GRID-SCALE ENERGY STORAGE

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March 1, 2010
ARPA-E Pre-Summit Workshop

www.arpa-e.energy.gov

Overview of Electric Storage Problems

Technology Landscape

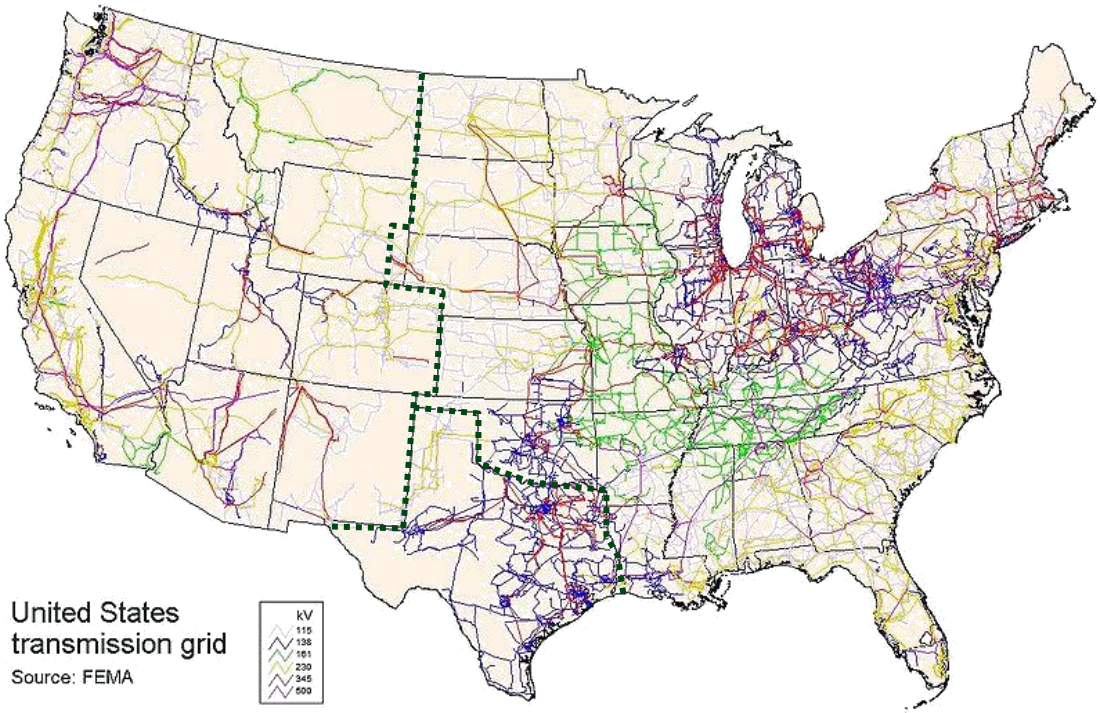
ARPA-E Workshop – Storage Media

Added Concepts on Storage

Summary Thoughts on Grid Scale Storage

POWER GRID: LARGE SUPPLY CHAIN WITH NO WAREHOUSE

- U.S. Generating Capacity:
  1,088 GW
- U.S. Storage Capacity:
  22 GW
  (Primarily Pumped Hydro)
- Electrification: Premier Engineering Accomplishment of the 20th Century [NAE]
- Harnessing Power:
  #1 Challenge for 21st Century



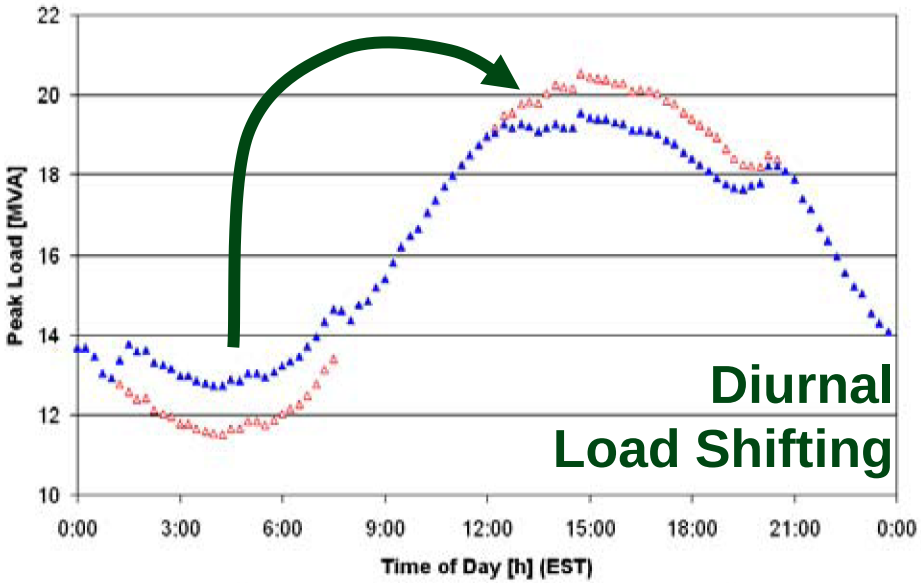
WHY STORAGE

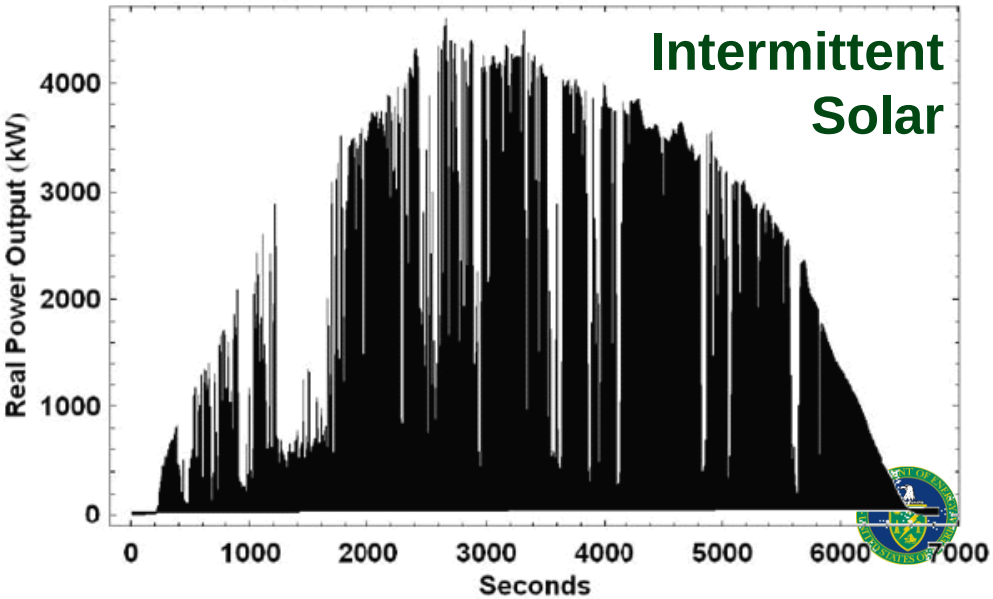
- Today's Grid connects electricity
  WHERE it is needed,

  Storage adds electricity
  WHEN it is needed

- New Needs
  - Renewable Generation and Electric Vehicle Integration
  - Peak Demand Shaping
  - Power Quality and Grid / Load Management

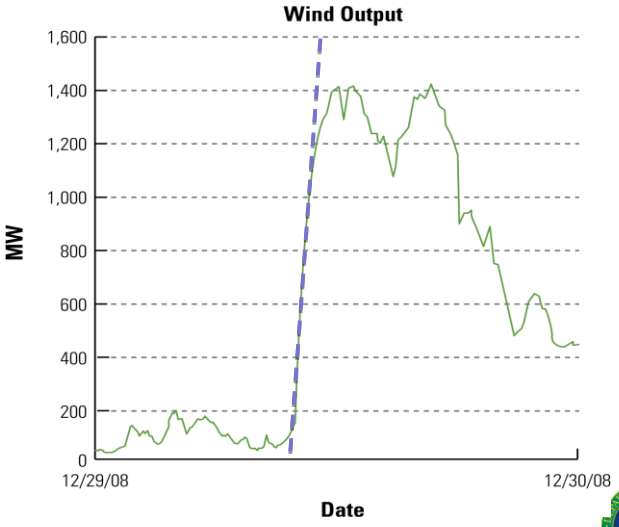
- Timing Matters
  1 cycle to 1 second: frequency
  1 second to 1 minute: voltage
  1 minute to 10 minutes: power
  10 minutes to hours: energy





