal: Grid storage that is dispatchable and rampable
ARPA-E Focus: Transformational approaches to energy storage to enable wide deployment of renewables

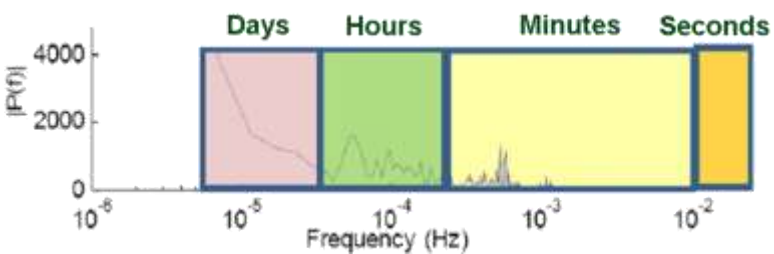
Generation and storage in high renewable penetration areas



WIND CAPACITY 3011 MW



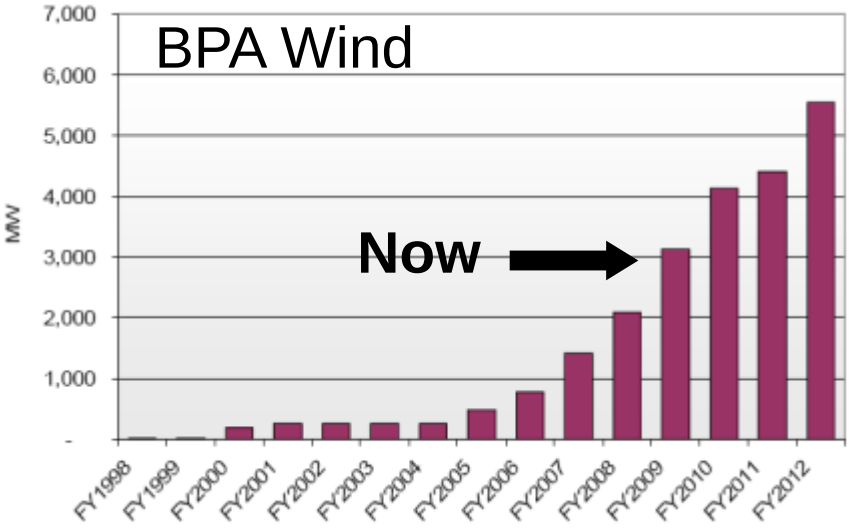
HYDROPOWER RANGE 1600-2000MW

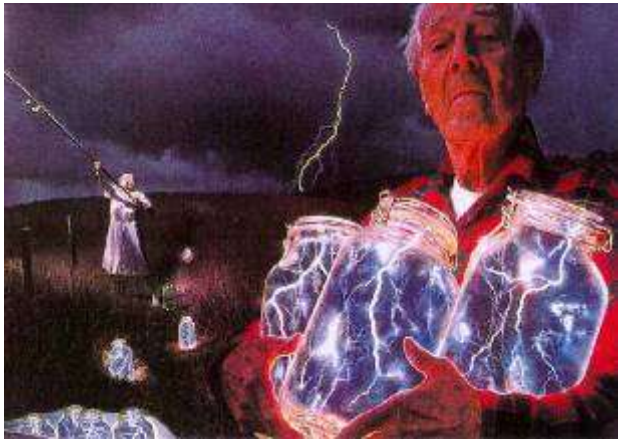


GRID IMBALANCE FREQUENCY SPECTRUM

Solving the Renewable Integration Challenge

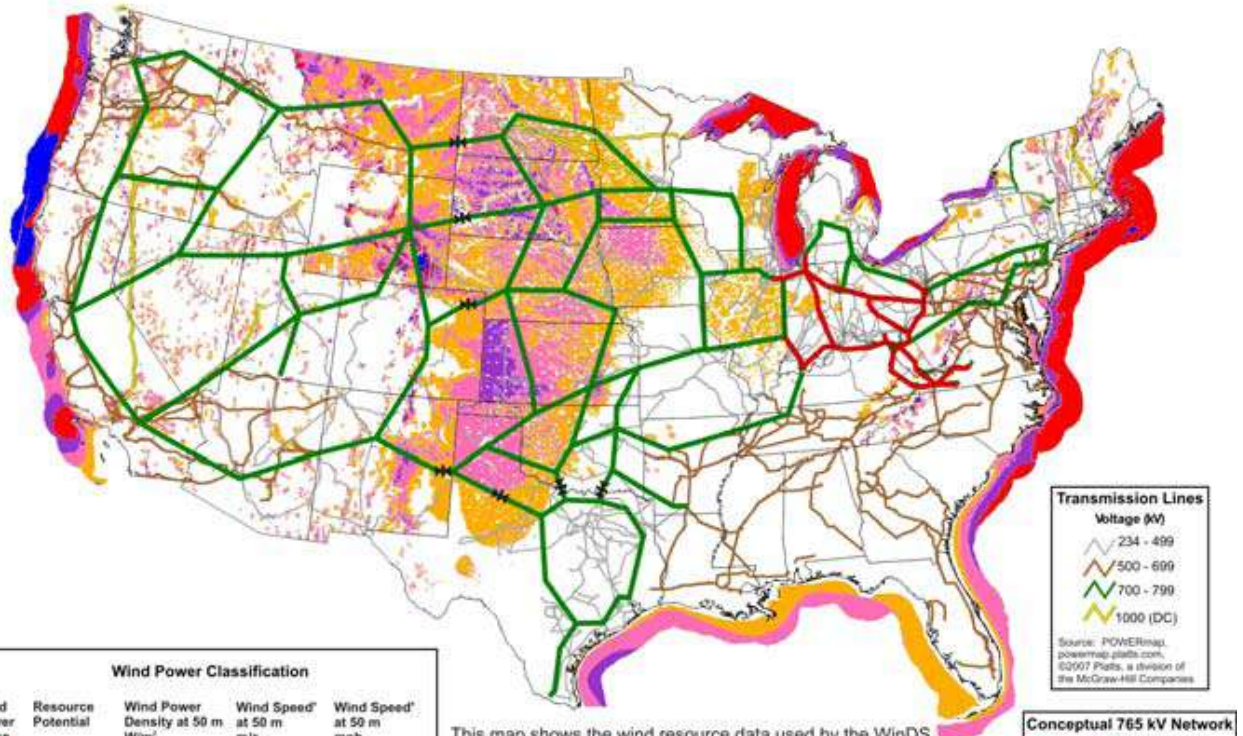
- Increase Balancing Authority Size
- Increase Transmission Capacity
- Improved Situational Awareness
  - Real Time Knowledge
