The STG Lecture Series

Distributed Energy Storage

Presented by

Dr. Ali Nourai

March 20, 2013

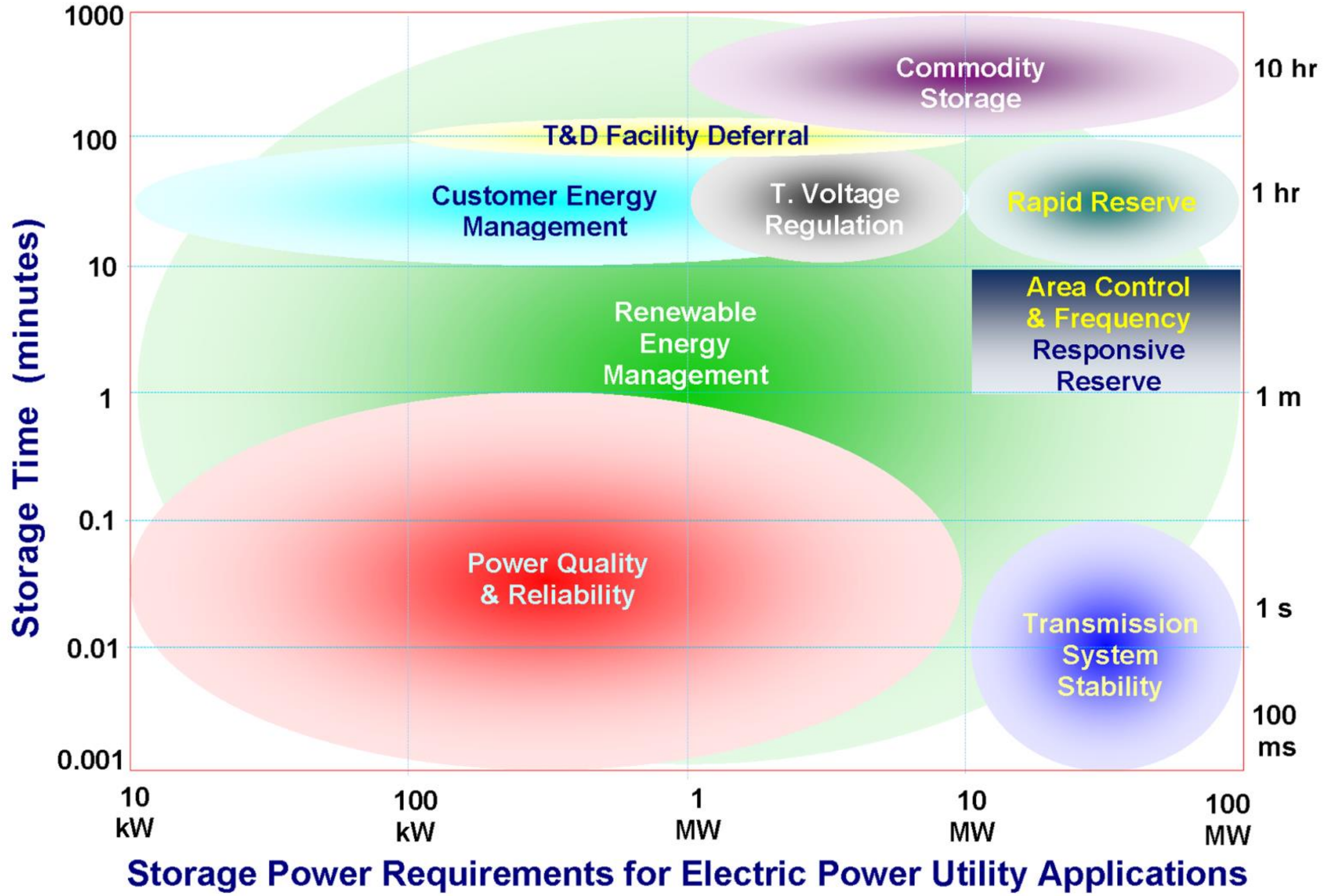
About the Lecturer…

- Dr. Ali Nourai is a graduate of RPI – Electric Power Engineering
- IEEE Fellow
- Executive Consultant with DNV KEMA
- Board member and former chairman of the Electricity Storage Association (ESA)
- Holds six patents
- Launched AEP's sodium sulfur (NaS) battery program
- Introduced the concept of the Community Energy Storage (CES).
- Contact information ali.nourai@dnvkema.com

Outline

1. Introduction
2. Current and evolving storage technologies
3. Storage Deployment Patterns
4. Merits of deploying storage at the “edge of the grid”
5. Storage Options for edge of the grid
6. ES-Select tool (publicly available through DoE)
7. Conclusions

Grid Applications of Energy Storage



Data from Sandia Report 2002-1314

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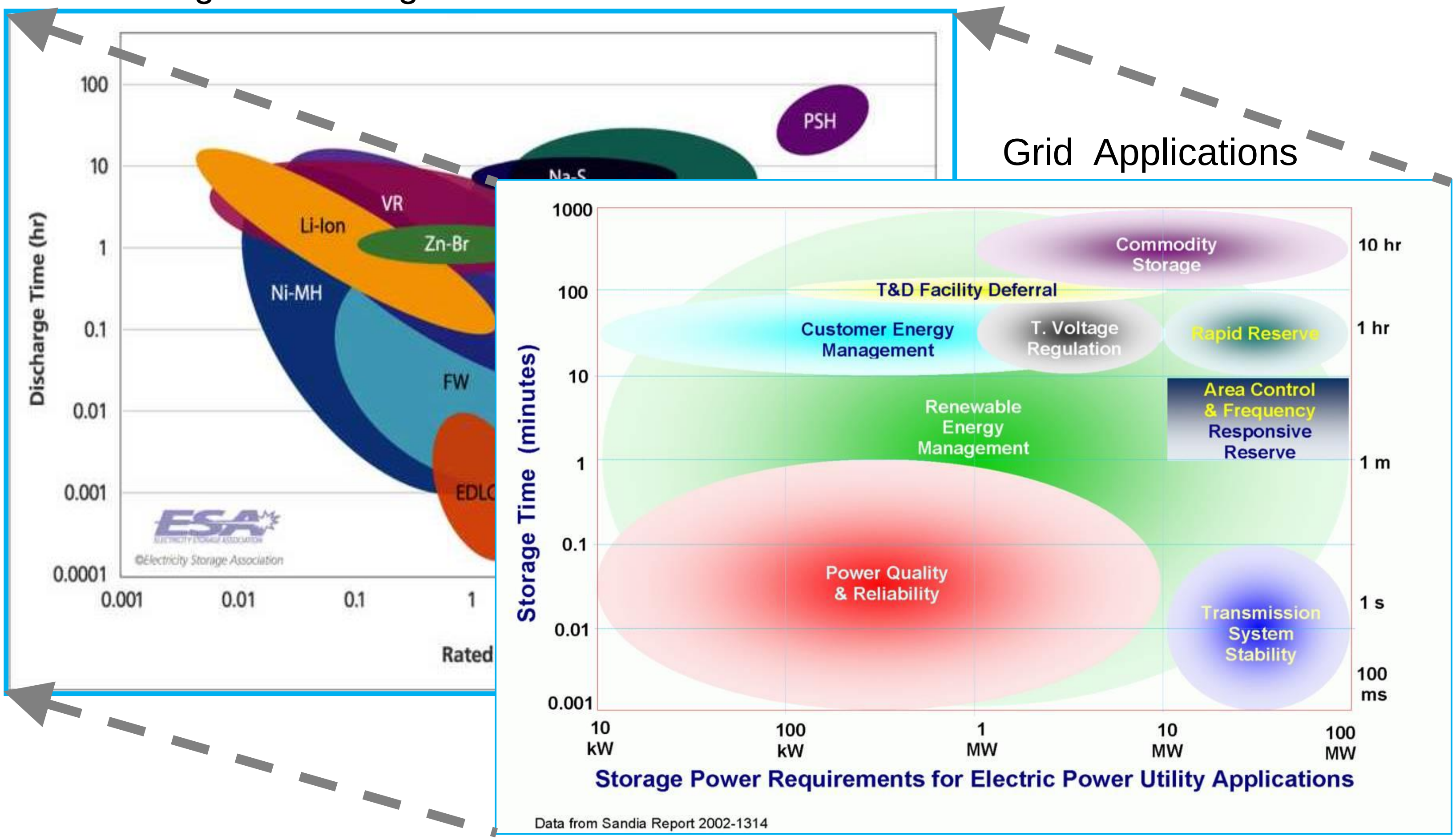
Mapping Storage Options to Grid Needs

Storage Technologies

Grid Applications



It looks simple but has many practical challenges & hurdles to overcome !

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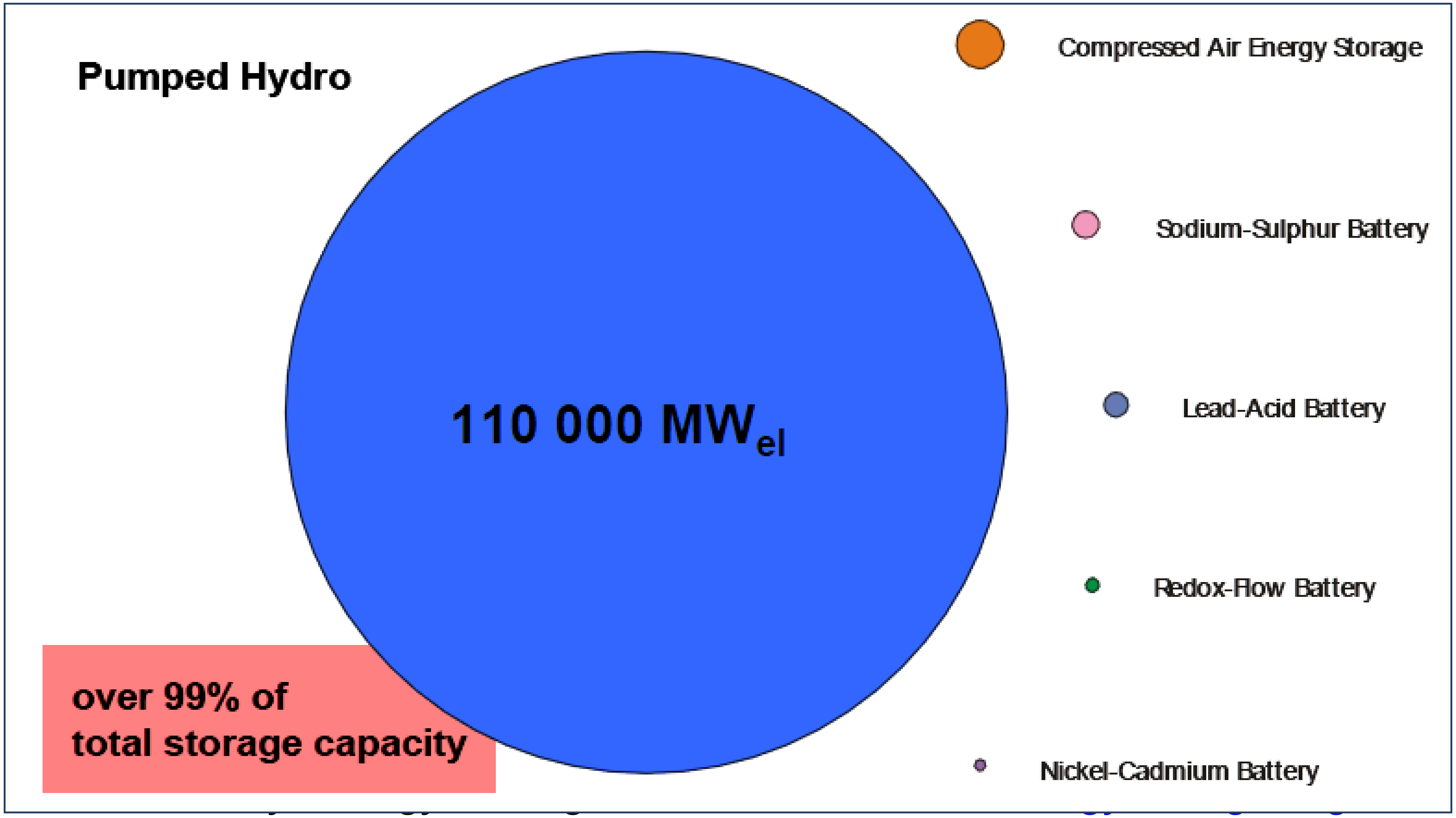
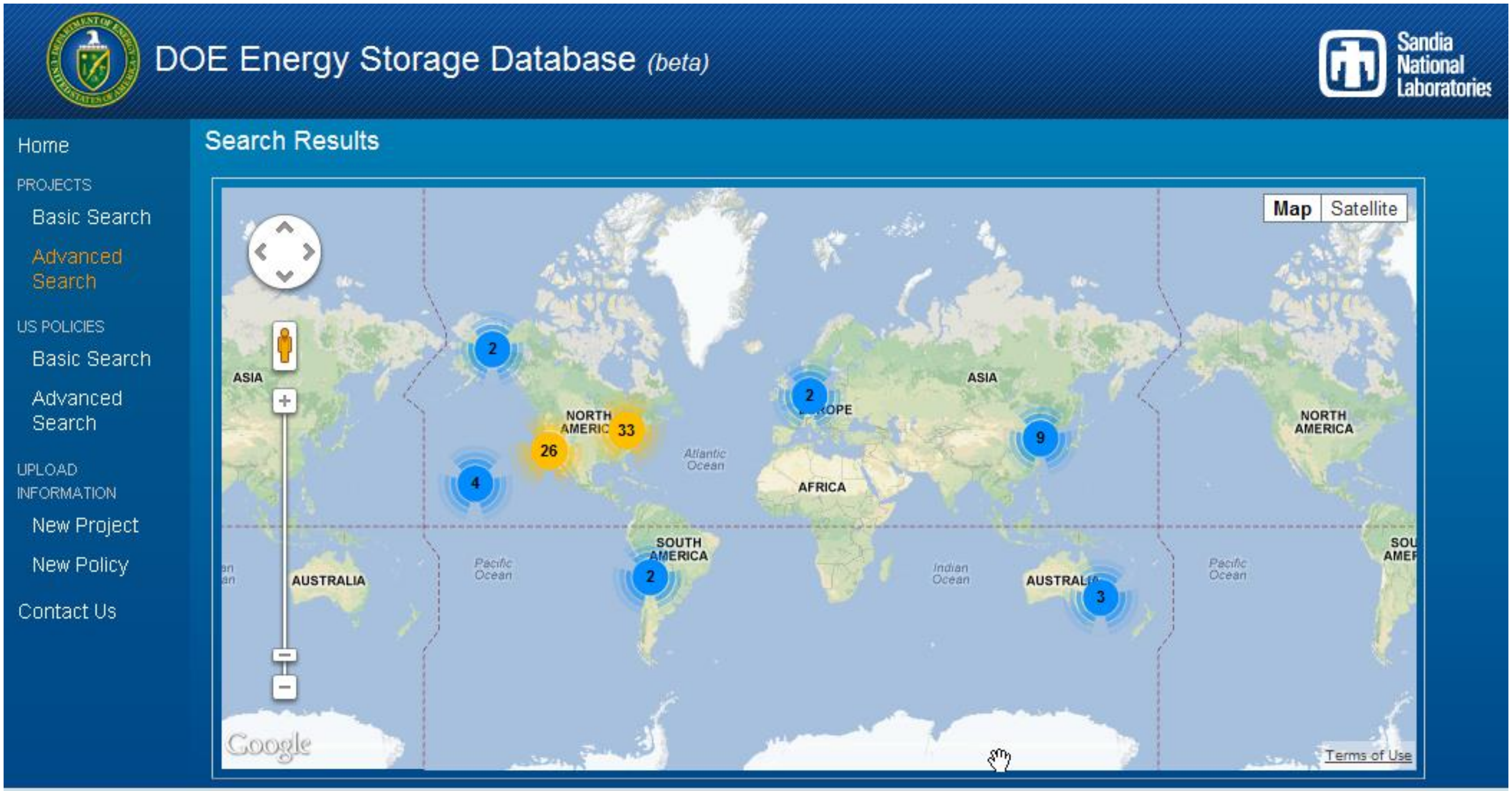
Global installation of energy storage