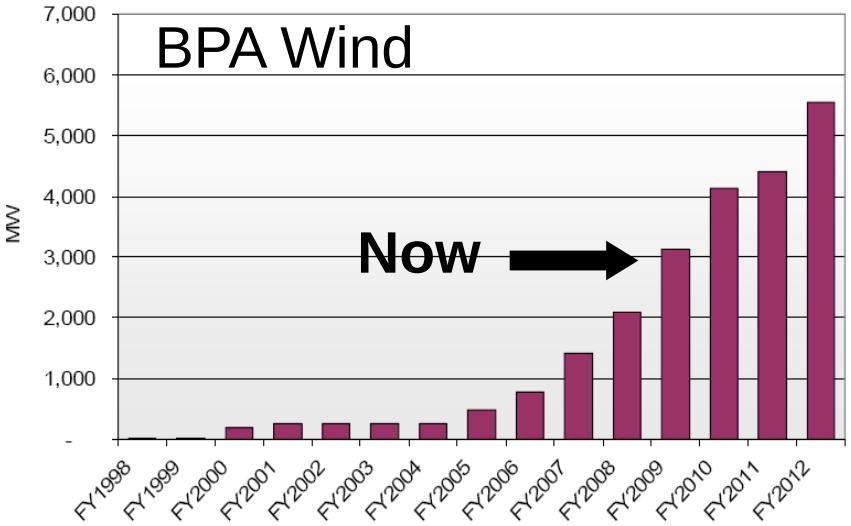
LINK BETWEEN RENEWABLE GENERATION AND STORAGE

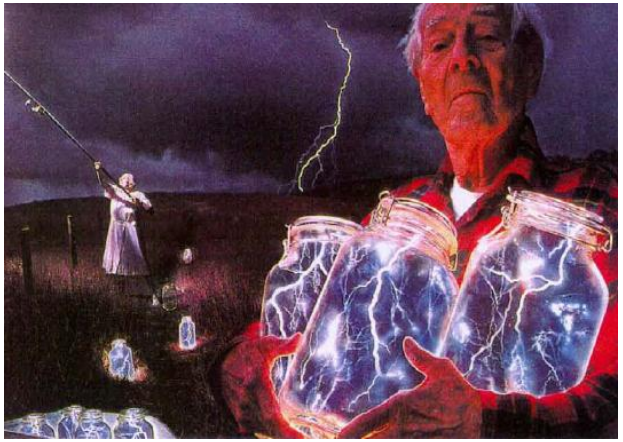
- "More than Hydro Alone Can Handle"
  -- BPA Transmission Executive
- 20% Renewable Integration Needs New Transmission Assets
- Financial Cost Point (% of Load) is well before System Collapse Point (% of Load)



Solving the Renewable Integration Challenge

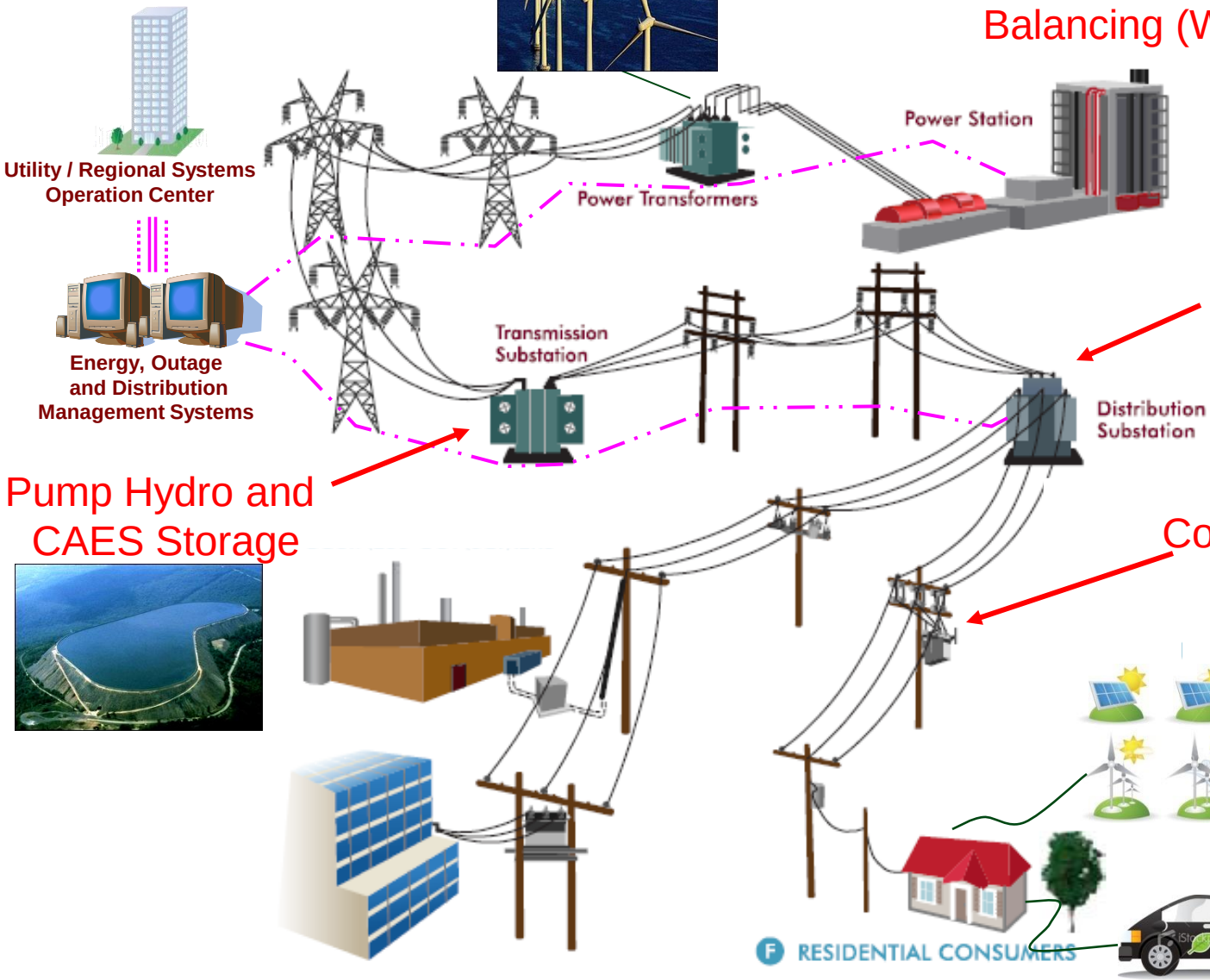
- Increase Balancing Authority Size
- Increase Transmission Capacity
- Improved Situational Awareness
  - Real Time Knowledge
  - Improved Weather Models
  - Generation Protocols
- New Storage Technologies





POTENTIAL STORAGE LOCATIONS

Large Scale Renewable Resource Balancing (Wind, Solar, etc)



Sub-Station Ride-through, Control and Balance

Pump Hydro and CAES Storage

Community Storage

Distributed Renewable Resources

V2G Storage

POWER U.S. WITH BATTERIES?

- Batteries (Nickel Cadmium) as an Existing Technology for Power Intermittency

- How much energy are we talking about for grid-scale storage?

For One 'Average' Hour of Electricity in the US:

~475 GWh per hour

or 525 million typical 12V / 75Ah 'car' batteries

Need Better Technologies

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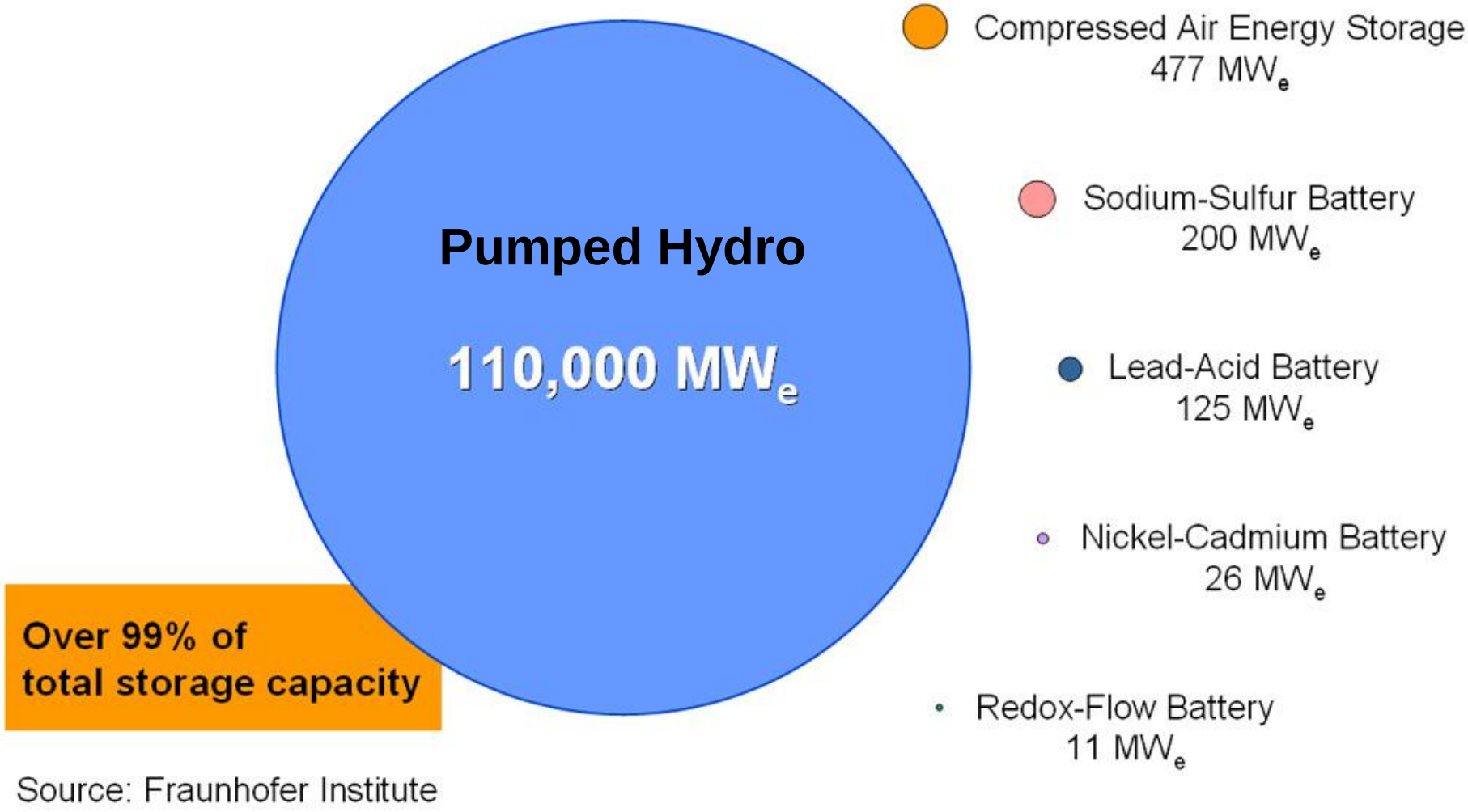
ARPA-E Workshop – Storage Media

Added Inputs on Grid-Scale Storage

Summary Thoughts on Grid Scale Storage

WORLDWIDE CAPACITY FOR ELECTRIC ENERGY STORAGE



courtesy: Imre Gyuk (OE)

ENERGY STORAGE TECHNOLOGIES

Energy

Power

- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Batteries
  - NaS
  - Flow Batteries
  - Lead Acid, Lead Carbon
  - Lithium Ion
  - NiMH
  - NiCad
- Flywheels
- Electrochemical Capacitors

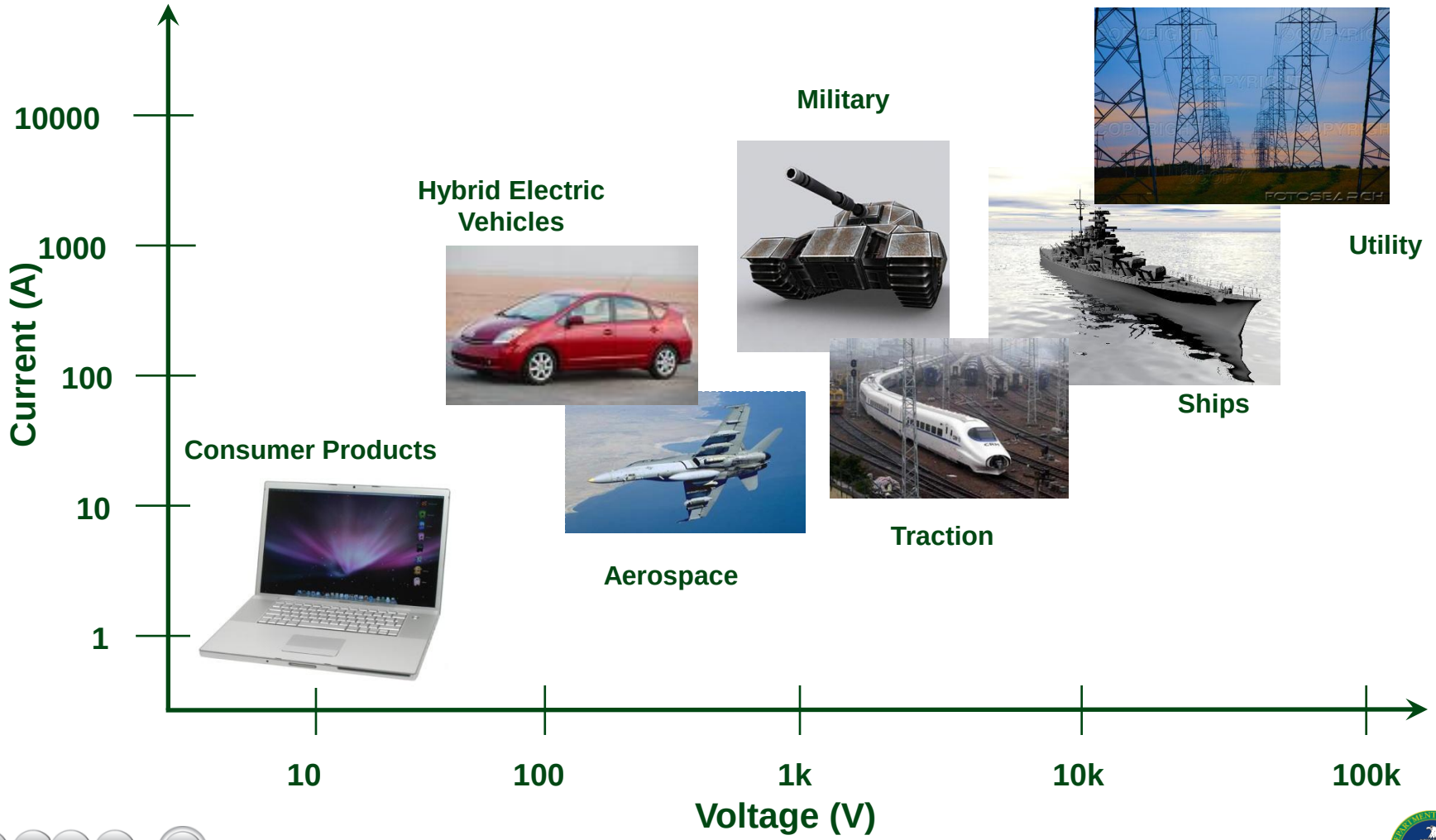
Taum Sauk
400 MW

NaS
2 MW

Flywheels
1 – 20 MW

courtesy: Imre Gyuk (OE)

SCALES OF POWER

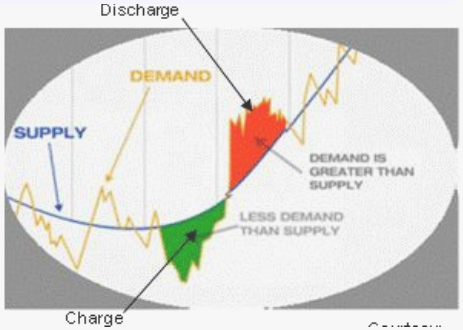


courtesy: Imre Gyuk (OE)

