Some Developing Technologies for Energy Storage in Power System Operation

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Grid Storage Requirements

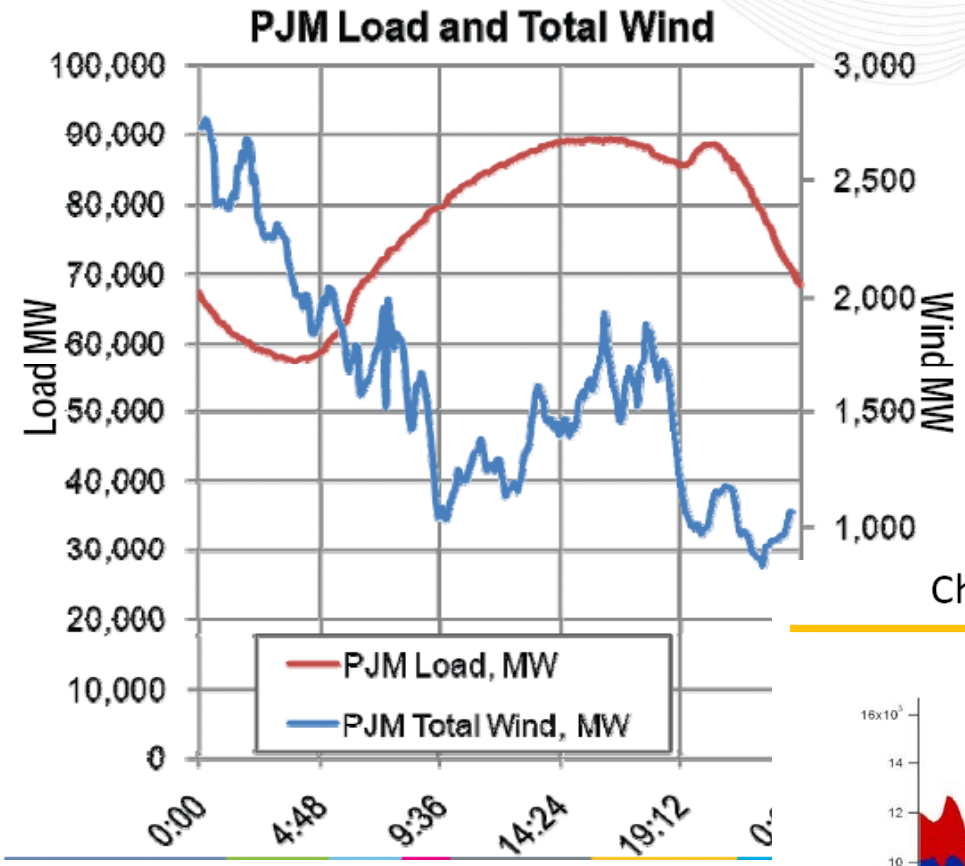
There are several reasons or benefits to adding storage to the "Grid". Some benefits accrue to the power generator, some to the distributor and some to the end user. Often, to make a business case for storage, several benefits must be agglomerated, but there is no clear single benefactor who is therefore willing to pay.

Generation Characteristics of AE sources are unique and potentially problematic in a couple of areas.