Source: Fraunhofer

DOE Database for Energy Storage Projects

WWW.Sandia.gov/ess http://www.energystorageexchange.org,



Advanced Operational US Storage Projects

Project Name	Technology Type	Rated Power (kW)	Duration @ Rated Power (HH:MM)	Status	Commission Date	State	Benefit Stream 1	Benefit Stream 2
Laurel Mountain	Lithium Ion Battery	32,000	0:15	Operational	September 30, 2011	West Virginia	Frequency Regulation	Ramping
Battery Energy Storage System (BESS)	Nickel Cadmium Battery	27,000	0:15	Operational	not stated	Alaska	Electric Supply Reserve Capacity - Spinning	Grid-Connected Residential (Reliability)
Beacon New York Flywheel Energy Storage Plant	Flywheel	20,000	0:15	Operational	not stated	New York	Frequency Regulation	
Kahuku Wind Farm	Advanced Lead Acid Battery	15,000	0:15	Operational	March 1, 2011	Hawaii	Renewables Capacity Firming	Ramping
Johnson City	Lithium Ion Battery	8,000	0:15	Operational	December 31, 2010	New York	Frequency Regulation	Electric Supply Reserve Capacity - Spinning
PJM Regulation Services Project	Ultra Battery	3,000	0:43	Operational	June 15, 2012	Pennsylvania	Frequency Regulation	Ramping
Santa Rita Jail Smart Grid – Advanced Energy Storage	Lithium Ferrous Phosphate	2,000	2:00	Operational	March 15, 2012	California	Electric Bill Management with Renewables	Electric Energy Time Shift
Kaheawa I Wind Project	Advanced Lead Acid Battery	1,500	0:15	Operational	July 1, 2009	Hawaii	Renewables Capacity Firming	Ramping
Kaua'i Island Utility Cooperative	Advanced Lead Acid Battery	1,500	0:15	Operational	December 1, 2011	Hawaii	Electric Supply Reserve Capacity - Non-Spinning	Ramping
Xcel and SolarTAC	Advanced Lead Acid Battery	1,500	0:15	Operational	December 15, 2011	Colorado	Ramping	Renewables Capacity Firming
Lanai Sustainability Research	Advanced Lead Acid Battery	1,125	0:15	Operational	September 1, 2011	Hawaii	Ramping	Renewables Capacity Firming
Detroit Edison Community Energy Storage Project	Lithium Ion Battery	1,000	2:00	Operational	July 1, 2011	Michigan	Voltage Support	Renewables Energy Time Shift
Metlakatla BESS	Lead Acid Battery	1,000	1:24	Operational	not stated	Alaska	Electric Supply Reserve Capacity - Spinning	Frequency Regulation
Wind-to-Battery MinnWind Project	Sodium Sulfur Battery	1,000	7:00	Operational	October 1, 2008	Minnesota	Renewables Energy Time Shift	Ramping
	TOTAL KW>>>	115,625						

Source: http://www.energystorageexchange.org, partial list of U.S. operating systems ≥ 1MW

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Selected U.S. Storage Project Photos

AES Laurel Mont., li-ion, 32MW, 8MWh

Metlatakla, PbA, 1 MW, 1.5 MWh

Beacon Tyngsboro, Flywheel,1MW, 250 kWh

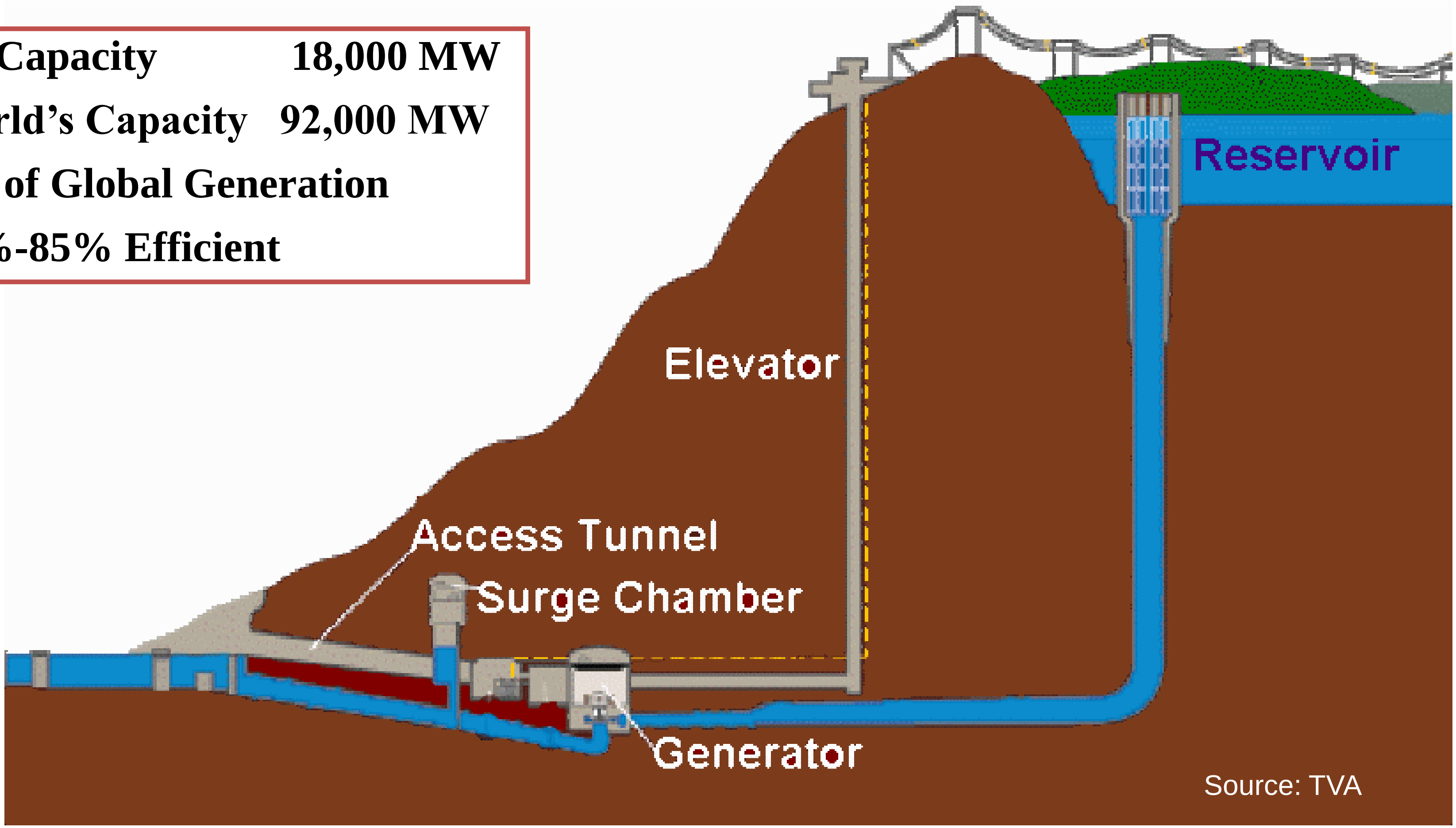
AEP Bluffton, NaS, 2MW, 14 MWh

2. An overview of current & evolving storage technologies

- Pumped Storage
- Compressed air
- Flywheels
- Storage systems with no electric output
- Electrochemical batteries (including flow batteries)

Pumped Storage Facility

US Capacity	**18,000 MW**
World's Capacity	**92,000 MW**
3% of Global Generation	
70%-85% Efficient	

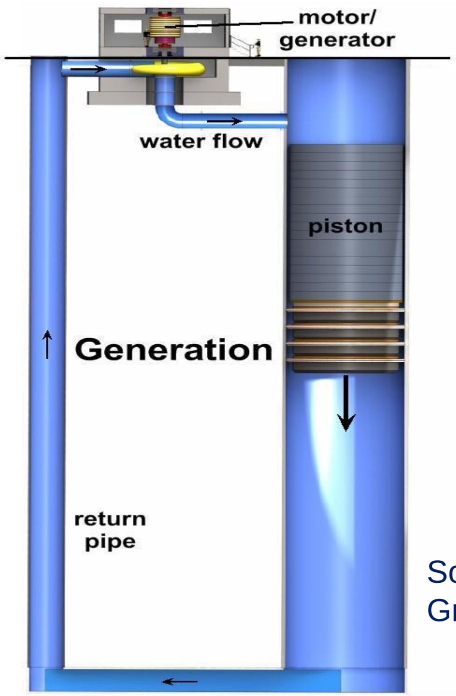


High Capacity - Medium Cost - Special Site Requirement

Pumped Storage – Special Cases

Energy Island (concept):

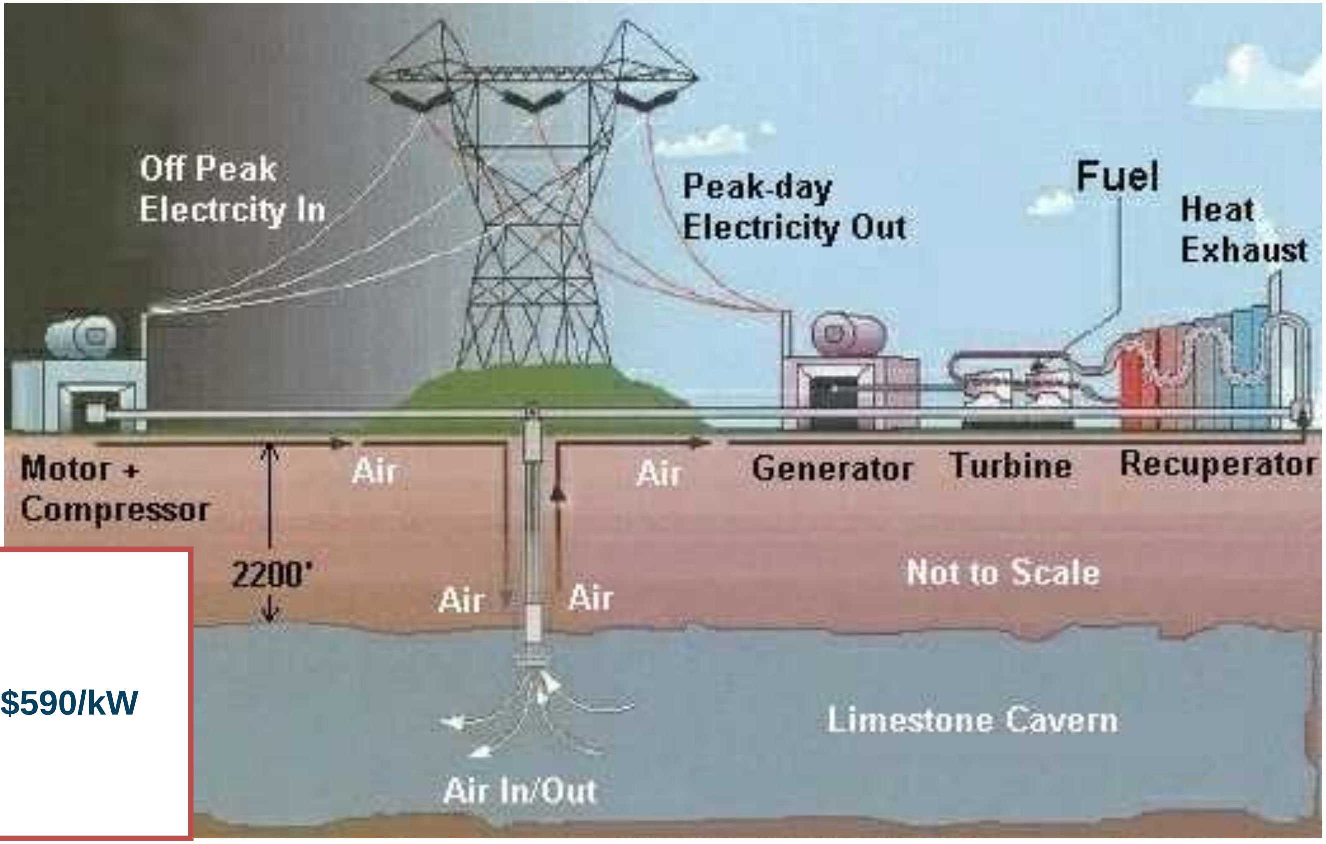
- Surface area =10x6 km^2,
- water depth of inner lake = 32 to 40 m
- Storage capacity = 20 GWh
- Power = 1,500 MW
- Enabler for wind turbines = 300-500 MW



Source:
Gravity Power

Gravitational Storage (concept):
Low energy density - Lifting 100 kg up by 10 m would provide the same energy as a single AA battery.