ENERGY STORAGE APPLICATION TIME REGIMES

Seconds to Minutes

Voltage & Frequency Regulation

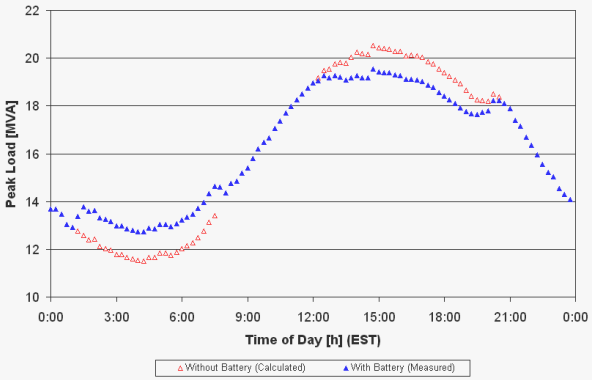


Minutes - One Hour

Power Ramping

Several Hours - One Day

Energy Peak Shaving and Load Leveling



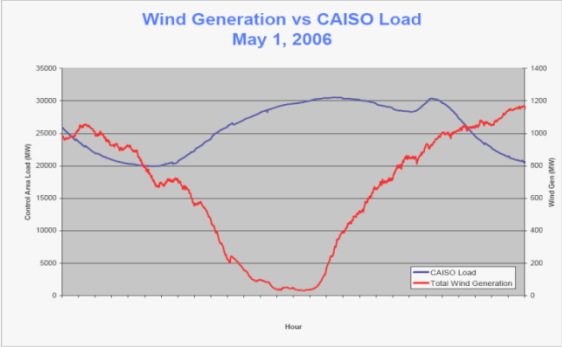
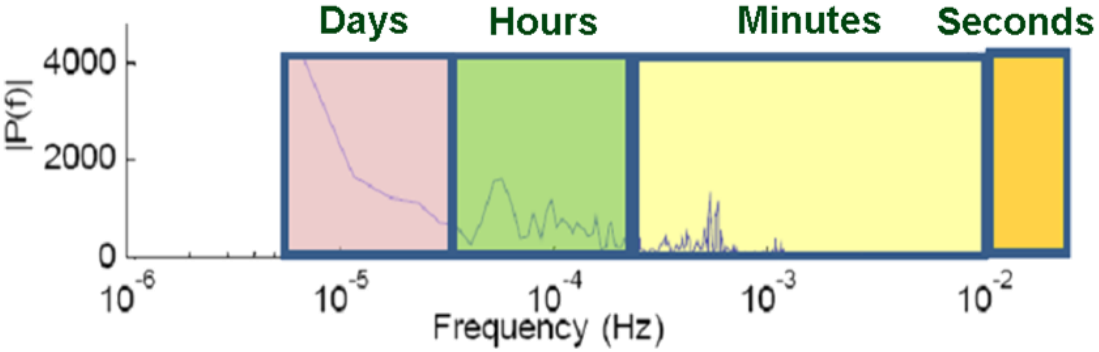


Figure 11: Total Wind vs. CAISO Load



courtesy: Imre Gyuk (OE) and PNNL

ENERGY STORAGE CHALLENGES AND NEEDS

Challenges

- Cost of energy storage systems
- Reliability of energy storage systems
- Cost/Benefit ratio
- Regulatory treatment of energy storage

Needs

- Improved materials and system integration
- New over-the-horizon proof-of-concept technology demonstration
- Utility scale field tests to demonstrate reliability
- Identification of benefits accruing from storage

courtesy: Imre Gyuk (OE)

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Workshop: Gridscale Energy Storage
October 4, 2009
Seattle Renaissance Hotel
Seattle, Washington

At Electric Energy Storage and Applications Technology Conference (2009)

Defining the need for storage

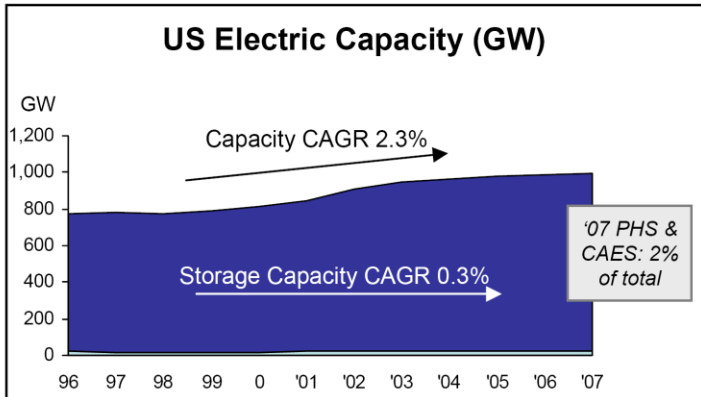
Possible storage solutions

Energy Storage Technologies

Key Findings Summary

www.arpa-e.energy.gov

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



Energy Storage Benefits

- Enabling **renewable** penetration
- Reduction of **Generation and Delivery Inefficiencies**
- **Distributed Generation**
- **Demand/Peak Load Management**
- **T&D Asset Optimization**
- Ensuring a **Robust/Reliable Grid**
- **Electricity Arbitrage**

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, or nonlinear often cause various types of power quali 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

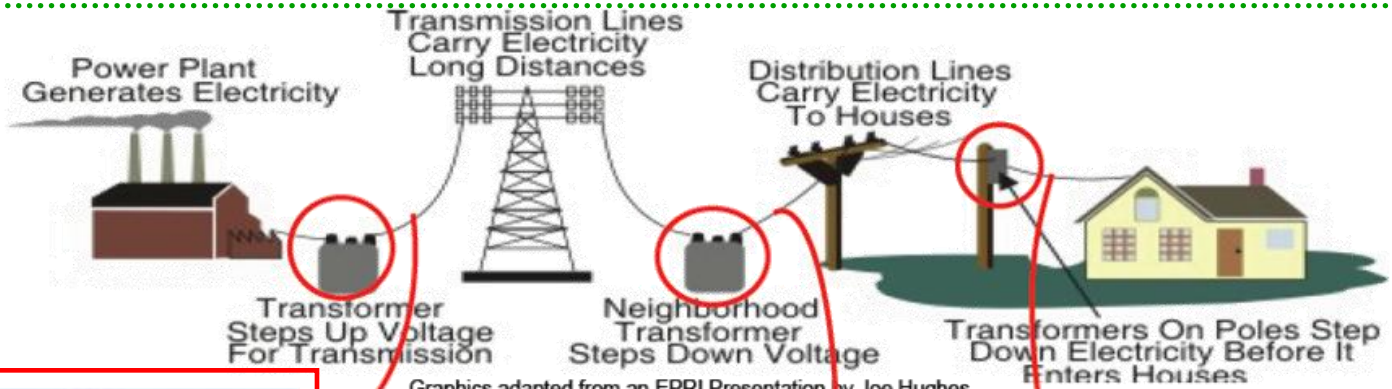
Where can ARPA-E make the greatest impact?

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

ENERGY STORAGE CAN PROVIDE A VARIETY OF BENEFITS

Generation - Supply Side	Delivery – Transmission and Distribution
Renewables Integration	T&D Network Investment Deferral
Rate Optimization	T&D Component Life Extension
Price Arbitrage / Peak Shaving	Transmission Access / Congestion Charge Management
Capacity Value	T&D Asset Utilization
Cycling Cost Management	Reliability
Ancillary Services	Power Quality