  - Improved Weather Models
  - Generation Protocols
- New Storage Technologies





AWEA projects substantial traditional transmission construction is necessary to meet a 20% wind scenario, higher renewable penetration would require even more

Conceptual Transmission Expansion Plan to Accommodate 400 Gigawatts (GW) of Wind Power



Wind Power Classification

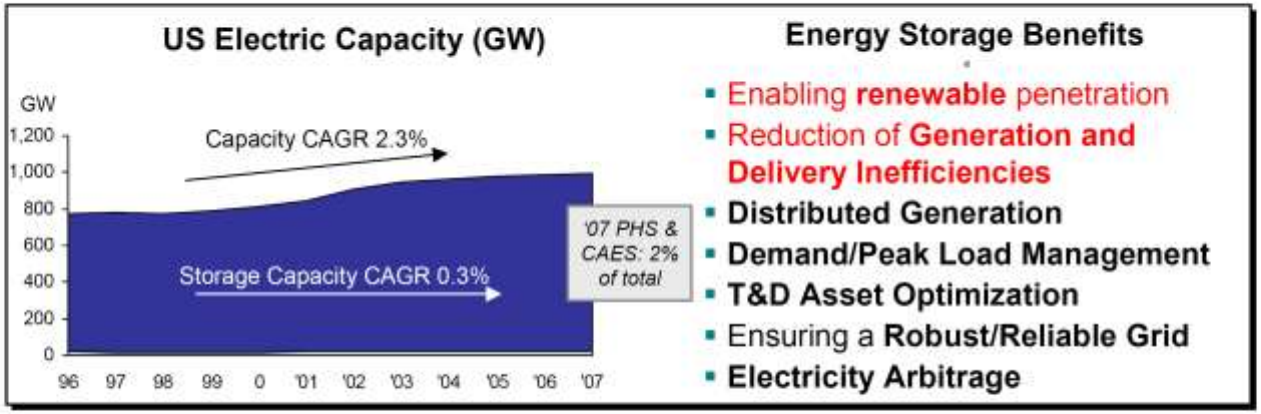
Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

* Wind speeds are based on a Weibull k value of 2.0

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

Source: AWEA, "Building a Green Power Superhighway"