Compressed Air Energy Storage (CAES)

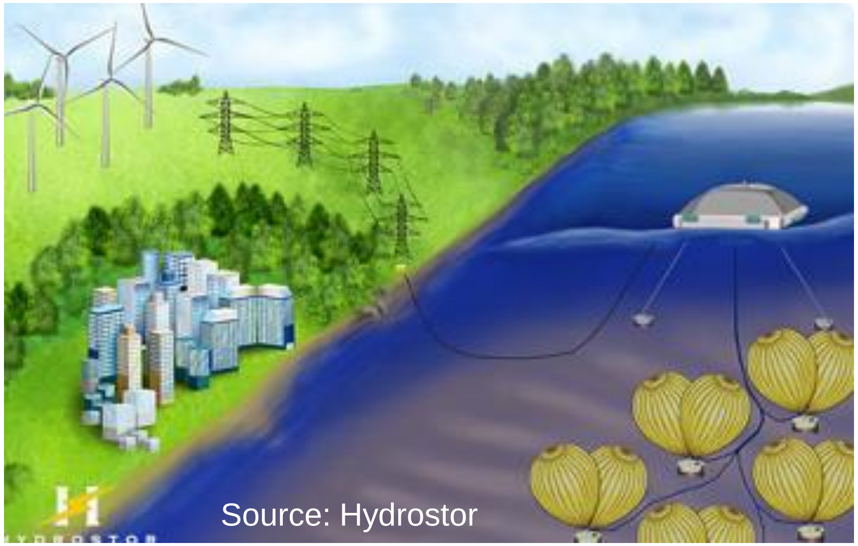


- 1978 Germany 290 MW
- 1991 Alabama 110 MW, $590/kW

High Capacity - Low Cost - Special Site Requirement -Gas Fuel

CAES – Special Cases

Isothermal CAES
Above ground
10's of MW



Underwater CAES
10's of MW

Flywheels

- Kinetic Energy Systems
- Steel Flywheels
  (up to 8,000 RPM)
- Composite Flywheels
  (up to 60,000 RPM)
- Magnetic Bearings
  (Levitated Rotor)
- 100 kW for 15 minutes (typical)
- High efficiency (> 90%)
- Long life (up to 20 years possible)

Source: Beacon

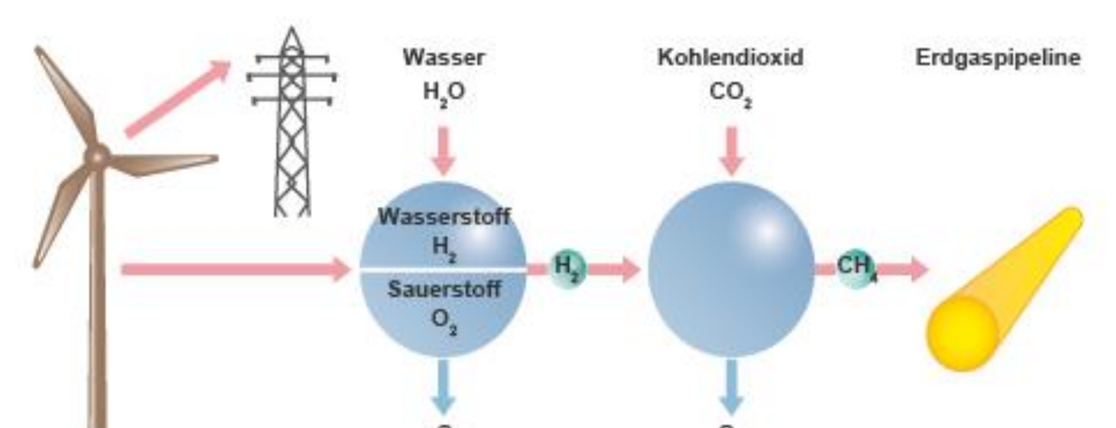
Storage with No Eclectic Output !

- Thermal Storage (cold or hot)
- Power-to-Gas (electrolysis)

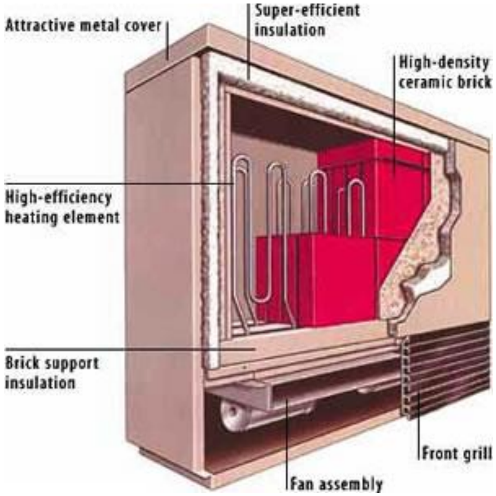
Drivers:

- Low cost
- The non-electric byproducts are useful
- Conversion to electricity is inefficient

Source: ICE-Energy



Source: Vaillant

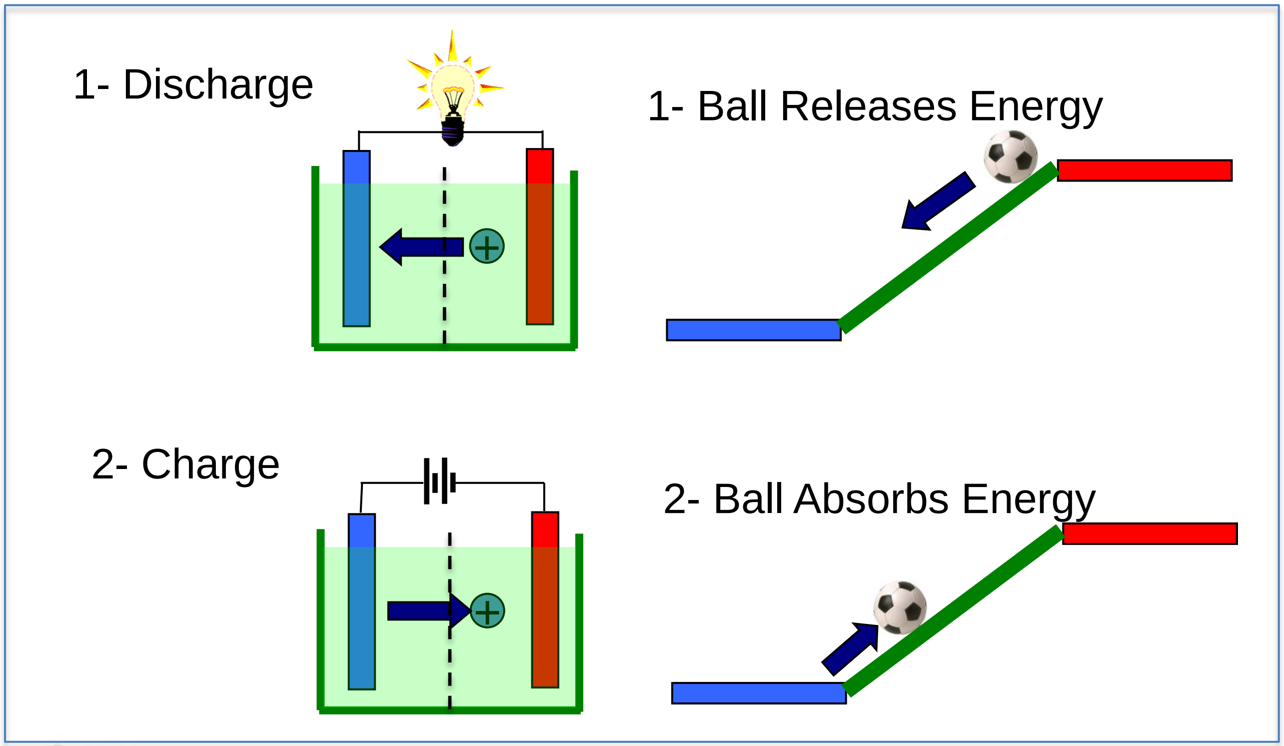


Source: Steffes

Electrochemical Batteries - Mechanical Analogy

Key Components:

1. Two different electrodes
2. Ions that tend to go from ene electrode to another
3. Ion path (electrolyte)
4. Need an ion-conducting separator if electrodes are too close



Sodium Sulfur (NaS) Battery

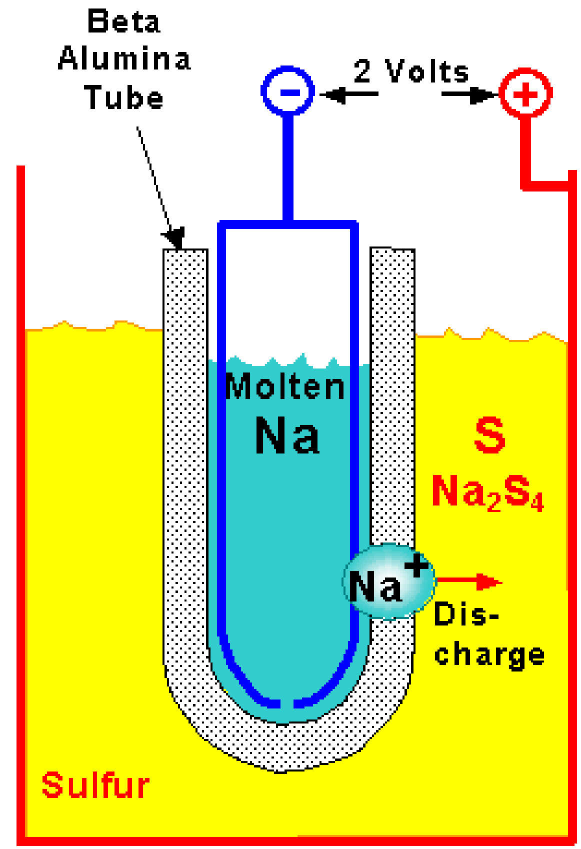
Liquid electrodes with solid electrolyte

89% efficient

2500 – 4500 cycle life

1.0 MW, 7 MWh Battery

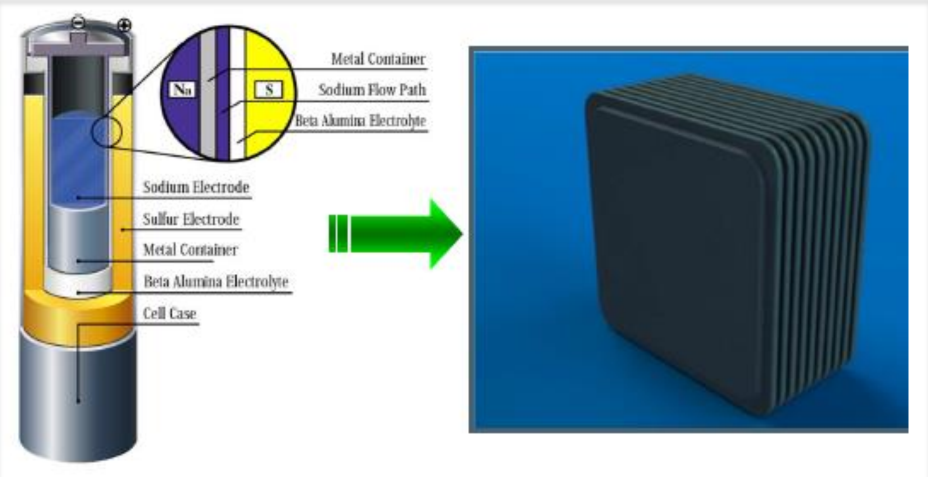
Source: AEP



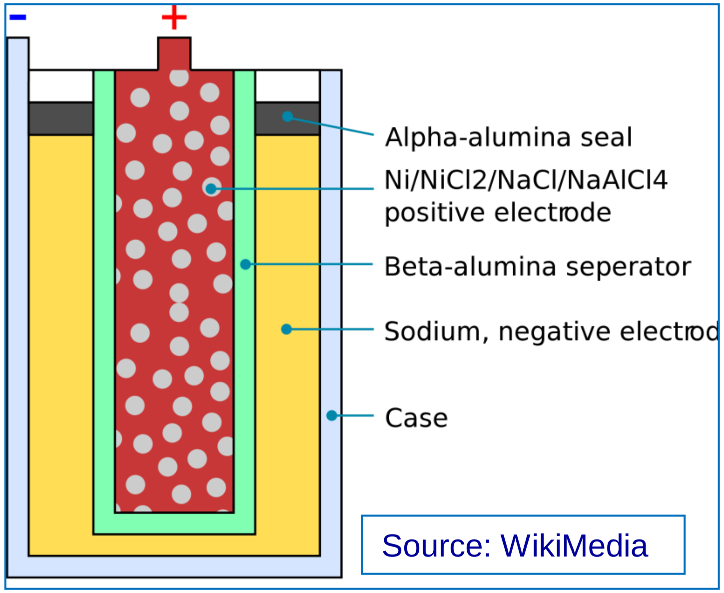
Sketch of a 2V NAS Battery Cell

Other Sodium-based Batteries

- Planar Sodium Sulfur (higher power density, less fragile)
- Sodium Nickel Chloride (higher energy density)



Source: Eagle Picher

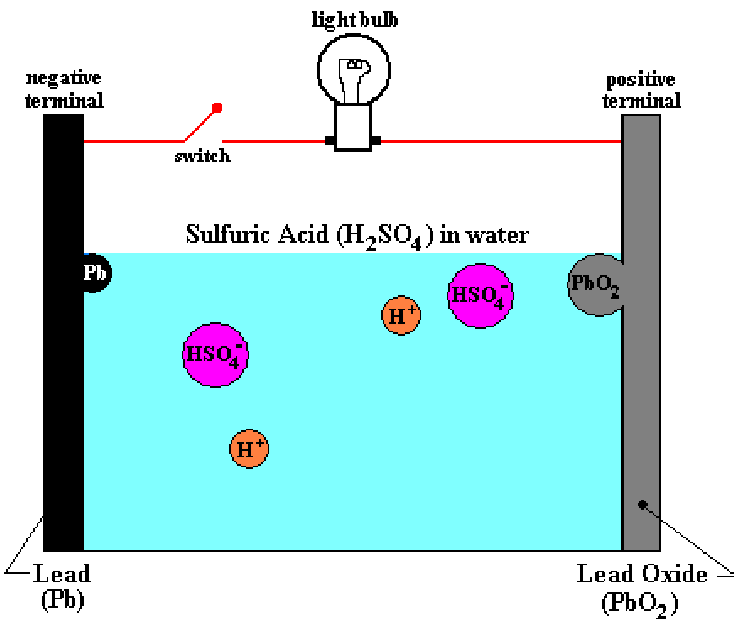


Source: WikiMedia

Lead-Acid Battery

- Low Capital Cost
- Short Cycle Life
- Low Efficiency

- A few MW-scale storage systems were built but none are operating now
- Advanced lead acid batteries with higher efficiency and longer life replaced them for grid applications