UTILITIES: STORAGE IS HEADED TOWARD WIDE UTILIZATION FROM GENERATION TO INDIVIDUAL HOMES



Graphics adapted from an EPRI Presentation by Joe Hughes

Large Central Units

Substation Batteries

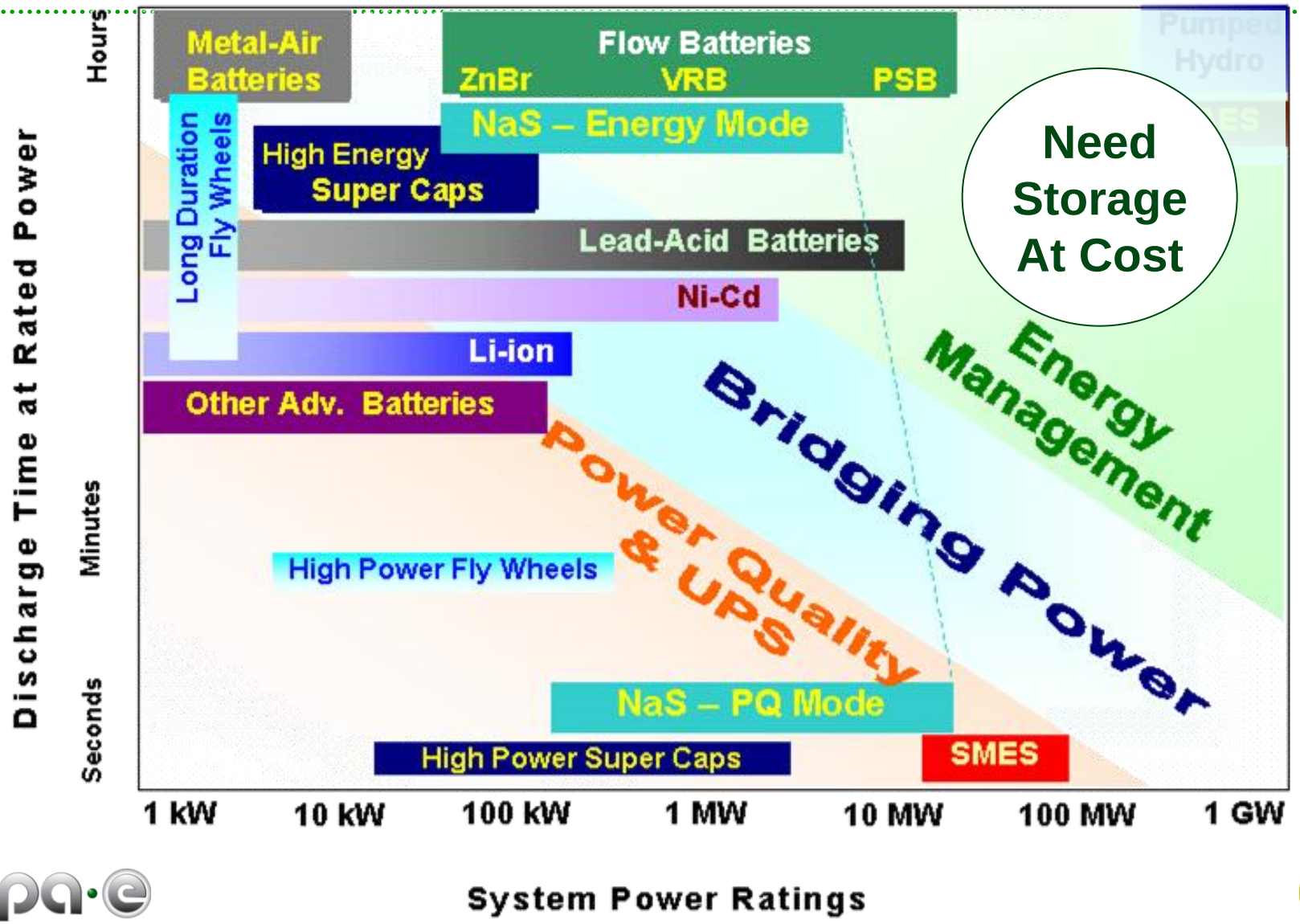
Storage at Grid Edge

"Residental generation from renewables has doubled every year for the last decade". A. Nourai - AEP

… each technology has technical challenges, and room for development within ARPA-E.

Source: A. Nourai, American Electrical Power, Inc.

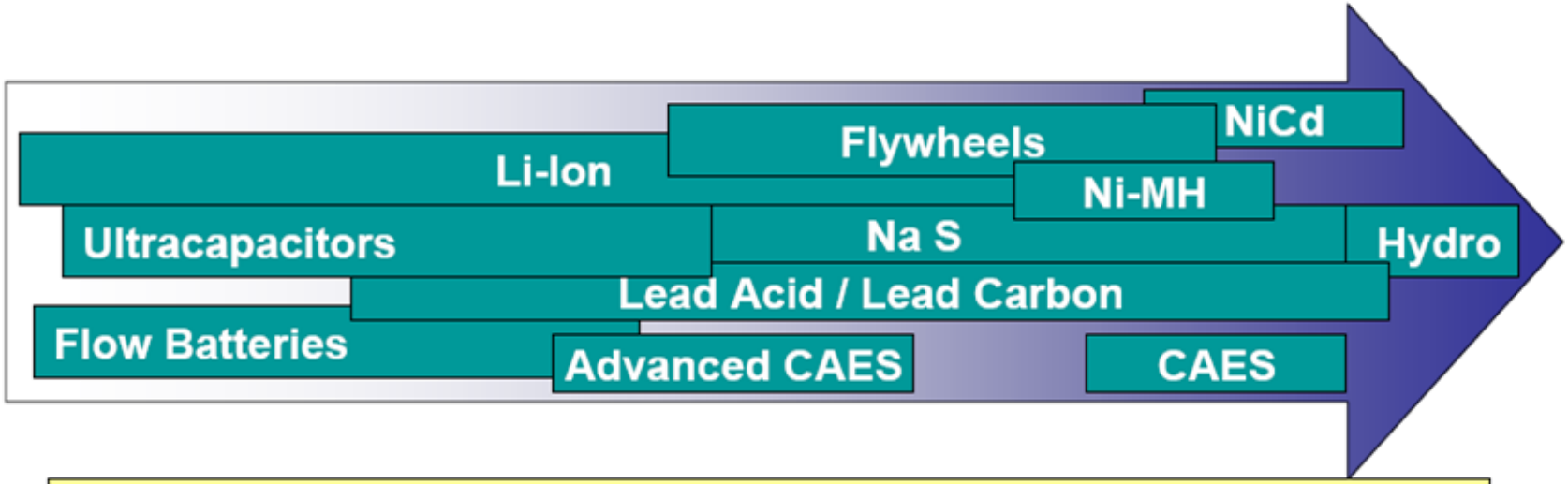
STORAGE TECHNOLOGIES AND APPLICATION SPACES



courtesy: Imre Gyuk (OE)

GRID-SCALE STORAGE – RANGE OF TECHNOLOGY READINESS LEVELS

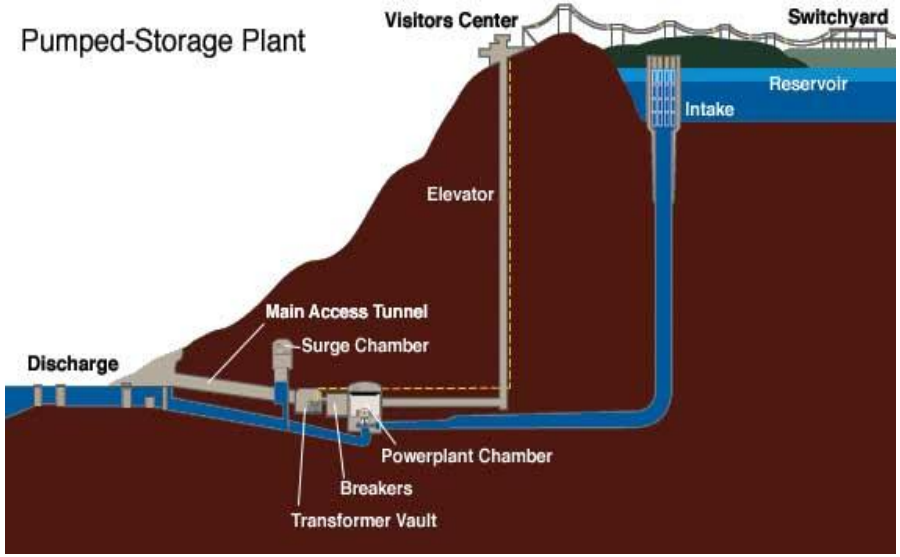
Grid Storage Stages of Maturity by Technology



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

OVERVIEW: PUMPED HYDRO STORAGE



Technology Maturity

R&D — Bench-scale — Pilot-scale — Demonstration — Commercial

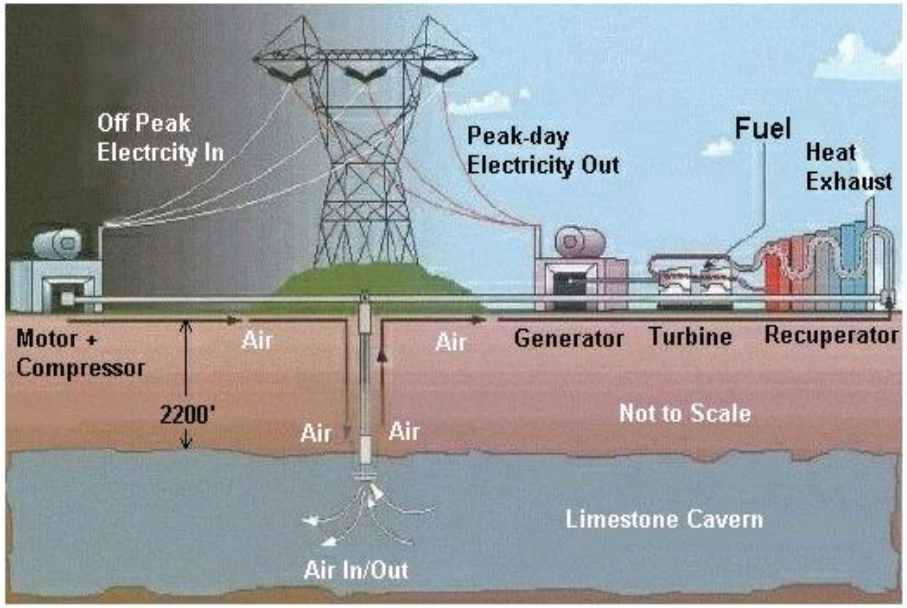
Description

- **Most widely deployed storage technology: 38 US Facilities with 22 GW total capacity**
- **Provides ancillary services and storage**
- **Acceptable sites for future facilities are limited due to need for significant elevation changes in plant designs:**

  Higher Elevation Difference Pumped Hydro Systems
- **Economically attractive:**

  $2200/kW and $80 - $120/kWh

OVERVIEW: COMPRESSED AIR ENERGY STORAGE (CAES)