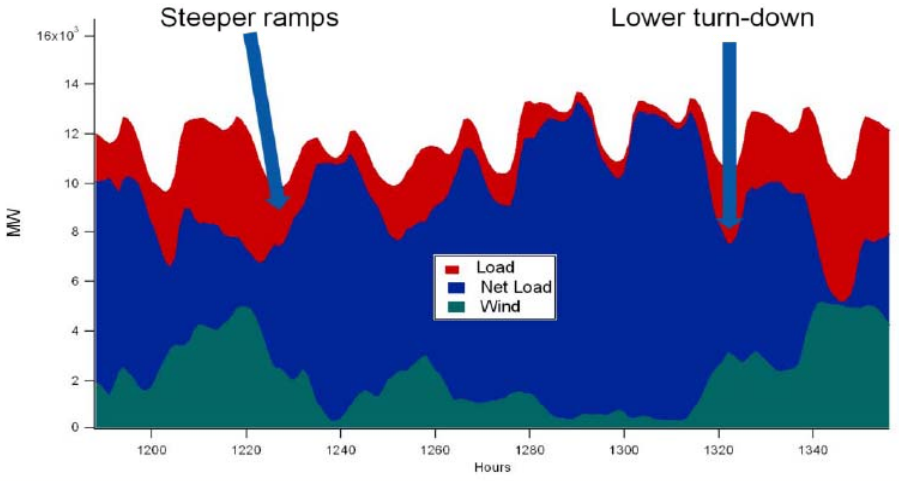
Benefits by Category

Category	Benefits
Electric Supply	1. Electric Energy Time-Shift 2. Electric Supply Capacity
Grid Operations (Ancillary Services)	3. Load Following 4. Area Regulation 5. Electric Supply Reserve Capacity 6. Voltage Support 7. Black Start
Grid Infrastructure	8. Transmission Support 9. Transmission Congestion Relief 10. Transmission and Distribution Upgrade Deferral 11. Substation Onsite Power
End-User	12. Time-of-Use Energy Cost Management 13. Demand Charge Management 14. Electric Service Reliability 15. Electric Service Power Quality
Renewables Integration	16. Renewables Energy Time-Shift 17. Renewables Generation Capacity Firming 18. Wind Generation Grid Integration

Wind Generation Characteristics



Challenges in integration of renewables



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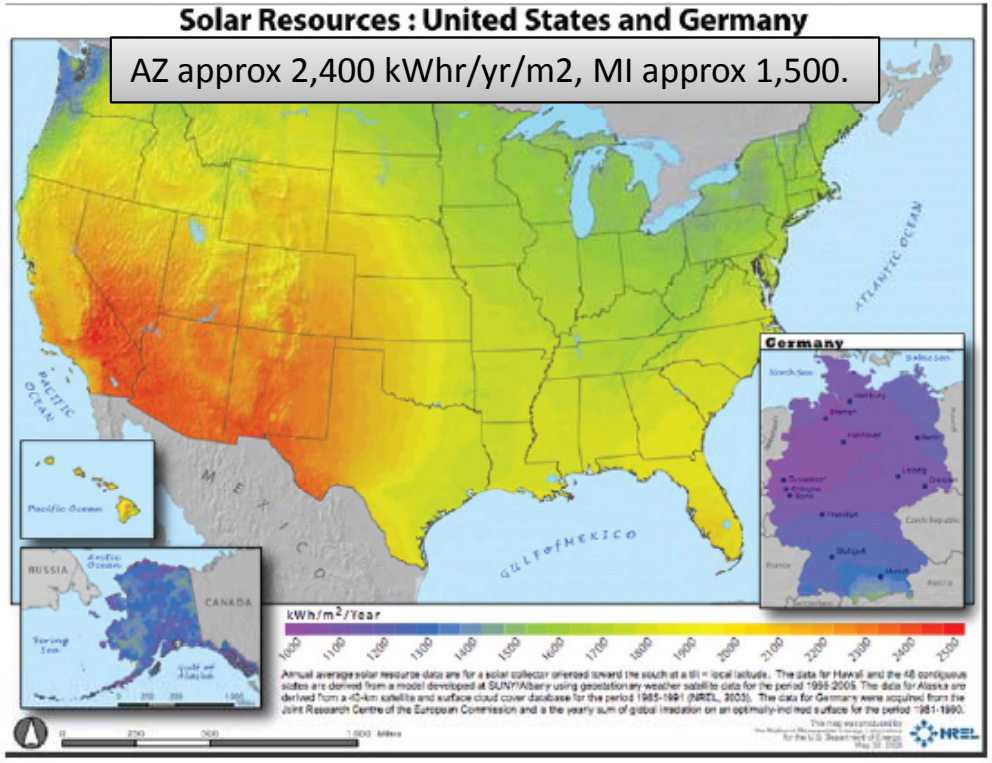
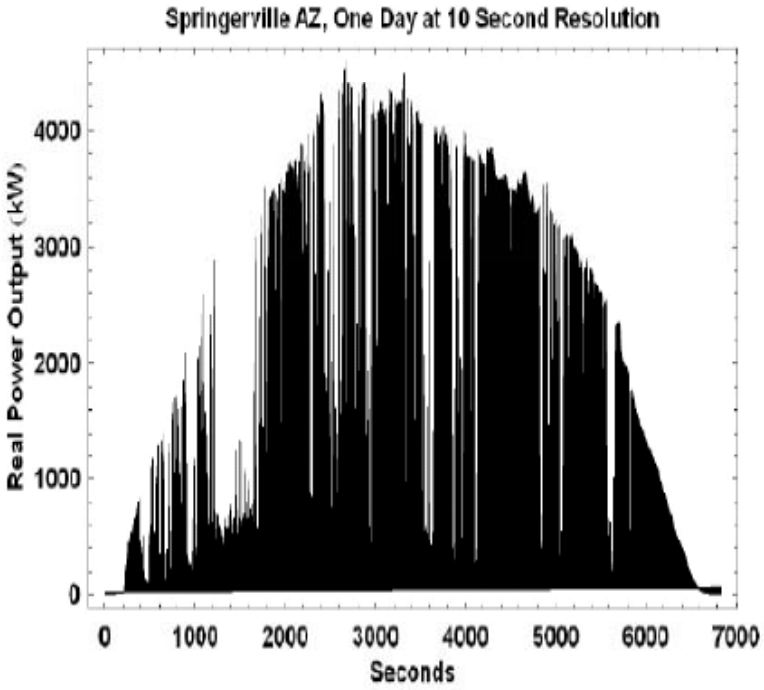
Source: Dr. Michael Milligan NREL / AWEA