Source: ww2.Ignatius.edu

Advanced Lead Acid Batteries

A soft or spongy electrode made from activated carbon, nanotubes or other fluffy but conductive material is used for the following benefits:

1) Sponge does not breath (change dimension) with cycling – thus, no mechanical fatigue – thus longer cycle life
2) Sponge has more effective surface area than a solid electrode of the same dimensions – thus it can hold or store more ions (higher capacity)
3) Fast movement of ions through porous sponge causes high power

Courtesy: Xtreme Power

Lithium-ion Battery

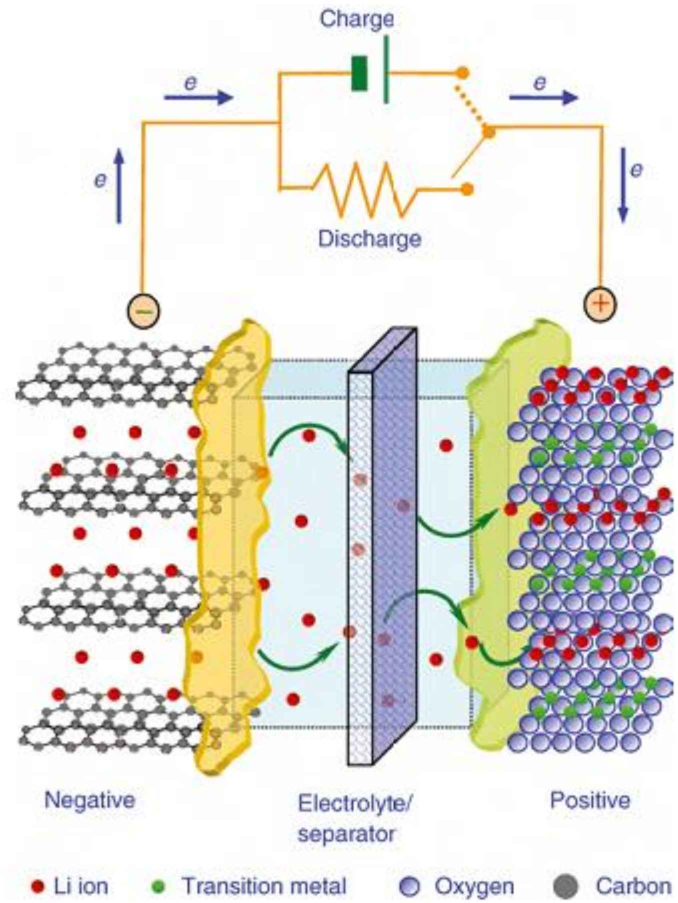
3.6 V cell

95% efficient

5000 cycle life

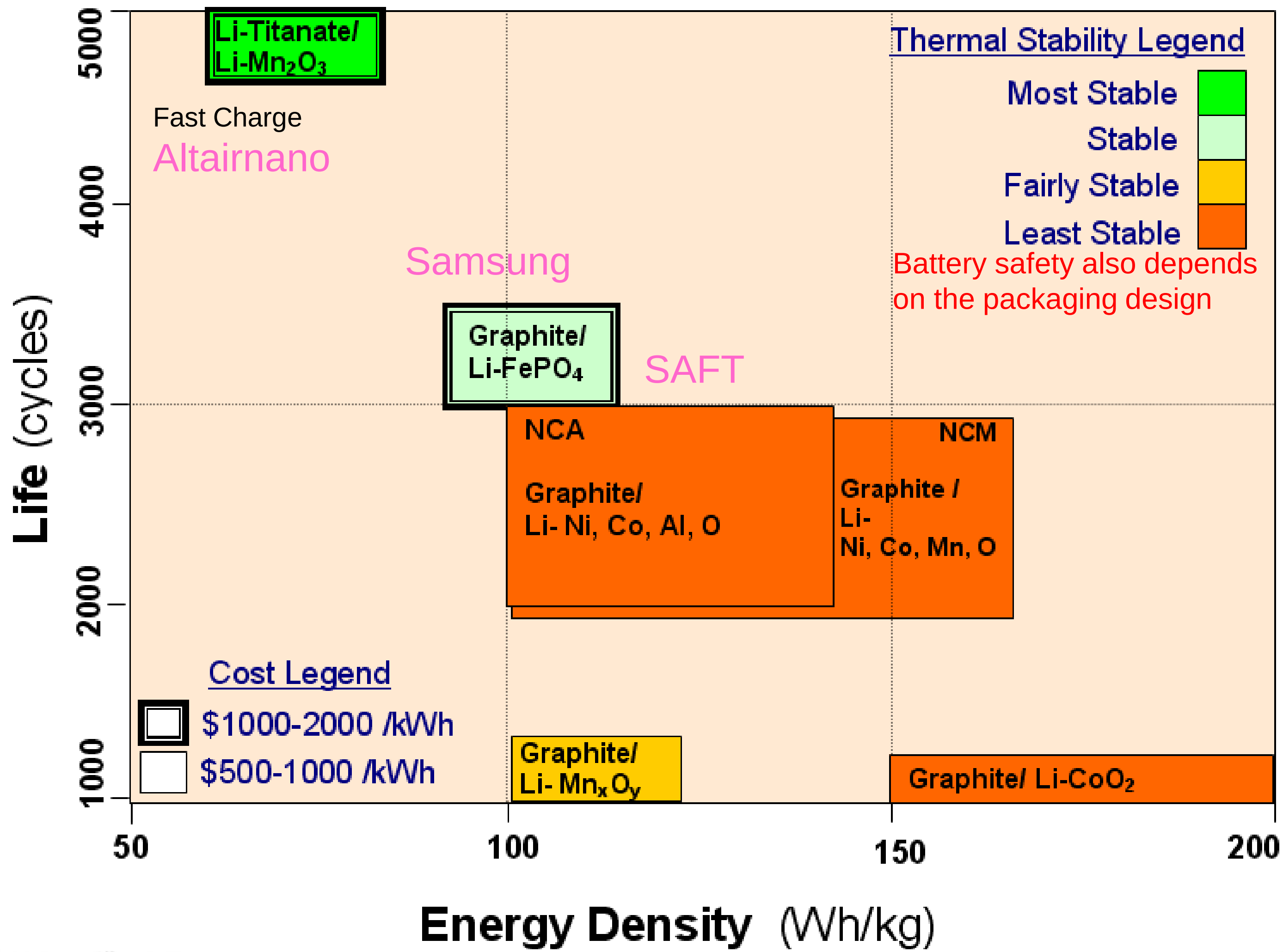
32 MW, 8MWh,
Laurel Mountain project, WV

Source: AES



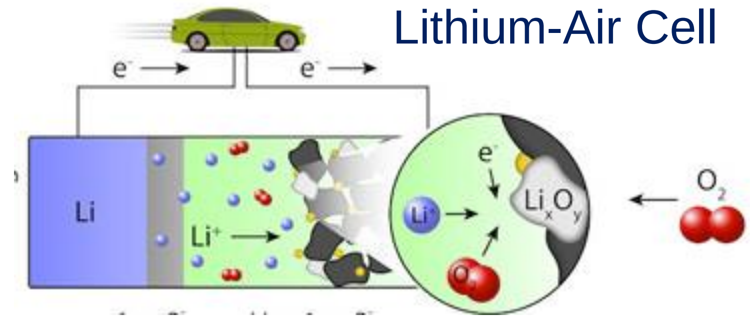
Source: Encyclopedia of Electrochemical Power Sources

Varieties of Li-ion Batteries

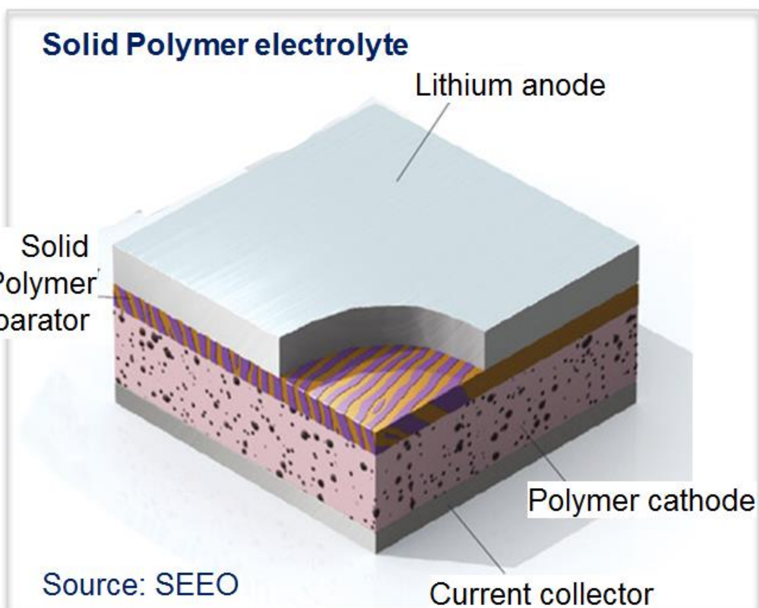


Other Li-based batteries

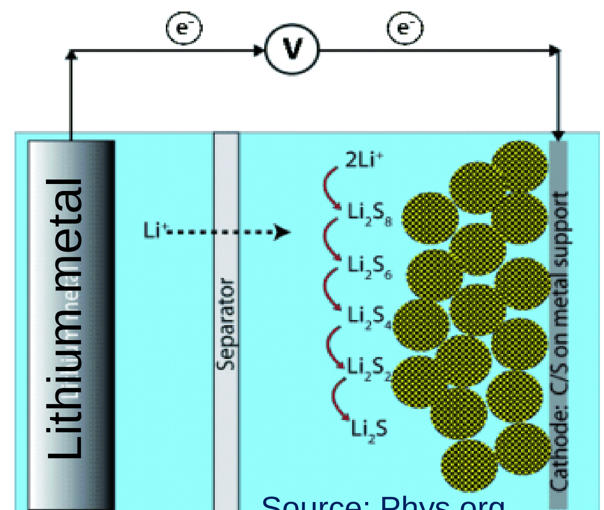
- Li-ion with solid polymer electrolyte
- Lithium Sulfur (high energy density, volatile)
- Li-air (extremely high energy density)



Lithium-Air Cell



Source: SEEO



Source: Phys.org

Lithium Sulfur Cell

Flow Battery Systems

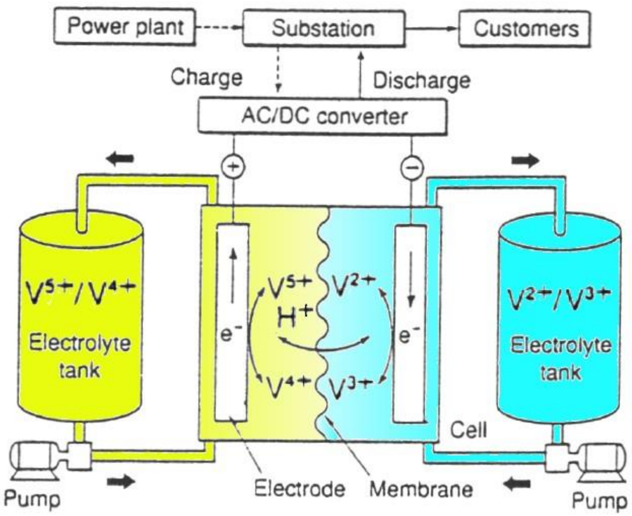
Common flow battery types:

- Vanadium Redox
- Zinc Bromine
- Iron Chromium

General Features:

- Power and energy ratings are independent
- High cycle life
- Low-medium efficiency
- Low energy density (large size)
- Can be turned off (safe maintenance)