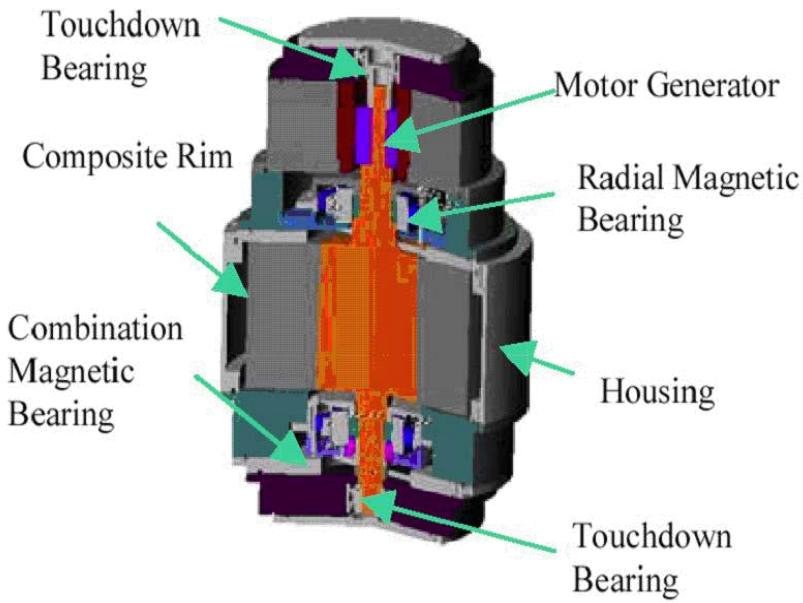
Technology Maturity

R&D — Bench-scale — Pilot-scale — Demonstration — Commercial

Description

- Deployment where favorable geological formations are available
- Power and energy from improved efficiency in coupled gas turbine generation systems
- New approaches:
  - Above ground (to MWh scale)
  - Adiabatic or Isothermal systems
  - Novel storage media
- Economically acceptable: $100 /kWh

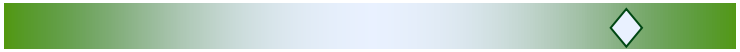
OVERVIEW: FLYWHEEL STORAGE



Cross-Section Of A Flywheel Module

(*Courtesy NASA Glenn Research Center*)

Technology Maturity

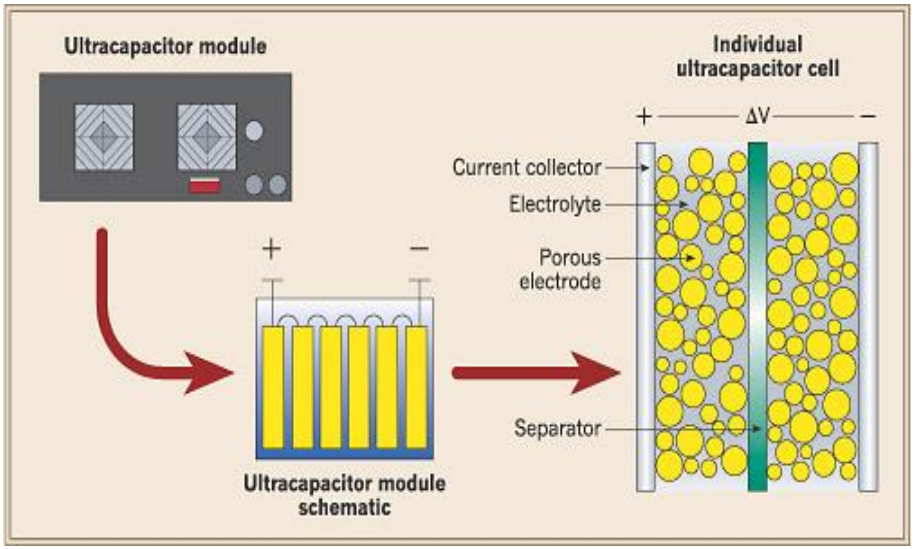


R&D | Bench-scale | Pilot-scale | Demonstration | Commercial

Description

- **Flywheels store energy mechanically (kinetic)**
- **High cycle life (100,000+ cycles) ideal for frequent charge/discharge of power.**
- **Power and energy scale independently, but there are practical limit to energy density:**
  - **Higher Moment of Inertia Materials**
  - **Low Cost Structures**
- **Commercial plants are on-line providing frequency regulation: 3MW in Massachusetts, 20MW planned in New York and Illinois**

OVERVIEW: ULTRACAPACITORS



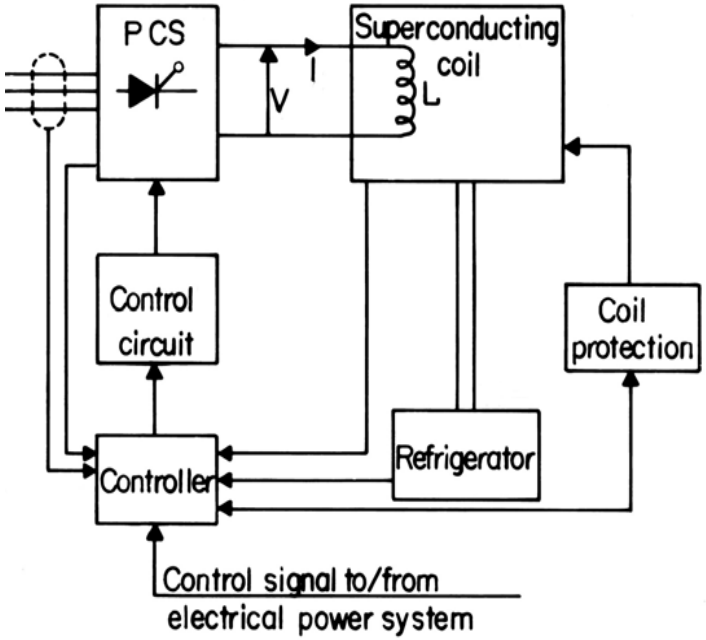
Technology Maturity

R&D — Bench-scale — Pilot-scale — Demonstration — Commercial

Description

- Ultracapacitors store electricity in two a high surface area electric double layer (EDL)
- High power, but lower energy density than batteries
- Cycled 100,000+ times: ideal for applications with frequent charge/discharge requirements.
- Needs:
  - Higher Energy Density Materials and Hybrid Structures
  - High Surface Area Nanomaterials Electrodes
  - Increase Cell Voltages (2X)
- DOE-funded 450kW (30 sec) demonstration unit in CA

OVERVIEW: SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES)



SMES schematic

Technology Maturity

Description

- SMES store electricity in magnetic field of a superconducting coil cryogenically cooled below its critical temperature.
- Efficient energy storage
- Power available instantaneously
- Several large (3MW) demonstration units are installed in the US (Wisconsin, Texas), as are numerous “micro-SMES” units
- New Technology For Longer Duration:
  - Reduce Cost of Superconducting Material Structures
  - High Critical Temperature Superconductors

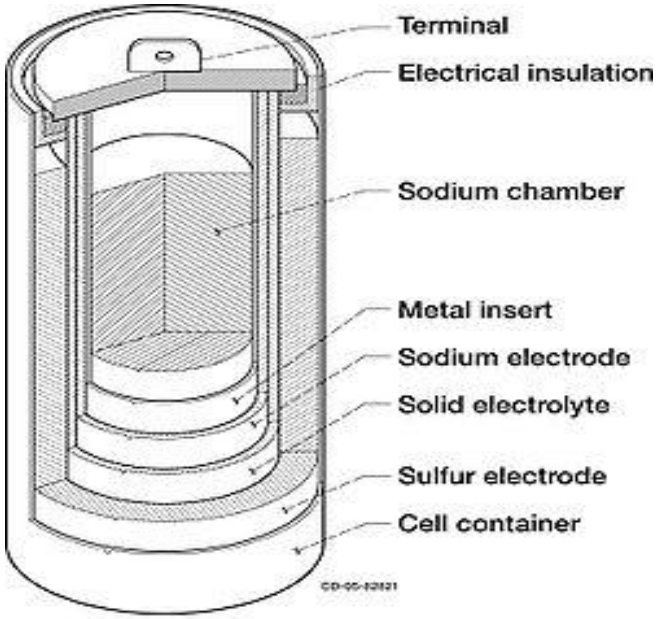
OVERVIEW: LEAD-ACID BATTERIES

Technology Maturity

Description

- Oldest and most developed battery technology
- Energy management applications have been installed (California, Hawaii, Puerto Rico, and Germany) with power from 3 to 10 MW
- Highly-sensitive to operating temperature and charge profiles; corrosion, sulfation, and active material shedding as traditional issues
- New Areas in 200 Year Old Technology:
  - Innovative Lead-carbon Electrodes
  - Advanced Power Conditioning Systems