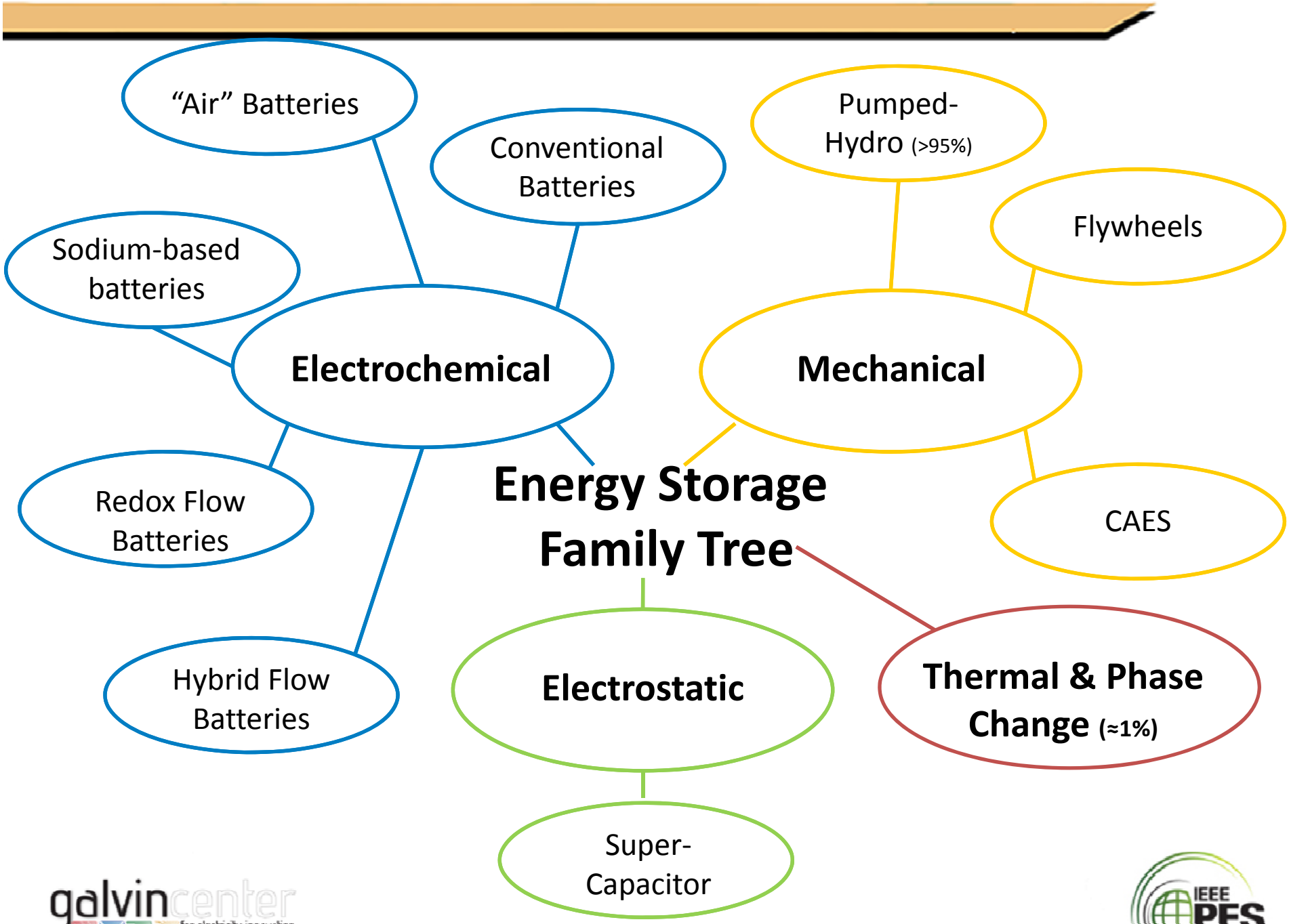
Solar PV Characteristics

- Current growth concentrated in Ca, Nv, Az, NJ
- Significant intermittency problems exist for PV

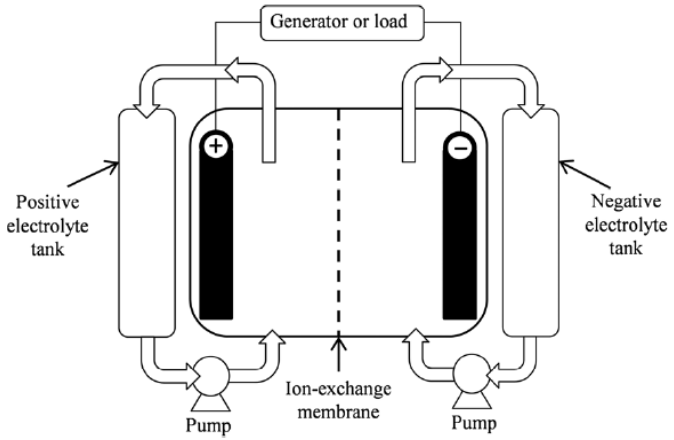




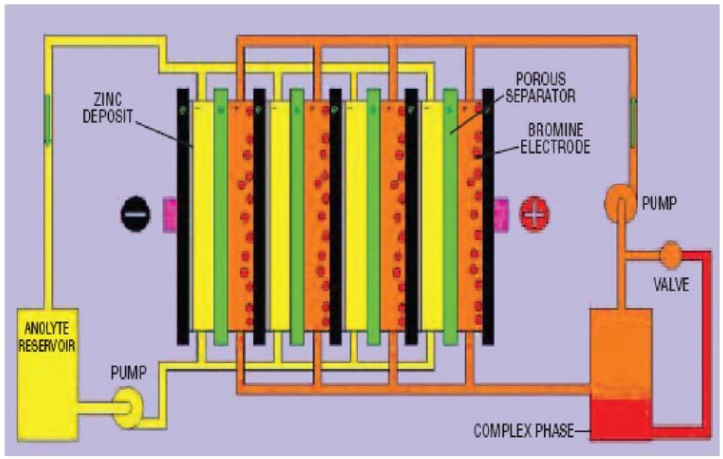
PV generation characteristics have some issues too :
- Time shifting a bit less severe, but still present
- Rate of change of generation much more severe.