Vanadium Redox Flow Battery

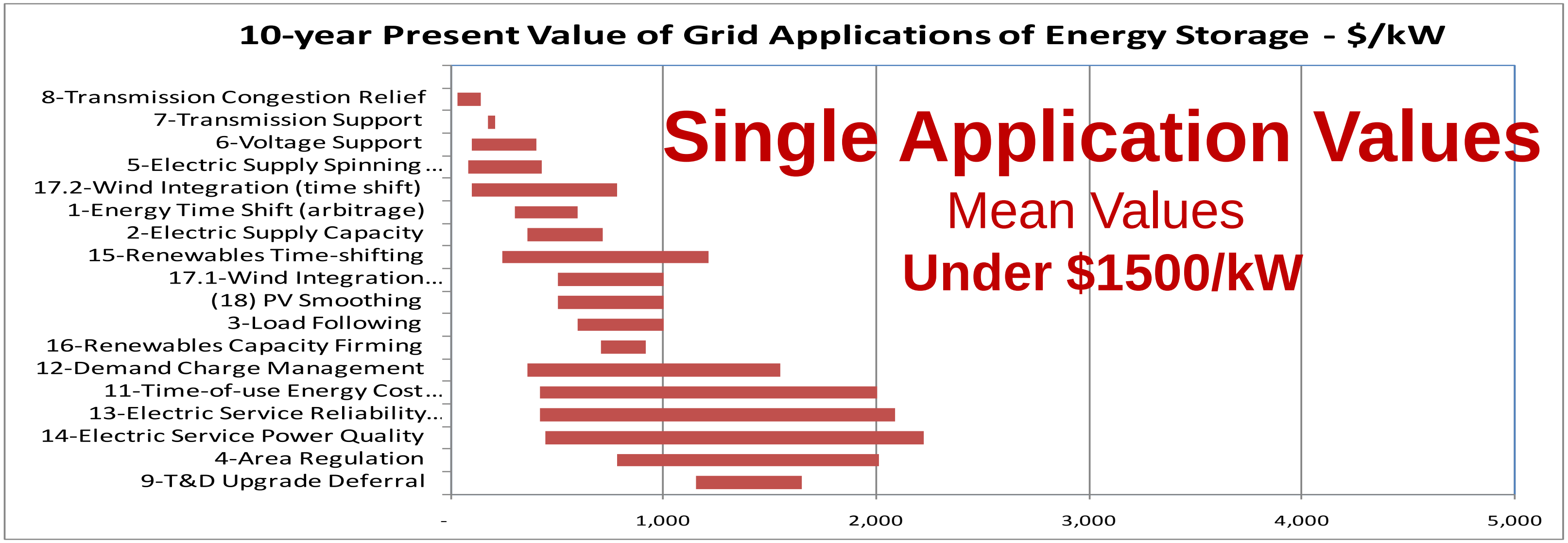


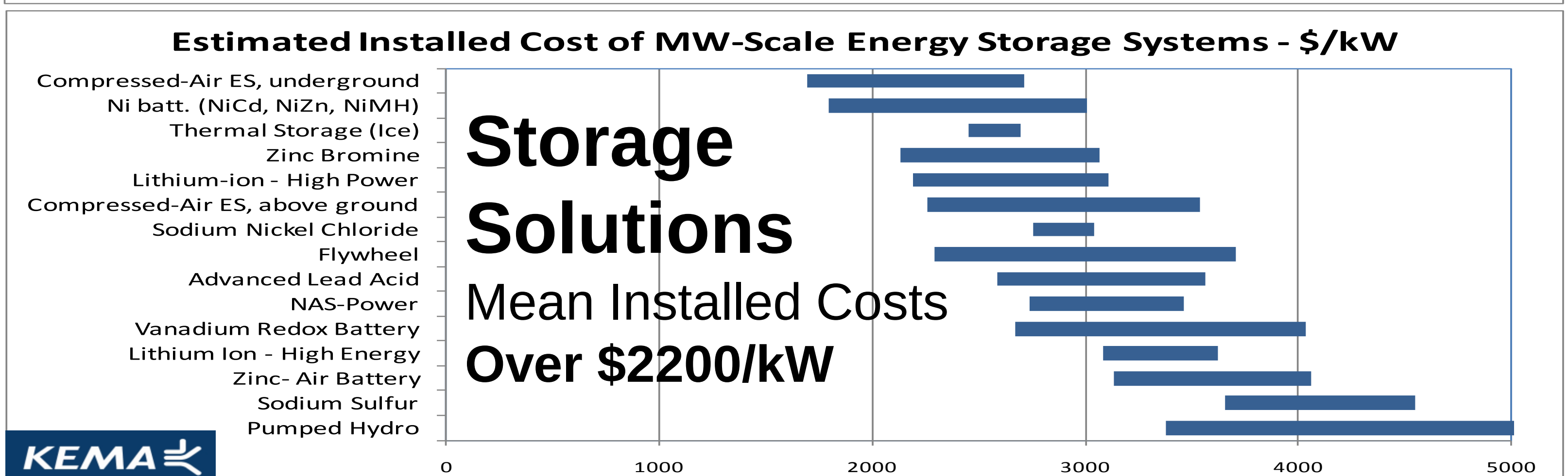
Source: Sumitomo Electric Industries (SEI)

Gills Onion VRB – 600kW, 6 hours

Source: Prudent / Gills Onion

Storage Cost vs. Benefit of “Single” Applications





3. Storage Deployment Patterns - Central vs. Distributed

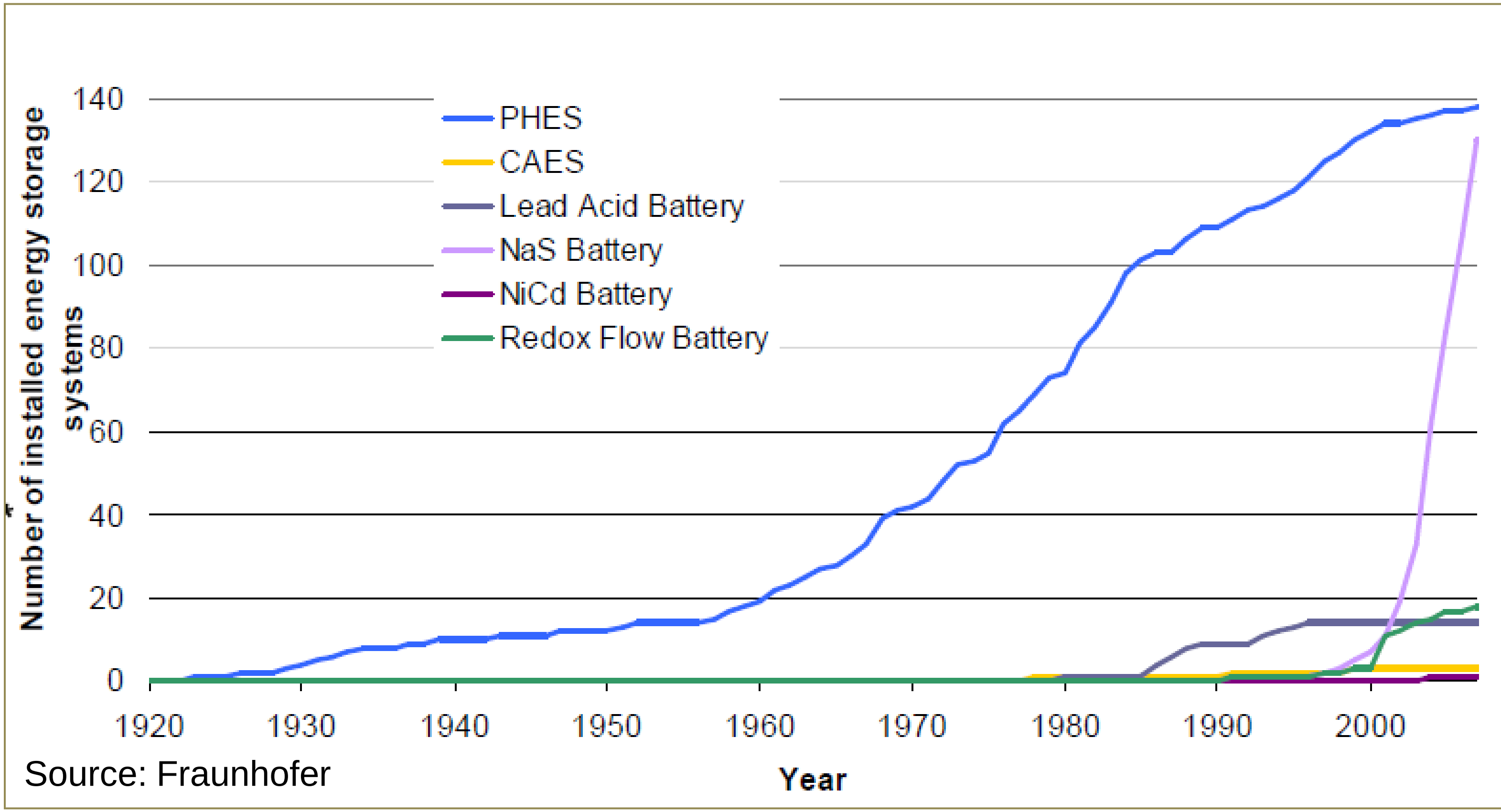
- Drivers
- Restrictions
- Technology Options

Factors Shaping the deployment patterns

- **Drivers**
  - Nuclear power plants in 30's and 40's (slow driver - slow deployment of large central storage)
  - Distributed renewables (fast driver – fast deployment over wide geographic areas)
- **Restrictions**
  - Geological restrictions for pumped hydro and CAES
  - Required licensing for large installations
- **Technology Options**
  - Battery cells are only a few volts, easier to aggregate small units than make a large central unit from millions of cells.
  - Communications and control for aggregation of distributed assets

Installation History of Storage Technologies

Drivers behind storage deployment have changed over the years



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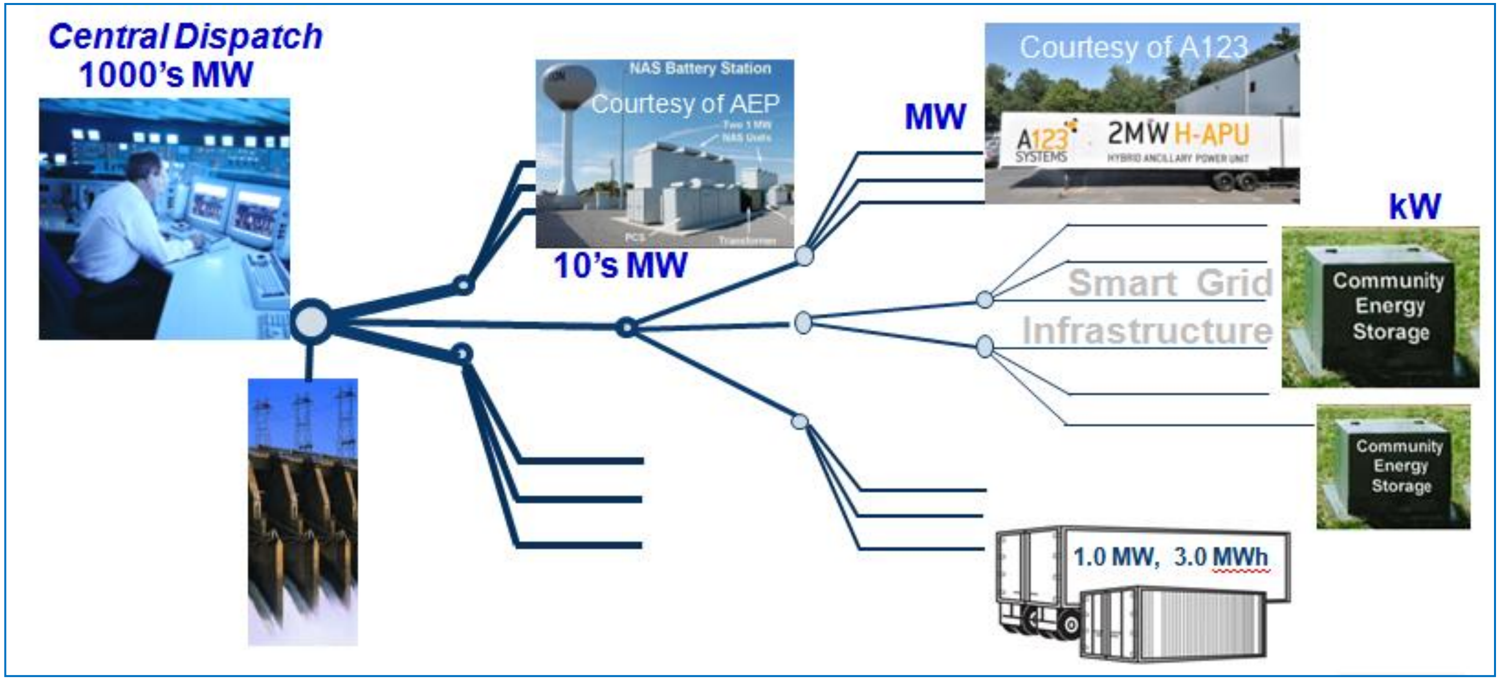
"Distributed Bulk" Storage !!

Aggregation of Distributed Storage Units

- Realizing Distributed *Benefits*
- Exercising Central *Control*



Distributed bulk is made possible by communication and control technologies

Central vs. "Distributed Bulk" Storage

Advantages of "distributed bulk" storage

Economics

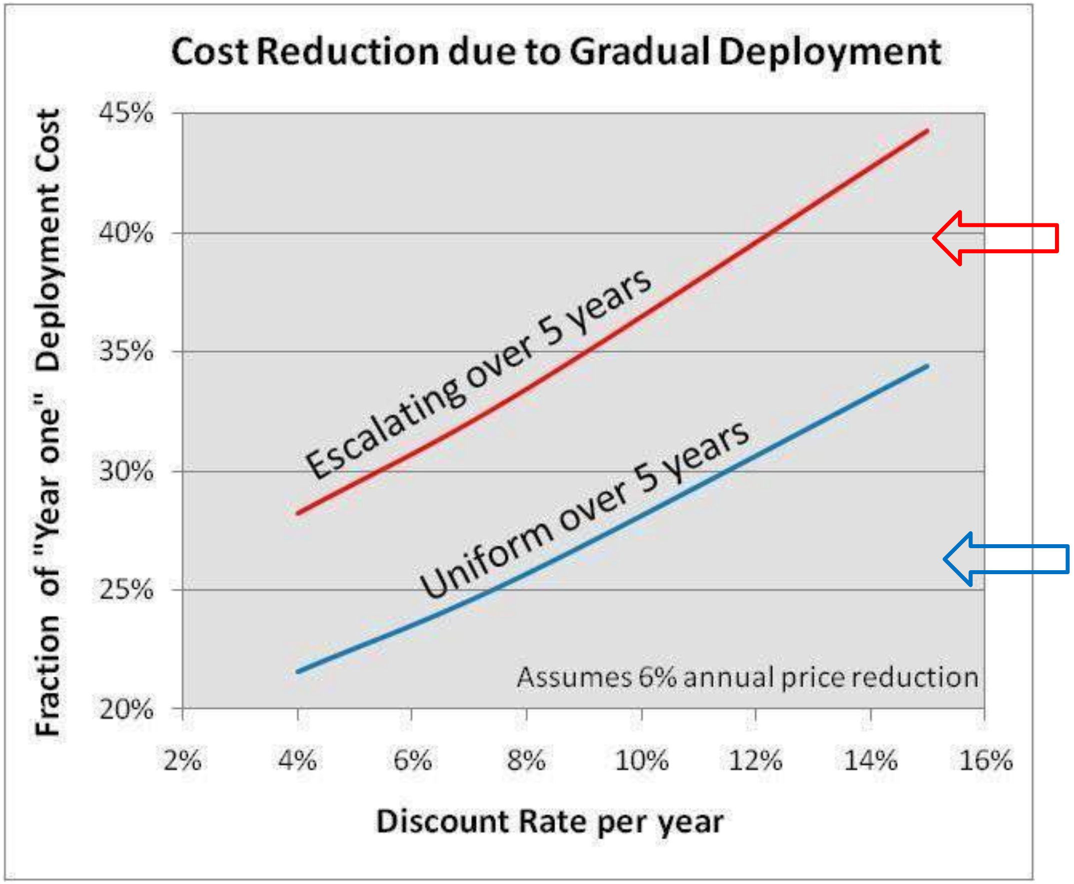
1. Smaller startup cost
2. Lower total cost if purchased and deployed gradually
3. Could become a "low-cost commodity" like small transformers
4. Higher market synergy with EV batteries
5. Lower line losses

