U.S. DEPARTMENT OF ENERGY

Energy Storage Grand Challenge

South/Southwest Regional Workshop

MAY 19, 2020

U.S. DEPARTMENT OF ENERGY

Welcome and Opening Remarks

Sharon Wood

Dean of Engineering

University of Texas

Manufacturing and Supply Chain Recap

Diana Bauer

Energy Efficiency and Renewable Energy

U.S. Department of Energy

Manufacturing and Supply Chain

Purpose:

Build and diversify a strong domestic manufacturing base with integrated supply chains to support U.S. energy storage leadership.

Need:

To fully capture the benefits of energy storage technologies, the United States needs a robust manufacturing enterprise that can drive down costs, rapidly integrate and scale production of innovations, and reliably source critical materials and components.

Mission:

Pursue a coordinated strategy that prioritized and integrates investments to:

- Address major technical barriers in manufacturing of energy storage materials, components, and systems to lower costs and improve performance
- Accelerate scale up of manufacturing innovations from laboratory bench to demonstrate commercialization
- Enable reliable sourcing of critical materials and components across supply chains

Manufacturing and Supply Chain

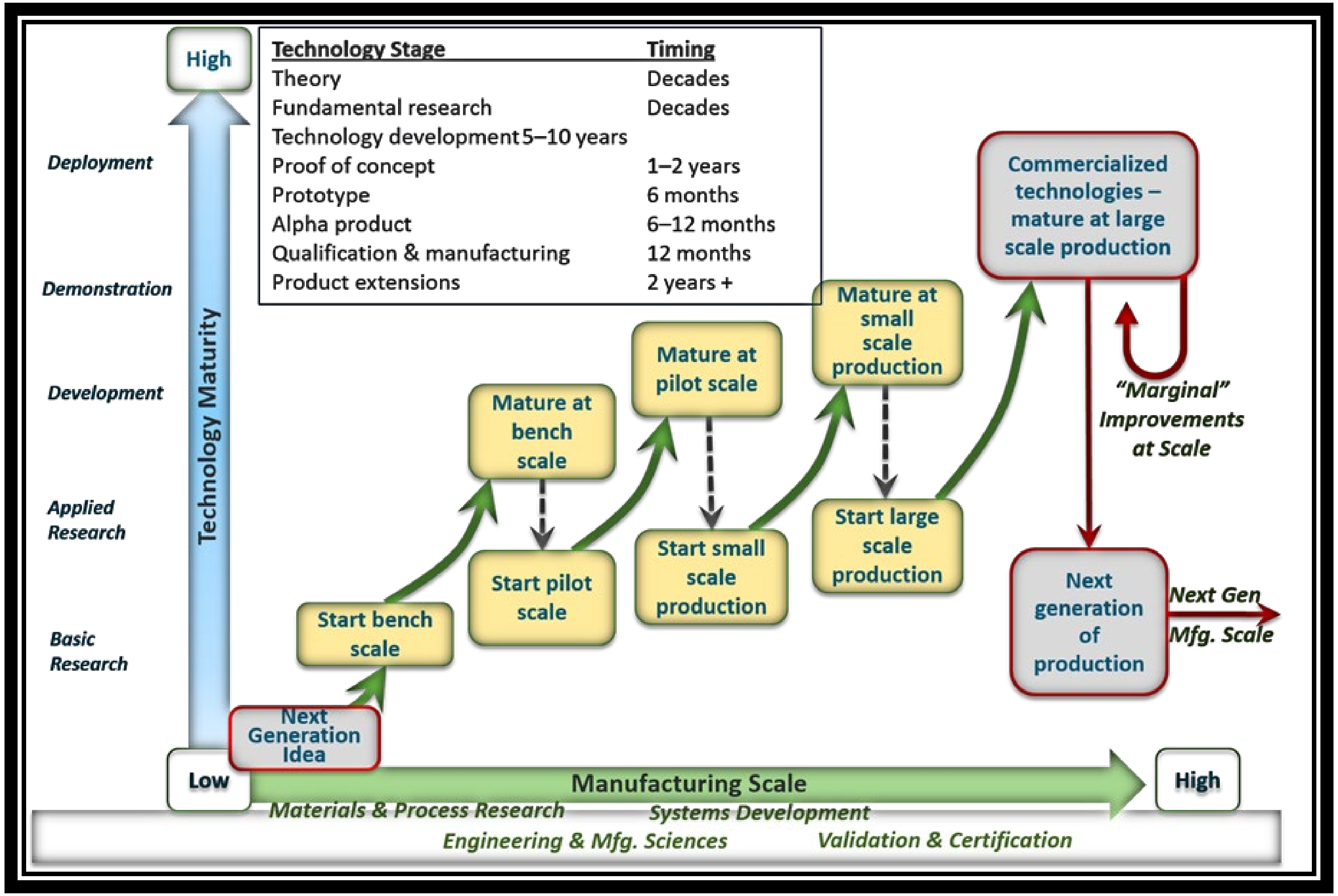
Manufacturing and supply chains are focused on "Make Here," addressing manufacturing scale-up, reduced domestic manufacturing cost, improved performance, and domestic supply chain resilience