"Air" Batteries
Conventional Batteries
Sodium-based batteries
Electrochemical
Redox Flow Batteries
Hybrid Flow Batteries
Pumped-Hydro (>95%)
Flywheels
Mechanical
CAES
Energy Storage Family Tree
Electrostatic
Super-Capacitor
Thermal & Phase Change (≈1%)

“Unconventional" Batteries

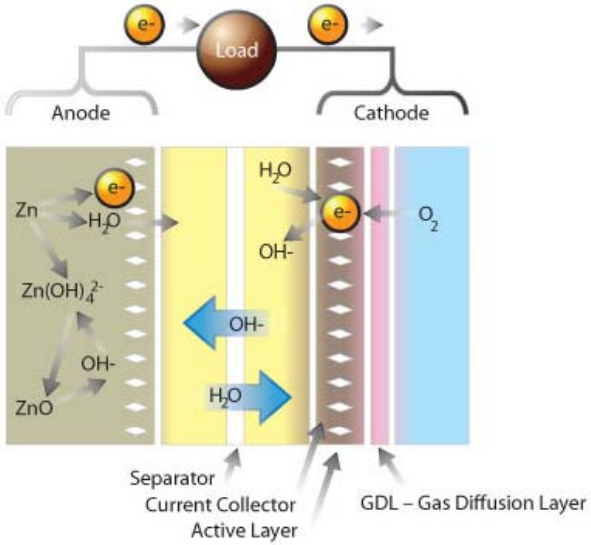


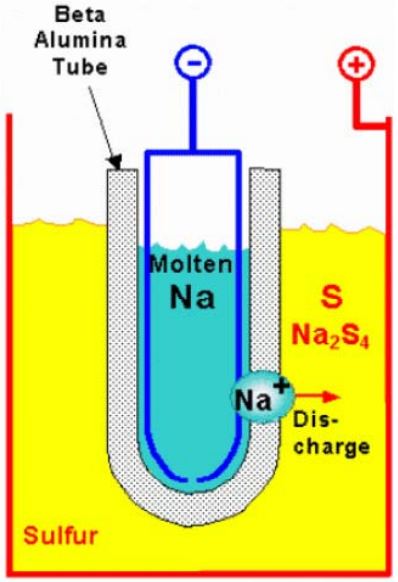
Redox Flow Battery: VRB, ICB



Hybrid Flow Battery: ZnBr, ZnCl, ZnMnO

Metal-Air Battery: Zinc, Lithium, Magnesium





Sodium-Based: NaS, Sodium-Ion, Sodium Metal-Halide (ZEBRA)