TWO GRID-SCALE STORAGE BREAKOUT SESSIONS (OCT 2009): ENERGY (LONG) & POWER (SHORT)



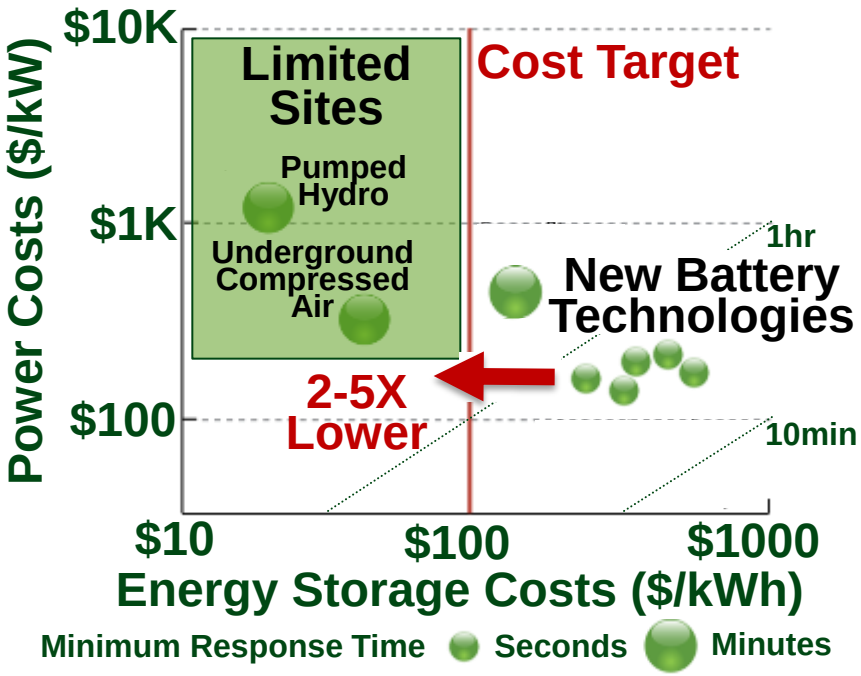
Storage Applications	Description	Performance Metrics	Technology Examples
Energy Management (*hours/ diurnal*)	The strategy of adjusting and optimizing energy generation including reducing the large fluctuations that occur in electricity demand by storing excess electricity during periods of low demand for use during periods of high demand	▪ Discharge Time ▪ System Power Rating ▪ Round Trip Efficiency ▪ Capital Cost ▪ Cycle and Calendar Life	▪ Pumped Hydro Storage ▪ CAES ▪ Bulk Electrochemical Storage ▪ Advanced Batteries ▪ Chemical Storage
Power Applications (*seconds/ minutes*)	Faults, dynamic operations, o often cause various types of p disturbances such as voltage sags, voltage swells, impulses, notches, flickers, harmonics, etc.	▪ Capital Cost ▪ Cycle and Calendar Life	torage ▪ Ultracapacitors ▪ SMES

Renewable Generation Integration is Middle-Space Requiring BOTH High Energy and Power Delivery

Where can ARPA-E make the greatest impact?

12 *Source: DOE Electric Power Annual 2007, Energy Storage Association, BAH Analysis*

Grid-scale Rampable Intermittent Dispatachable Storage (GRIDS)



Need: **Innovative Technologies for Cost-Effective Energy Storage**

Goal: Grid storage that is dispatchable and rampable
Focus: Transformational approaches to energy storage to enable wide deployment at very low cost

GRIDS: Gridscale Renewable Intermittent Dispatchable Storage

- Economics of Pumped Hydro, but Deployable Anywhere

- Technology Agnostic – Any Stationary Energy Storage Media

  Electrochemical: Battery, Flow Battery, Re-FC…
  Electromechanical: Flywheel, aboveground CAES…
  Electrical: SMES, Ultracap, etc.
  Systems: PCS and BoP

- Two Categories: Advanced Systems Prototypes (20kW)

  ~ TRL 3/4 to TRL 6

  Proof-of-Concept Component

  ~ TRL 2/3 to TRL 5

- Connect Across US Gov't and Private Industry for subsequent exit

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Metrics from FOA-00000290

Gridscale Rampable Intermittently Dispatchable Storage

PRIMARY TECHNICAL REQUIREMENTS:

Requirement ID Number	*Requirement Category*	*Value (Units)*
1.1	System Capital Cost per Unit of Rated Energy Capacity (for measured capacity at Rated Power)	<$100/kWh
1.2	Minimum Operating Time at Rated Power (time at Rated Power for charge and discharge)	60 minutes
1.3	Maximum Response Time (time for system to go from 0% to 100% of rated power in discharge and in charge mode)	10 minutes
1.4	Rated Power Capacity for Charge and Discharge in Advanced System Prototypes	≥20kW

SECONDARY TECHNICAL TARGETS:

Target ID Number	*Target Category*	*Description*
2.1	Cycle Life (cycled at rated power between charge & discharge)	5,000 cycle minimum, defined as number of cycles at which >20% reduction in total energy/power capability occurs relative to initial rated values
2.2	Round-Trip Efficiency	80% at rated power for of charge and discharge
2.3	Maximum Dwell Time	Maximum 10 minute response time for reversal between charge and discharge
2.4	Scalability of Storage Technology for Grid-scale Application	Potential for subsequent scaling for grid-scale deployment (1-10MW). Scalability will be assessed at the power/energy ratio of the advanced systems prototype proposed.
2.5	Internal Losses	Less than 5% loss of energy in 24 hours from fully charged state.
2.6	Safety	Consistent with transmission and distribution grid deployment at unattended locations
2.7	Calendar Life	10 years, minimum

Portfolio of Projects

PRIMUS POWER
Smart Grid Storage

New Flow
Battery Electrode

Beacon POWER.

Long Duration
Flywheel

United Technologies Research Center

Advanced
Flow Battery

Berkeley Lab

Advanced
Flow Battery

FLUIDIC ENERGY™

High Power
Metal-air Storage

GENERAL COMPRESSION

Fuel-Free Isothermal
Compression

ABB

2G-HTS
SMES

CUNY The City University of New York

Rechargable
Zn-MnO_2 Battery

Proton ENERGY SYSTEMS

Neutral Water
Fuel Cell

GENERAL ATOMICS AND AFFILIATED COMPANIES

Soluble Lead
Flow Battery

BOEING®

High-Energy
Flywheel

USC Viterbi School of Engineering

Rechargable
Fe-Air Battery

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Summary of New Scientific Opportunities in Related to Storage