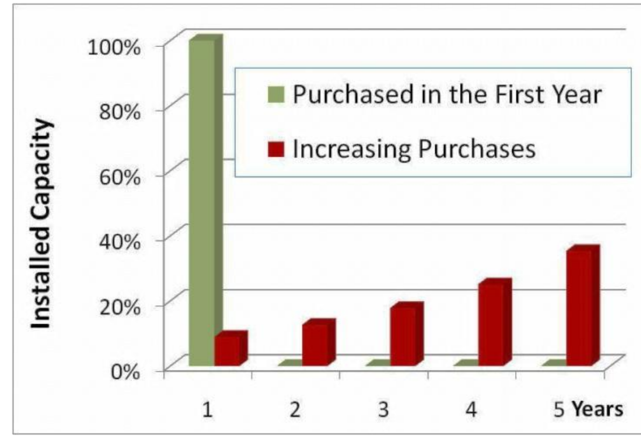
Operations

1. Better buffer for EV charging and Renewables *(except farms)*
2. Higher flexibility (to target where the problem is)
3. Higher electric service reliability (backup power)
4. Better solution for line congestion
5. Redundancy (unit outage is less critical to grid operations)

Gradual Deployment Saves 25% - 40%

Impact of Gradual Deployment on Present Value of Investment

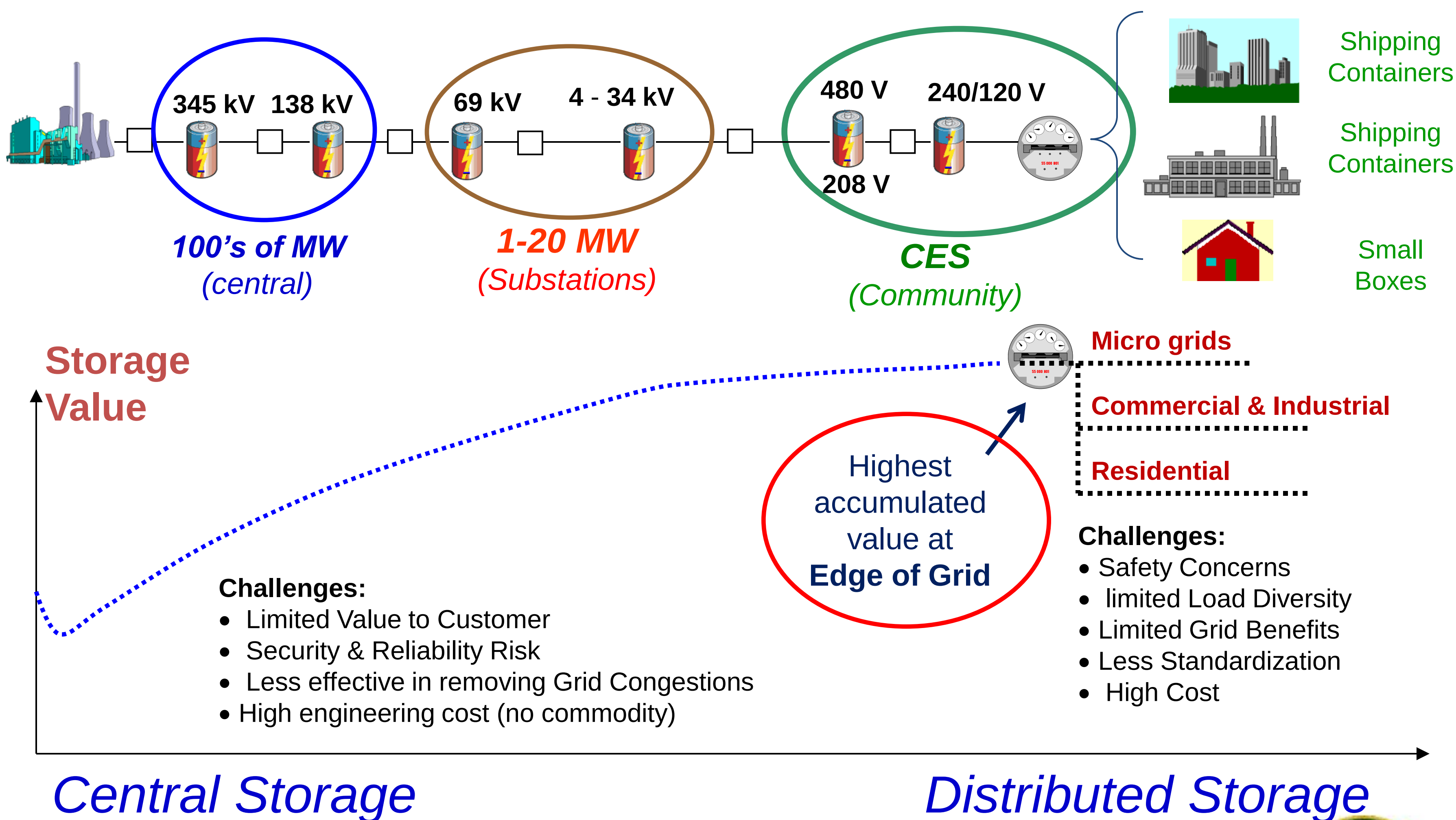




4. Merits of deploying storage at the "edge of the grid"

- Accumulated values (multiple applications)
- Issues of National Interest
- Larger storage options

Storage offers Value at All Grid Locations



Utility Storage Categories by Location

	Central	Substations	Grid Edge
Example	CAES, Pumped Hydro	Batteries & Non-cavern CAES	Shipping containers, CES
Power range	> 50MW	0.5 -50 MW	< 500kW
Main Applications	Upgrade Deferral, Ancillary, Spinning Reserve	**PLUS:** T&D Deferral, Renewable Integration, Backup	**PLUS:** EV Charging Buffer, Higher Service Reliability
Main Challenges	Siting, Permitting, Slow Installation Initial Capital		Aesthetics, Getting ahead of standards

The closer a storage is to the grid edge, the easier it would be to serve multiple applications (cumulative values)

A "National Interest" Perspective

Deployment near the grid edge is closer to the issues of National Interest (NaatBatt Report, 2012)

- Through Renewables & EV :
  - Cleaner Environment
  - Less Fossil Fuel
  - Less Oil Import

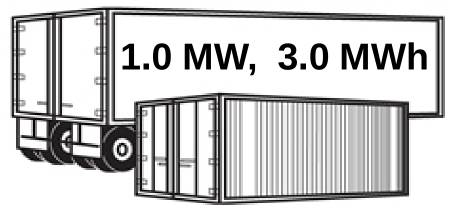
- Through the Grid :
  - Security
  - Stability
  - Reliability
  - Efficiency

5. Storage packages or "platforms" for the edge of the grid

- Plug & Play and Technology Neutral
- Subject to competition and standardization

Storage Packages for "Edge of Grid"

- Plug-&-Play
- Technology-neutral
- Low-Cost potential (competitive)
- Flexible



Courtesy of S&C and AEP

	Mobile Storage	CES
AC Power	1 MW - 2 MW	25kW - 75kW
Preferred Discharge Time (at rated power)	Up to 4 hours	Up to 3 hours
AC Voltage (US)	480V / 3 phase	240/120V
Preferred AC Efficiency	Over 85%	Over 85%
Islanding Capability	Yes	Yes

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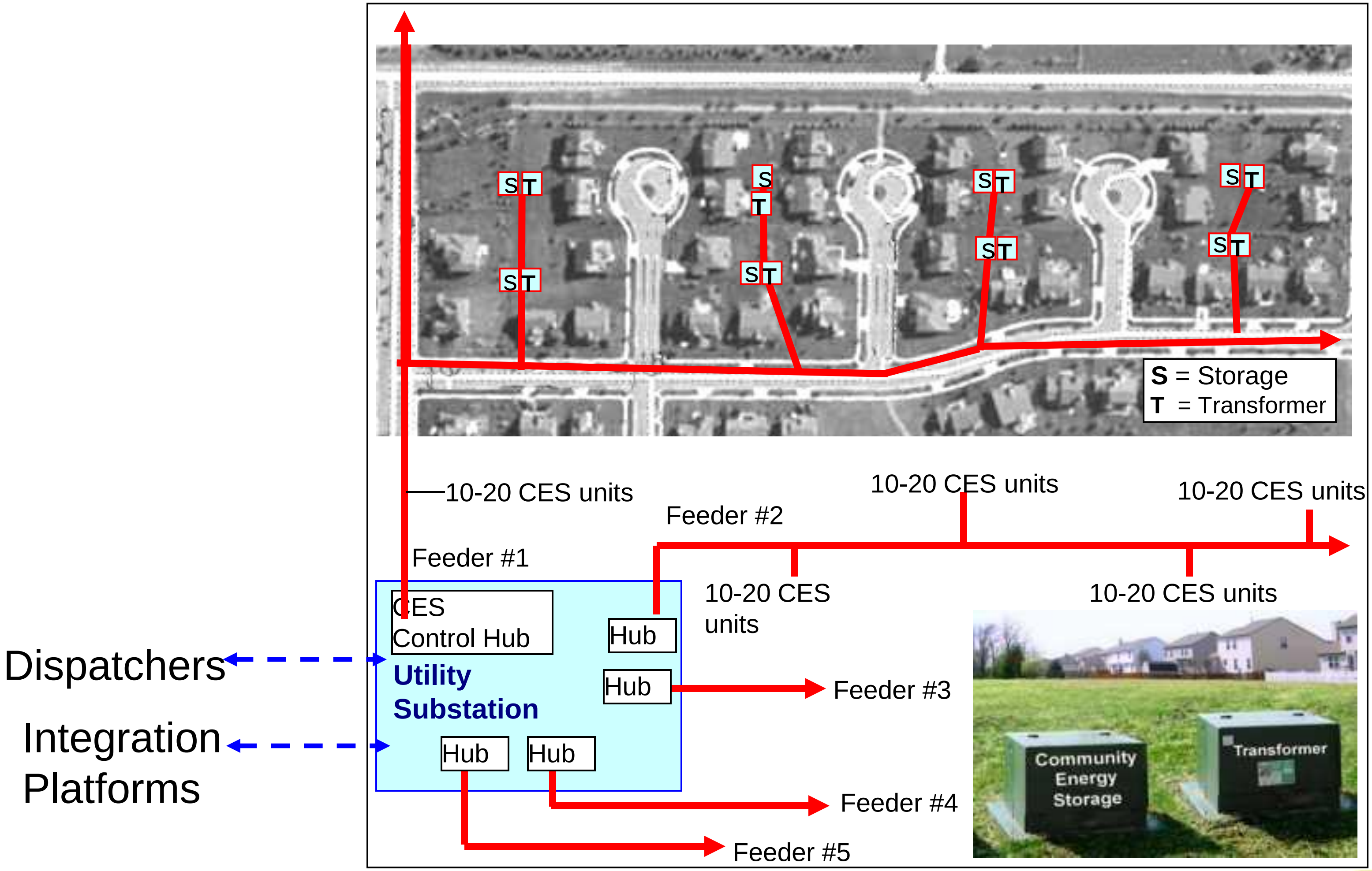
CES Deployment and Aggregation



CES Providers

Competition in Distributed Storage is starting . . .

S&C Electric

SOURCE: S&C

Beckett Energy Systems

SOURCE: Beckett

GreenSmith

SOURCE: GreenSmith

Demand Energy

SOURCE: Demand Energy

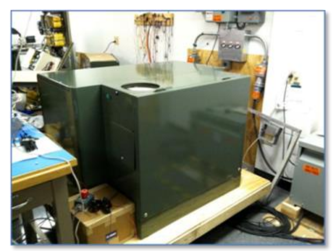
eCamion

SOURCE: Canada Newsline

ABB

SOURCE: ABB

GS Battery



SOURCE: GSB

PowerHub

SOURCE: PowerHub & SMUD

CES Providers - Continued

Competition in Distributed Storage is starting . . .

Fiamm	RedFlow	One Cycle Control	Silent Power
 SOURCE: Fiamm	 SOURCE: RedFlow	 SOURCE: OCC	 SOURCE: Silent Power

Utilities involved with CES

Over 60% apply CES to buffer the Renewable Impact

AEP AMERICAN ELECTRIC POWER

Xcel Energy

SMUD

Duke Energy

Hawaiian Electric Company

DTE Energy

Tucson Electric Power
A UniSource Energy Company

FirstEnergy

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

Richland Washington

GEORGIA POWER
A SOUTHERN COMPANY

SDGE connected
A Sempra Energy utility

BENTON P·U·D

SOUTHERN COMPANY

AVISTA Corp.

FRANKLIN PUD

aps

Idaho Falls Power

Consumers Energy
Count on Us

National Rural Electric Cooperative Association
A Touchstone Energy Cooperative

NVEnergy

Utilities outside USA

Canada	BC hydro REGENERATION 50
Dublin	SSE
Australia	Ausgrid
Italy	EDISON
South Korea	posco 포스코에너지
Toronto Hydro	TORONTO HYDRO