OVERVIEW: SODIUM β-ALUMINA BATTERIES



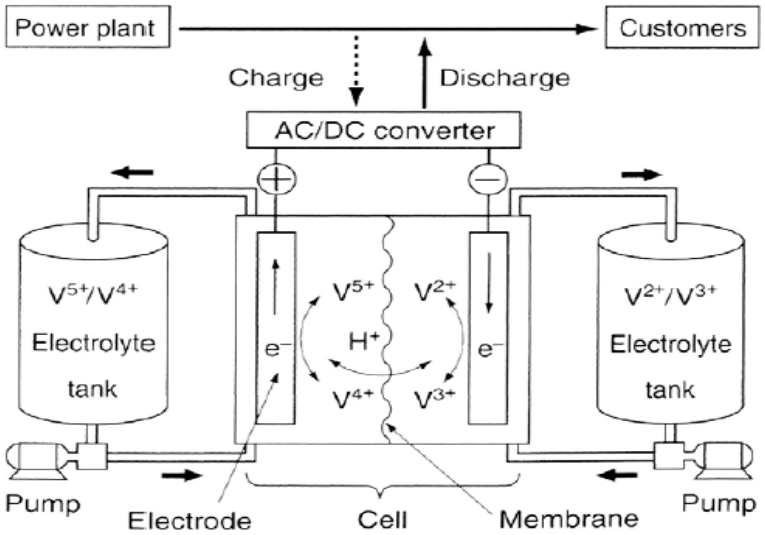
Sodium sulfur battery schematic

Technology Maturity

Description

- High-temperature (~300°C) liquid sodium cathode and sulfur anode with a β-alumina solid electrolyte (BASE)
- Heat produced by charging and discharging cycles maintains operating temperature, but:
  - Need utility scale reliability
  - Beyond sodium-sulfur for β-alumina
- Systems offer high efficiency (89-92%) and high cycle life (5000+ cycles)
- Several grid-storage installations:
  - Japan has 25 at 500kW or higher
  - US projects in New York, West Virginia and California.

OVERVIEW: FLOW BATTERY VANADIUM REDOX (VRB)



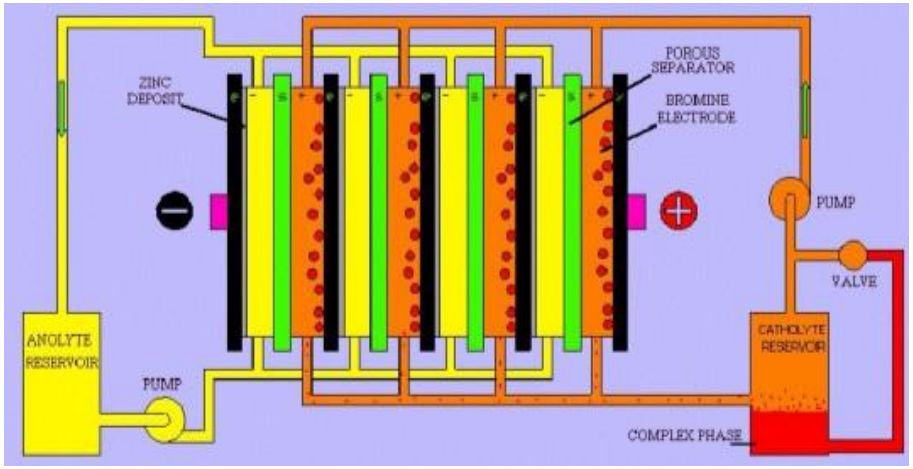
VRB Schematic

Technology Maturity

Description

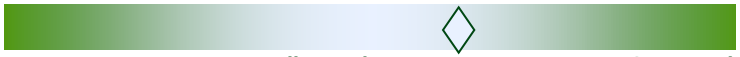
- Two aqueous electrolytes with vanadium species in different oxidation states are pumped through reaction cell halves
- Energy determined by externally-stored electrolyte; Power determined by cell stack
- High roundtrip efficiency (70-75%) and potential for low costs
- Needs:
  - Doubling of Energy Density and Improved Power Management
  - Long Duration Membranes Materials
  - High Energy Density Chemistries

OVERVIEW: ZINC BROMINE (Zn-Br) FLOW BATTERIES



Zinc-Bromine Flow Battery Schematic

Technology Maturity

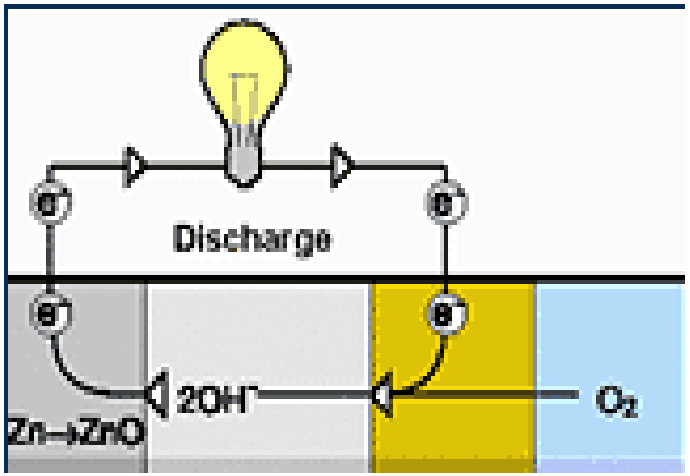


R&D | Bench-scale | Pilot-scale | Demonstration | Commercial

Description

- Solution of zinc-bromine in two tanks. Zinc is electroplated on anode and Bromine is evolved at cathode
- Power and energy can be scaled separately
- High roundtrip efficiency (70-80%) and potential for low cost
- Field tests in Japan, United States and Australia. Scaled 1MWh demonstration project in California
- Needs:
  - Interface, Membranes and Electrodes
  - Technology for Long Life Cycle (20yrs)

OVERVIEW: METAL-AIR BATTERIES



Metal Air Schematic

Technology Maturity

R&D | Bench-scale | Pilot-scale | Demonstration | Commercial

Description

- Metal air batteries combine reactive metal anode (zinc, lithium, magnesium, etc.) with an air electrode
- Metal-air batteries have potential for very high energy density at a low cost
- Need:
  - Recharging from the Grid
  - Long Cycle Life Challenges
- Flow-type designs in which consumed metal is mechanically replaced and reprocessed separately

PERSPECTIVES ON METRICS

General Metrics to Evaluate Grid Scale Energy Storage Projects

- Performance Metrics
  - **Duration**
  - **High cycle efficiency**
  - **Peak power capability**
  - **Cycle life, and Calendar life**
  - **Operation at temperature environment**
- Cost Metrics
  - **¢/kWh cycled (over lifetime)**
  - **$/kWh, delivered**
  - **Integrated power delivered**
  - **Total lifecycle cost**
- How to measure R&D program successes
  - **Include market pull as requirement in proposals**
  - **National utility scale testbed - badly needed**
  - **Understand storage reduction of GHG if charged with coal**

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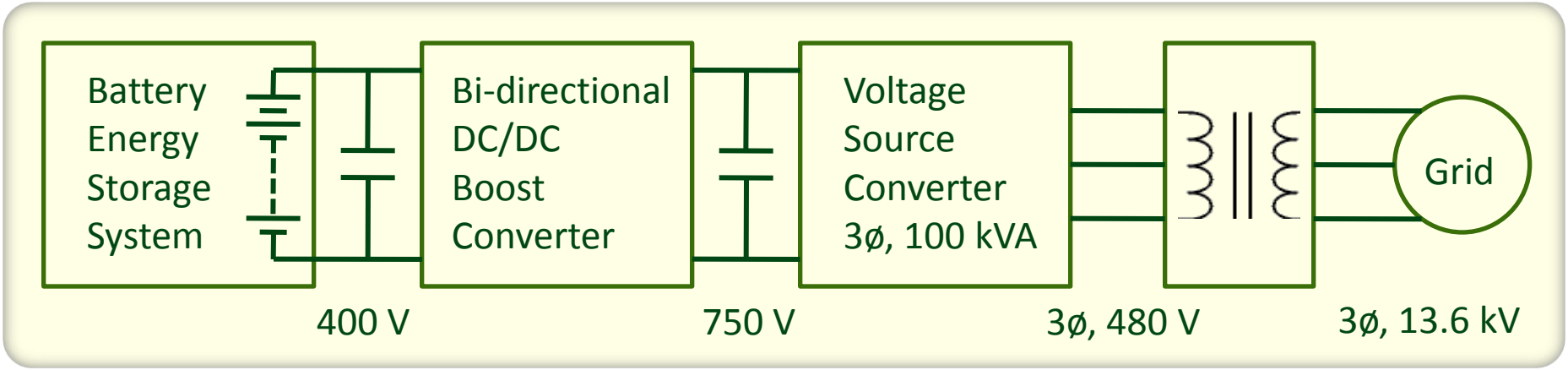
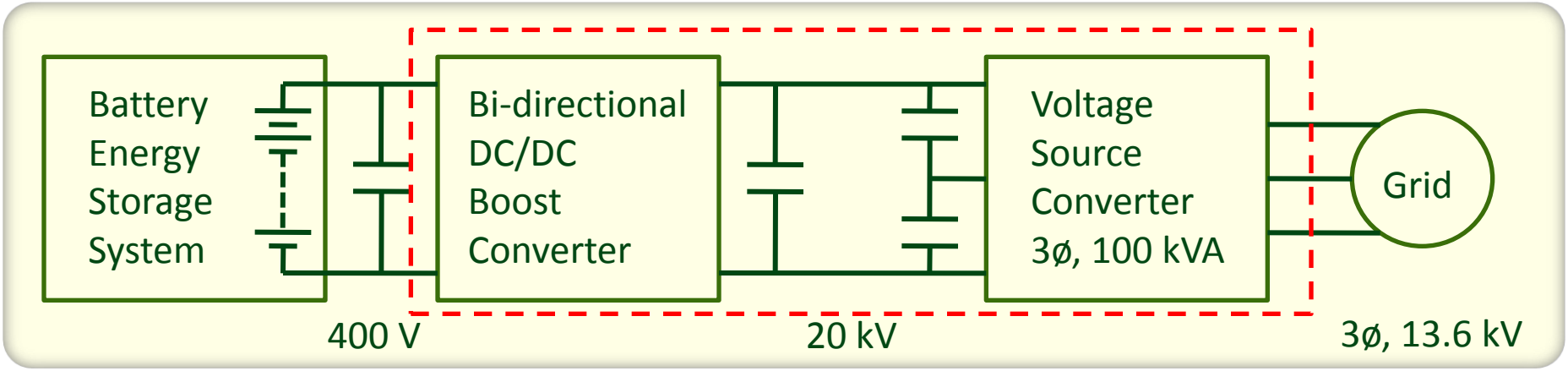
POWER ELECTRONICS INTERFACE FOR GRID SCALE STORAGE (GSS)