Source (Figures - clockwise): IJER 2012, Enervault 2011, DOE 2012, Zn-Air 2012

US VC Investments – Unconventional Batteries

2007-2012

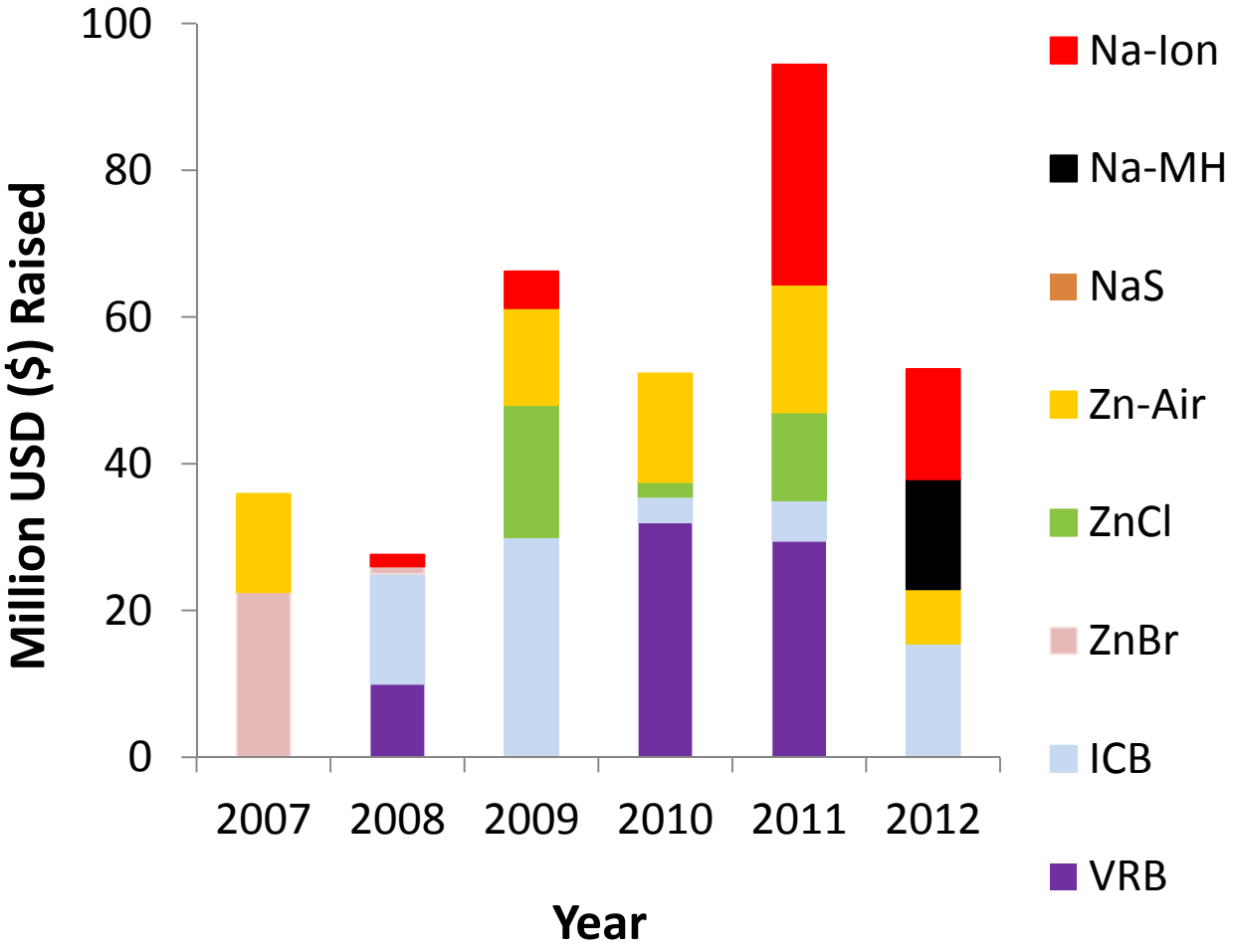