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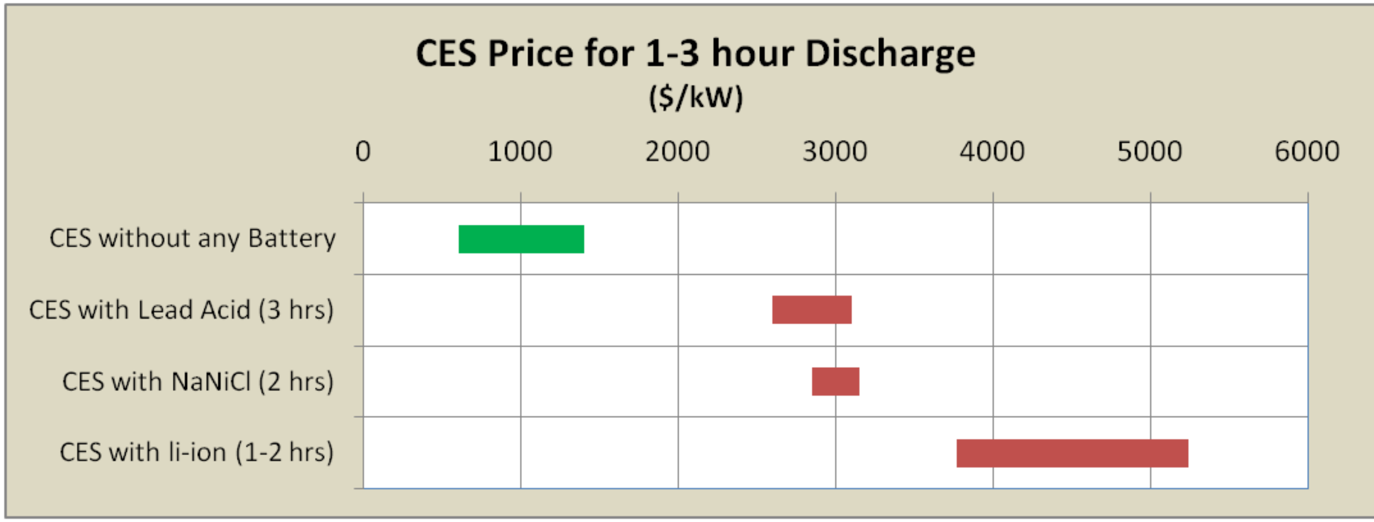
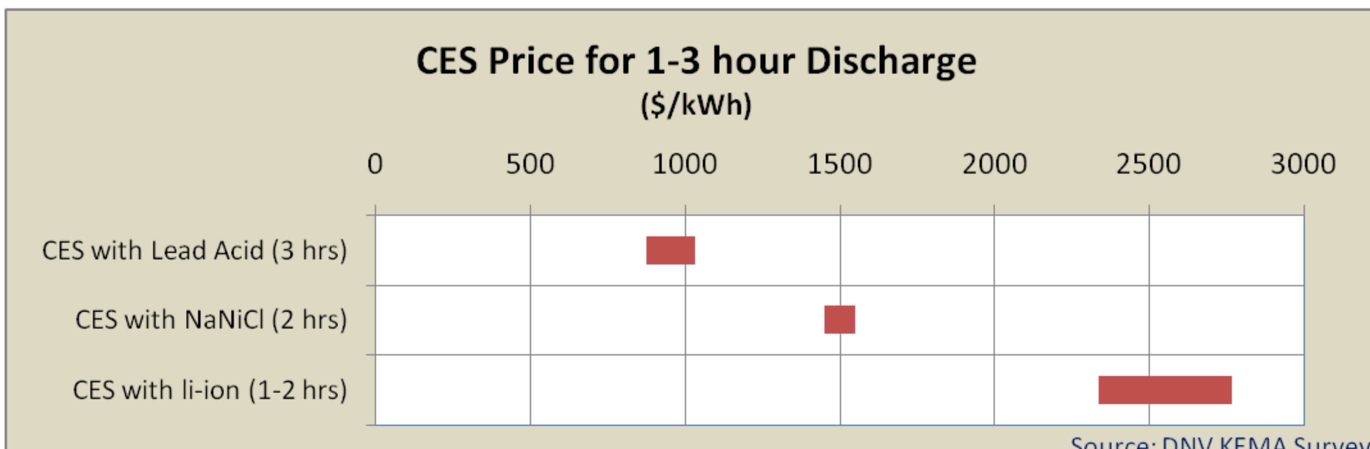
Installation of Distributed Storage

"Routine" plug-n-play practice reduces engineering costs

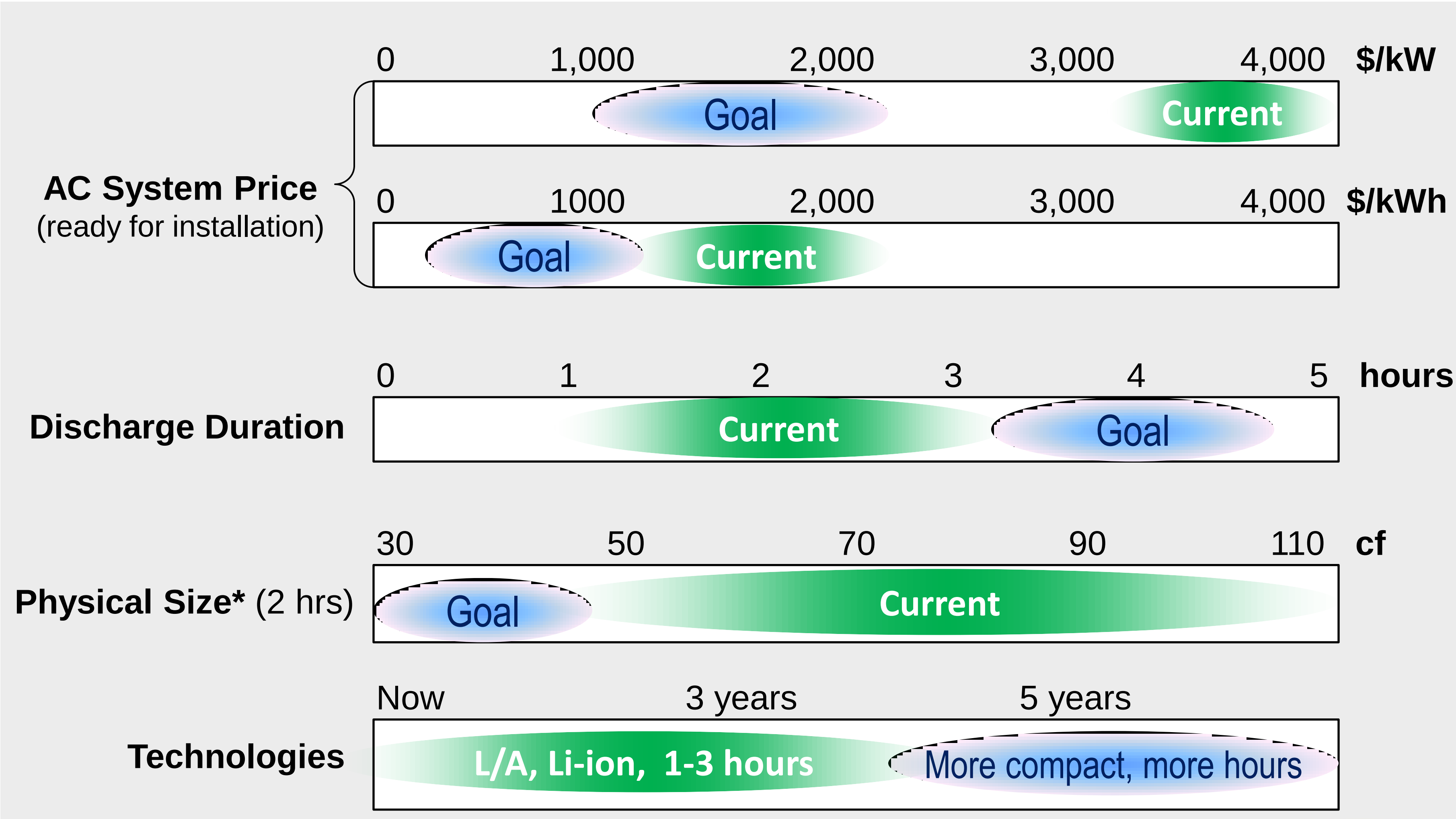
CES Price – 2012 and 2013 Surveys

25kW-100kW,
1-3 hours





Price & Performance Goals for distributed storage



* Above ground visible portion

6. Educational Tools for Selecting Feasible Storage Options

- Electricity Storage Association (ESA) is working on a comprehensive list
- ES-Select is available from DoE (Sandia lab)

ES-Select – A Storage Screening Tool

ES-Select™ has been created by KEMA and licensed to the Sandia National Laboratories for Public Use

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

INPUTS: Storage Applications and Location on the grid

OUTPUTS: Feasible Storage Options

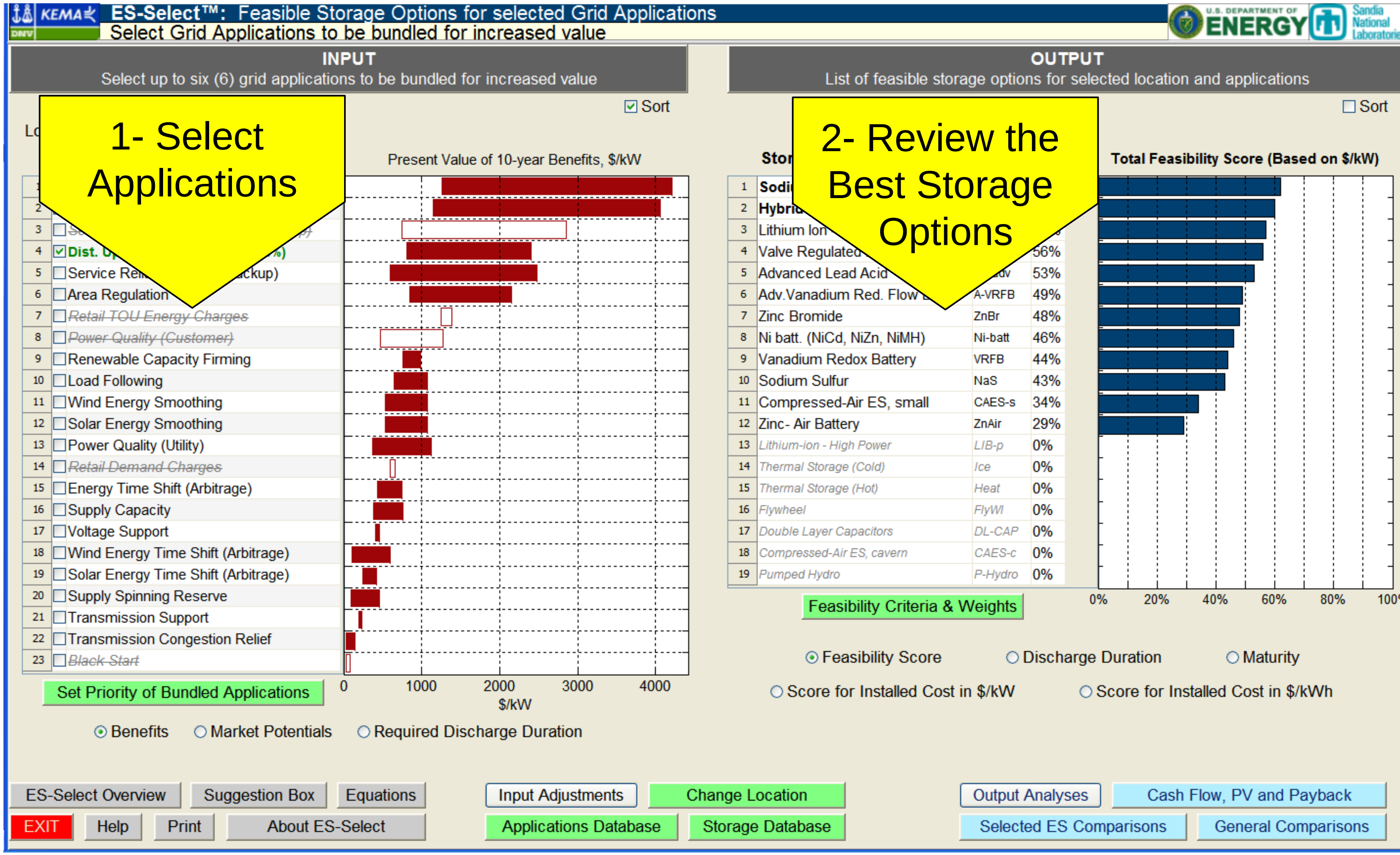
OTHER FEATURES:

- Assigns Relative Feasibility Scores to Storage Options
- Allows Bundling multiple Grid Applications
- Compares Storage Options
- Treats Uncertainties as Statistical Distributions

Funding was provided by the Department of Energy through Sandia National Laboratories and Pacific Northwest National Laboratory