Today: Silicon IGBTs:



Future: Advanced High Voltage Semiconductors:



Eliminating 13.6kV / 480V Transformer to Enhance PCS Round Trip Efficiency

OTHER GRID-SCALE STORAGE ISSUES AND NEEDS

- Low-Cost Materials, With Limited Use of Critical, Strategic Resources in Energy Storage
- Real-Time Knowledge of Storage Resources
  - Virtualization and Visualization Tools
  - Utility Compatible Knowledge Set
- Control Protocols and Standards
  - NIST/DoE Smart Grid Interoperability Panel:
    Open Standards for Grid Controls, Including Storage
  - Security for Storage Assets
- Seamless Integration of Storage with Grid Energy Management Systems as Realtime Dispatchable Electric Power

RELATED CURRENT ARPA-E PROJECT

- Electroville: High-Amperage Energy Storage Device-Energy Storage for the Neighborhood [MIT]
- Planar Na-beta Batteries for Renewable Integration and Grid Applications [Eagle-Pitcher & PNNL]
- Low Cost, High-Energy and Power Density, Nanotube-Enhanced Ultracapacitors [FastCAP Systems & MIT]
- Sustainable, High-Energy Density, Low-Cost Electrochemical Energy Storage - Metal-Air Ionic Liquid (MAIL) Batteries [Fluidic Energy & ASU]
- Silicon Coated Nanofiber Paper as a Lithium-Ion Anode [Inorganic Specialists, Ultramet, Eagle-Pitcher, Edison Materials Technology Center, Southeast Non-Wovens]
- High-Energy Density Lithium Batteries [Eniva Systems & ANL]

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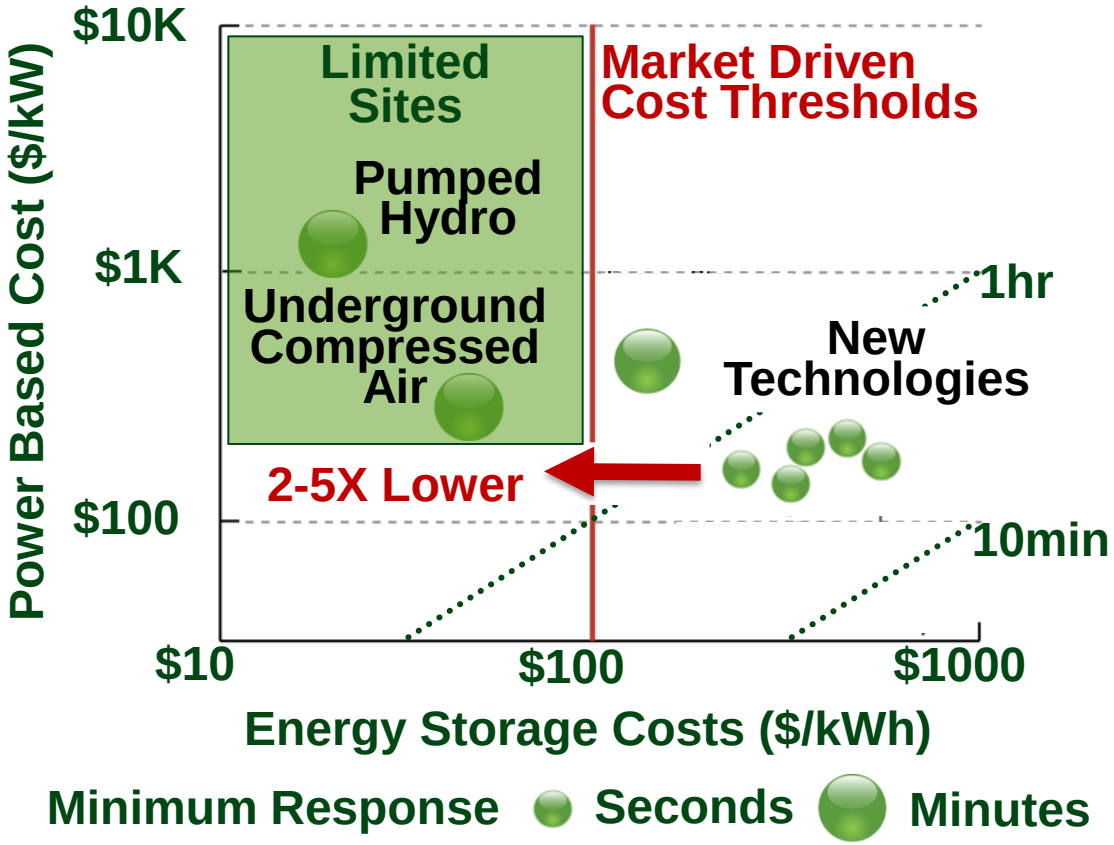
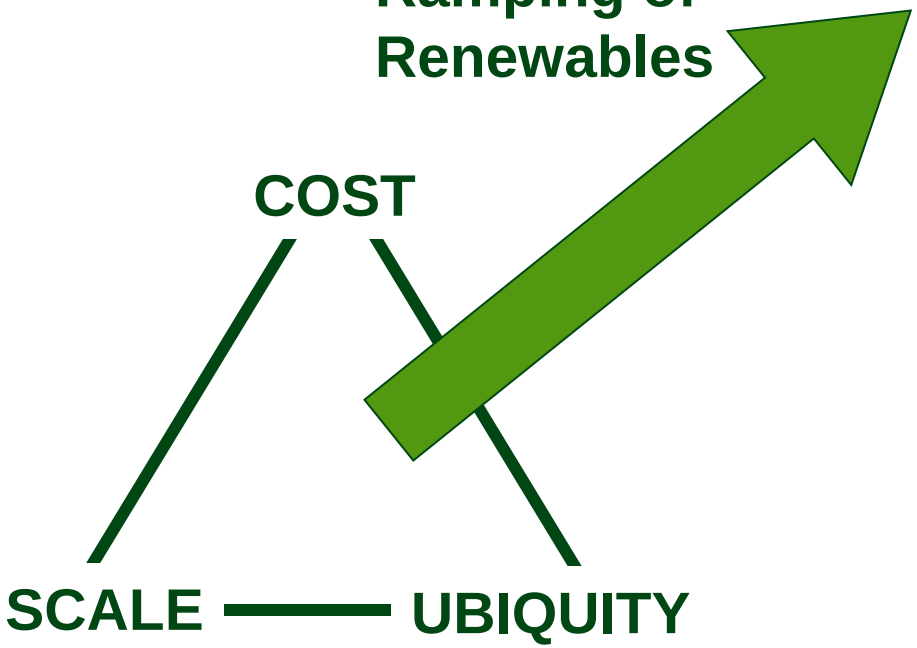
STORAGE TECNOLOGY TRAJECTORY

Storage for High Renewable Penetration



SUMMARY



- Scalable Technologies for Minutes to Hours Power and Energy (MWs and MWhs)
- Economics of Pumped Hydro, But Broadly Deployable
- Need Technology Breakthroughs for 2-5X Energy Cost Reduction at Power, Duration and Reliability

THANK YOU!