Low-Cost Materials & Chemistry

Beyond Lithium
Rechargeable Air Systems
Surfaces and Reactions

Minimize Need for Storage

Better Modeling, Simulation and Control Algorithms

Test-bed Capabilities

From Lab-scale to Power Lines

System Level Integration

Across traditional boundaries,
ex. Vehicle to Grid

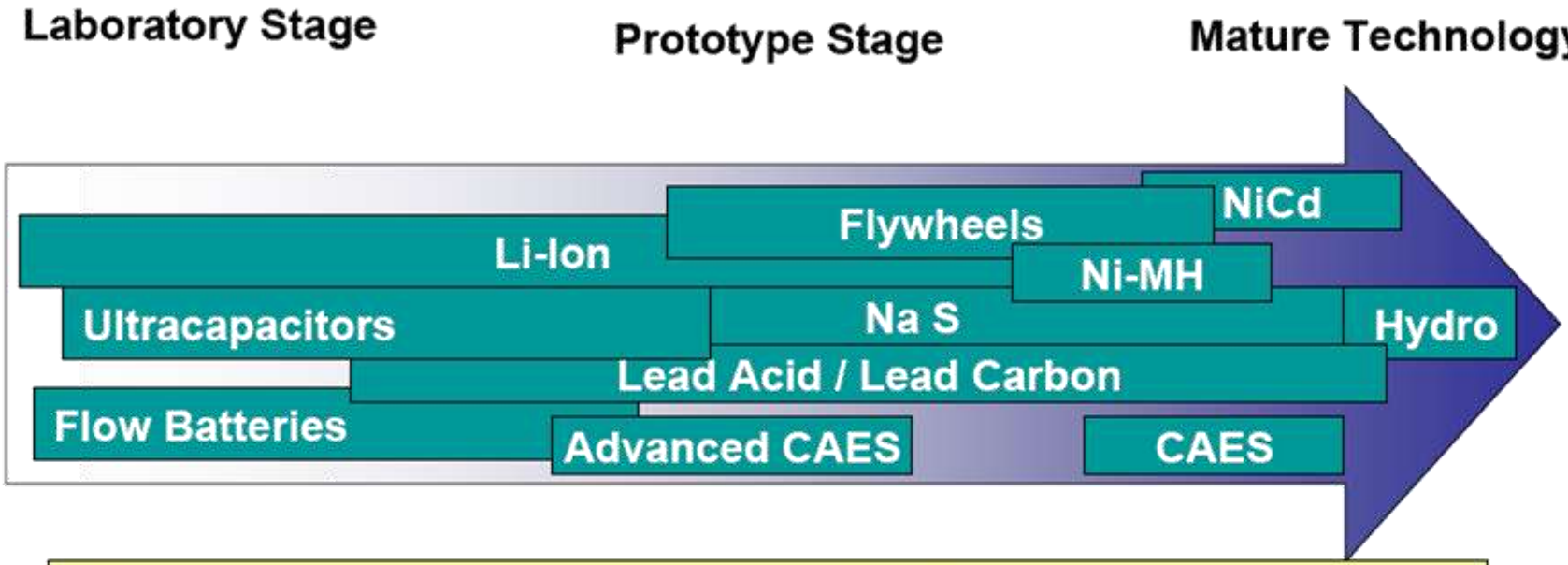
Overview of ARPA-E as an Agency

Overview of (GRIDS) as a Program

Technology Readiness as Benchmark

GRID-SCALE STORAGE – RANGE OF TECHNOLOGY READINESS LEVELS

Grid Storage Stages of Maturity by Technology



The participants would like to see ARPA-E catapult more of these technologies to maturity, in order to:

1) Increase functionality of renewables
2) Reduce the need for spinning reserves and thereby
3) Cut greenhouse gasses and
4) Reduce the use of fossil fuels

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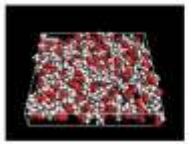
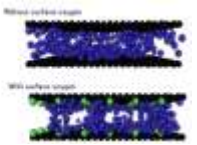
Technology Readiness Level Definitions Related to Energy Storage

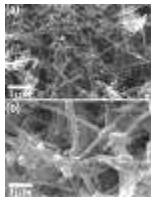
- **TRL-0: Scientific Capability for Research, Possibly Used for Energy Storage**
  - Example: New surface science instrument or supercomputer

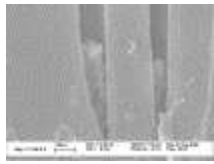
- **TRL-1: Basic Science Investigation**
  - Example: Validation of a new experimental method or insight or simulation of new chemistry or surface functionality



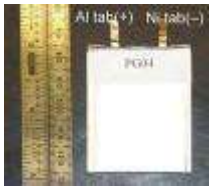


- **TRL-2: Platform Science Demonstrated or Formulated**
  - Example: Design, synthesis and characterization of nanostructures to study interfaces, or half-cell testing





- **TRL-3: Proof-of-Concept Device Fabrication and Test**
  - Example: Basic experimental testing of new battery for basic functionality

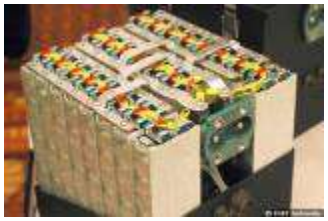


Technology Readiness Level Definitions Related to Energy Storage

- **TRL-4: Component Level Development on Lab Scale**
  - Example: Development and testing of functional storage as proof-of-concept device, for example in coin or 18650 cell size.

- **TRL-5: Component Development and Test at Prototype Scale**
  - Example: Development of functional prototype storage component at bench scale, for instance 1-25kW power rating, and tested for functionality as system relevant hardware.

- **TRL-6: System / Subsystem Prototype**
  - Example: Development of functional prototype storage system, including power conditioning and control interface, at bench scale. For instance, system of 1-25kW power rating tested in a controlled, use relevant, environment.



Technology Readiness Level Definitions Related to Energy Storage

- **TRL-7**: **System Prototype Validation Testing**
  - Example: Full-scale pilot-testing of a grid-scale storage system as hardware in the loop in a controlled test-bed, with capability for controlled environment testing.

- **TRL-8: Systems Qualification Testing**
  - Example: Full-scale pilot-testing of a grid-scale storage system as hardware on the grid in monitored test-bed under four-season environment conditions

- **TRL-9: Mission Deployment Assessment**
  - Example: Failure analysis or field reliability testir
  - of grid-deployed storage systems.

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Pilot Manufacturing,Testing, and Adoption

Follow-up?

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