Download from: www.sandia.gov/ess

ES-Select Home Page – two functions



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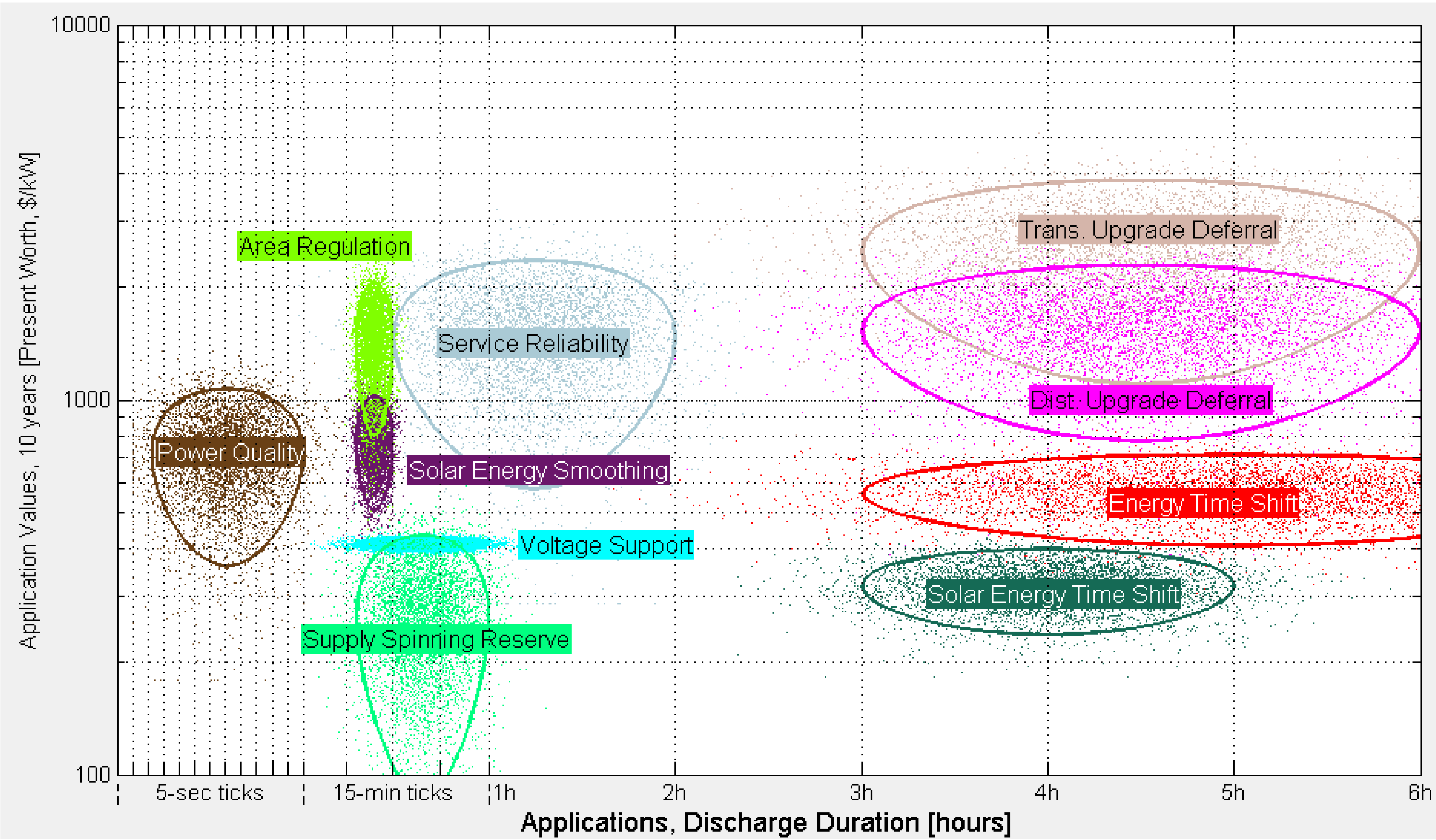
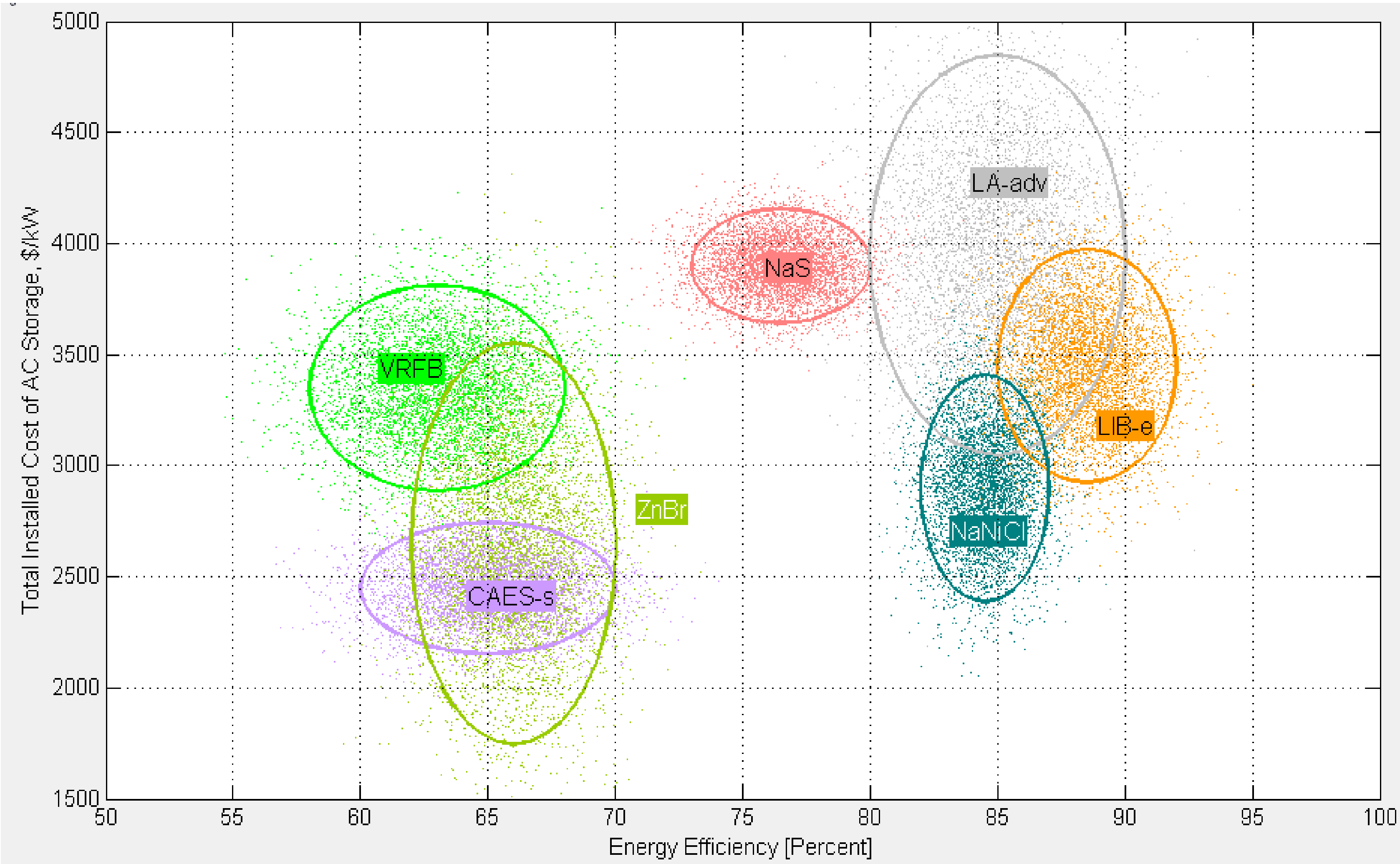
Grid Applications of Energy Storage



Comparison of storage options



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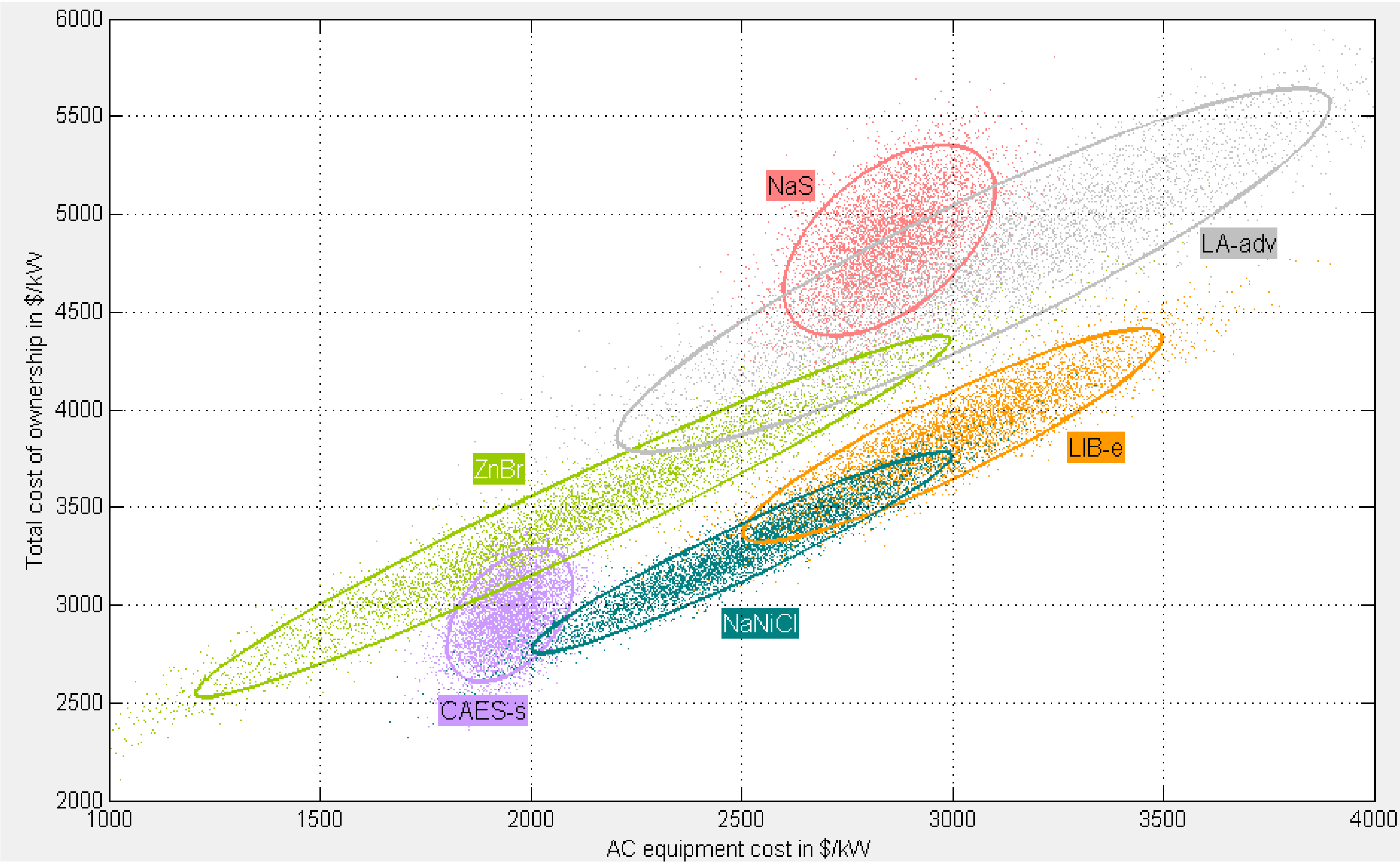
Comparison of storage options



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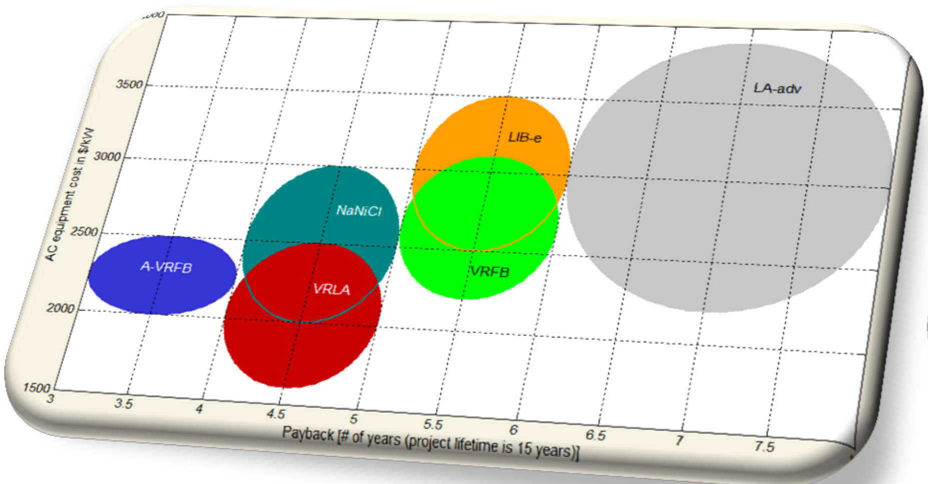
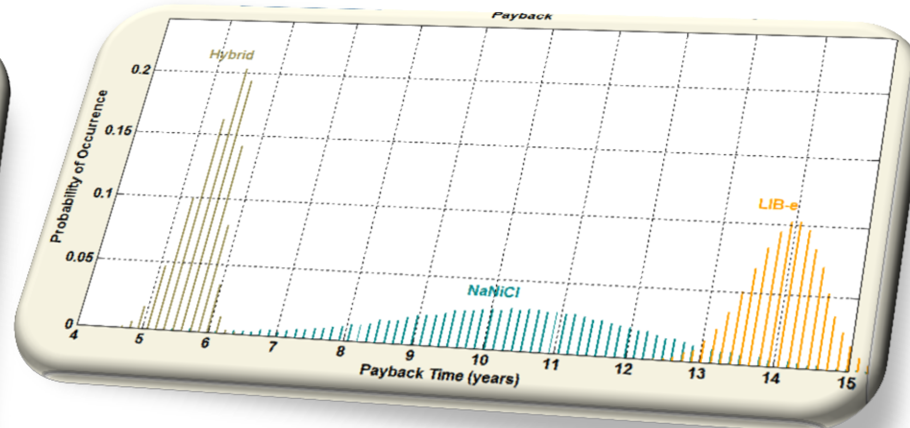
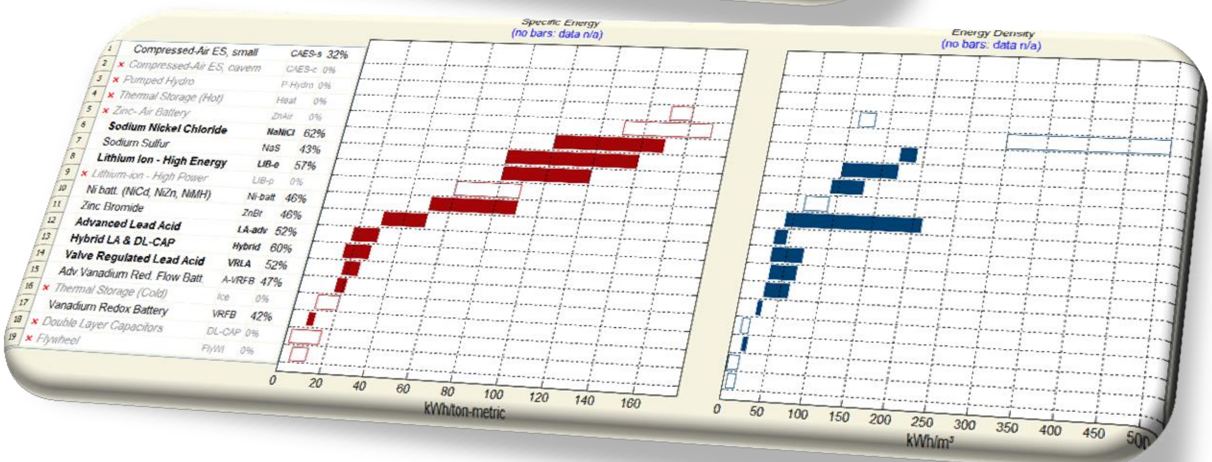
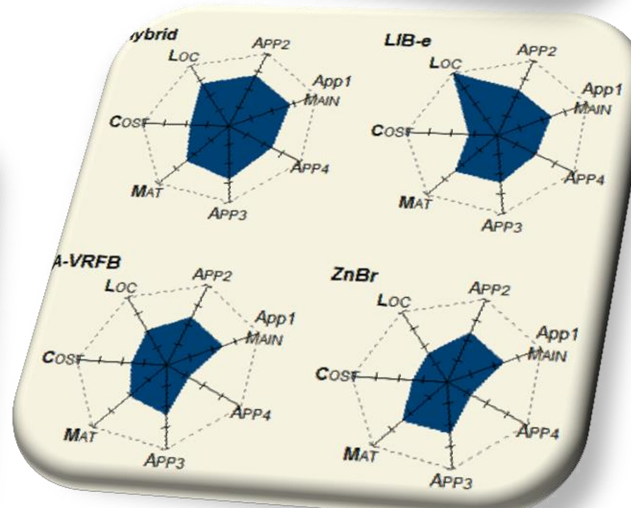
More Comparisons of storage options









Points to remember

1. Distributed Storage located at the edge of the grid could offer highest value through accumulated ‘stacked’ benefits
2. Market opportunities are driving the distributed storage to the customer side of the electric meter.
3. The competition for providing distributed storage solutions has already started but this promising sector of the market is still evolving
4. In the absence of standards, distributed storage is presently more expensive than central alternatives but option to deploy them gradually could make up for this difference.