Investment **not** booming in US

Why? Utilities are not buying

Risk averse

Need viable business proposition

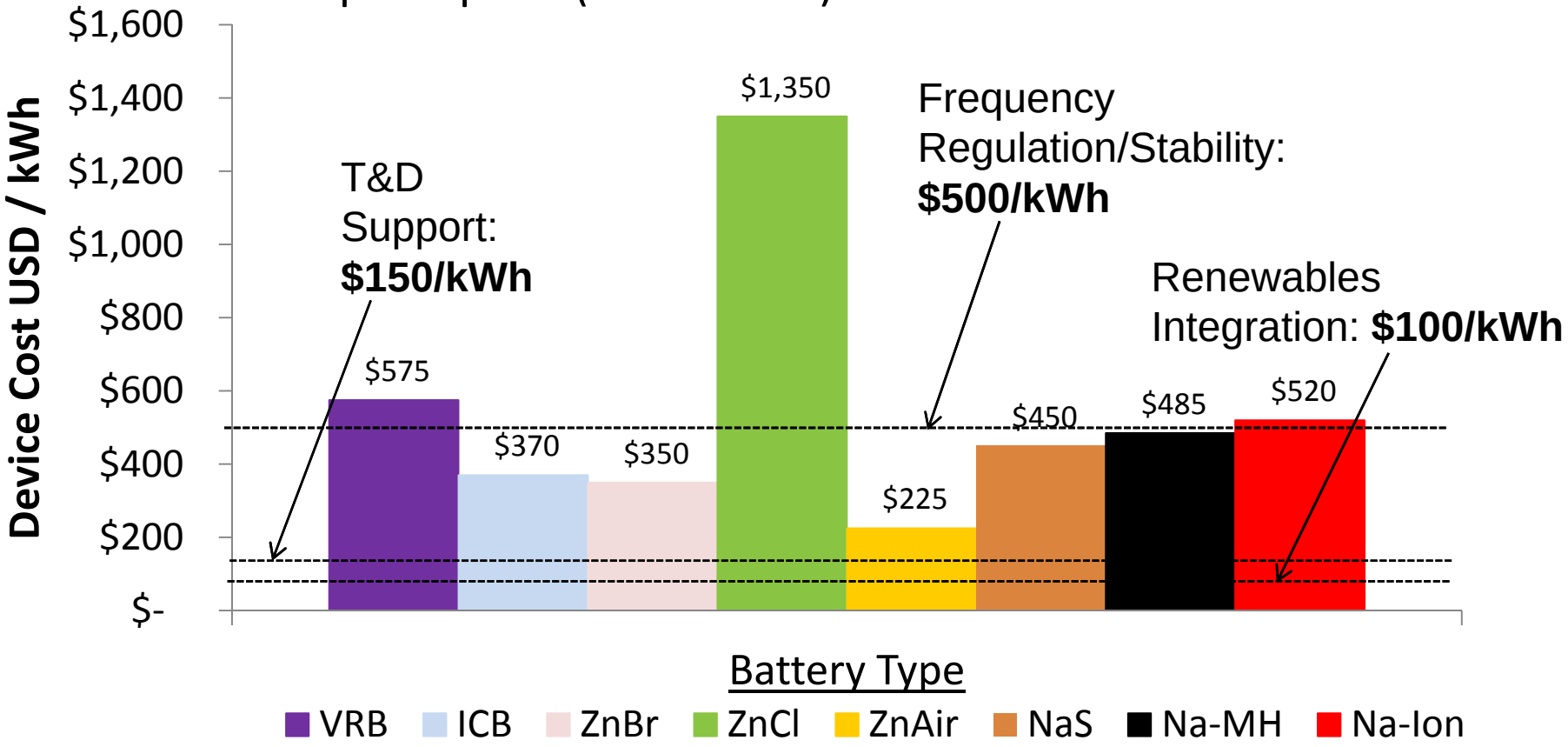
#'s incomplete without corporate investment



Source: Cleantech Group I3 database, 2012

Why Utilities Are Not Buying: Cost is Reason #1

Minimum adoption price (dotted-line)



Four Additional Factors

1. Reliability and safety concerns 2. Integration Cost 3. Competitive environment (natural gas prices) and 4. regulatory environment

Source: Cleantech Group, 2011, EPRI 2012, Boston Consulting Group, 2011

What's Next: Technology Roadmap

2012-2015		R&D Assignments
System Cost	Increase Round-Trip Efficiency (Above 75%)	• Model, optimize fluid flow through cell • Design more efficient thermal management • Improve quality of power conditioning system • Develop sensors to detect electrolyte impurities
	Increase Cycle Life (>4,000 cycles consistently)	• Improve membrane reliability, longevity • Optimize balance of plant (BOP) • Install automatic (de)activation of modules for changing loads • Design, test systems to optimize longevity • Reduce dendrite formation and impurities in electrolyte
	Reduce Price of Components	• Identify, test inexpensive electrode materials • Improve manufacturing efficiencies • Develop stronger, thermally tolerant resins • Test and validate less expensive technologies • Increase conductivity, reduce membrane resistance
System Reliability	Field Test & Collect Data	• Demonstrate different field applications • Test and validate prototypes of newer technologies • Increase safety, especially in hydrogen suppression technology • Design effective spill reduction safety systems for cells

Source: DOE 2011, International Journal of Energy Research, 2011, ARPA-E, 2012

What's Next: Key Market Drivers

2012-2015

Price & Reliability	• Capital cost and life cycle cost are currently uncompetitive • Data will be updated in 2013 DOE/Sandia Energy Storage Handbook
Utility Behavior	• Utilities' attitude toward large corporate batteries, like GE's Na-MH Durathon system, will dictate readiness of market • Selection of winners, losers will depend on utilities' models (EPRI)
Non-Storage Alternatives	• Natural Gas - Peaker plants w/ cheap nat. gas are more attractive • Energy Efficiency – Demand side reductions are less expensive • T&D Upgrade – Utilities can receive cost recovery from taxpayers
Domestic Policy	• Renewable portfolio standards (RPS) rise would increase demand for energy storage • Coherent energy storage policy would allow utilities to implement cost recovery from taxpayers, increase overall favorability
Foreign Competition	• Chinese investment in energy storage manufacturing will lower prices and compete with large American manufacturers and start-up companies

Source: DOE 2012, EPRI 2012, Cleantech Group 2011