Innovate Here

Make Here

Deploy Everywhere

Technology Maturity and Manufacturing Scale Pathways



Exploring Technologies and Supply Chains

Meeting the ESGC goal will require a combination of research and technology development across the manufacturing supply chain.

Raw materials → Refined materials → Component manufacturing → Energy storage system manufacturing → End user → Recycling/ Reuse/ Disposal

R&D AREAS

- Manufacturing process intensification
- Critical materials processing and separations
- Roll-to-roll manufacturing capabilities
- Membrane manufacturing processes
- New materials for harsh service environments and corresponding manufacturing processes

POTENTIAL TECHNOLOGIES

- Lithium-based batteries
- Non-lithium-based solid-state batteries
- Flow batteries
- Compressed air energy storage
- Pumped hydro
- Hydrogen generation and storage
- Synthetic fuels (e.g., synbiogas)
- Thermal energy storage
- Combined heat and power

March Manufacturing Webinar

Breakout Sessions:

- Electrochemical energy storage
- Flow batteries
- Chemical energy storage
- Thermal energy storage
- Industries as storage

Identified cross-cutting manufacturing challenges:

- Membranes
- Bipolar plates
- Hybrid systems
- Grid integration technologies, such as power electronics
- Raw material availability
- Translating low TRL innovations to high TRL prototypes

Addressing Technical Barriers in Manufacturing

CHALLENGES

1. **Lowering manufacturing cost for components**
   Membranes
   Anodes
   Cathodes
   Electrolyzers
   Materials
   Containment Structures
2. **Reducing manufacturing barriers to improve performance**
   Advanced Materials
   Bipolar Plates
   Heat Exchangers
   Others

ACTIONS

1. **Technology assessment studies** for energy storage and related technologies
2. **R&D investments across multiple offices** to improved performance and lower the cost to manufacture for materials and components

Accelerating Manufacturing Scale-Up

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Technical challenges to scaling up and integrating emerging technologies from lab to prototype to commercialization

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Scale up actions focused on:

1. Thermal storage
2. Li-based batteries
3. Grid scale deployment

Improving Critical Materials Supply Chain Resilience

CHALLENGE

Fragmented supply chain for lithium and cobalt in batteries

ACTIONS

1. R&D on lithium processing and separations innovations
2. R&D on batteries with reduced cobalt requirements
3. Innovations in battery recycling

Preview of RFI Questions

- What are the most pressing challenges for scaling up the manufacture of energy storage systems?
- What are the most pressing challenges to maintaining a strong, fully domestic supply chain for energy storage?
- What materials or components represent the largest barriers to directly lowering the cost of production for total energy storage system?
- Which manufacturing methods would provide the greatest impact for energy storage technology?
- What energy storage manufacturing and supply chain policies would help establish and maintain manufacturing capacity within the U.S.?

Keynote

Tom Pierpoint

Vice President, Electric System Engineering and Technical Services

Austin Energy

Questions

Please submit your questions
in the Chat box to the host. Reference the speaker or topic.

Panel 1: 2030 Goals and Vision

Moderator

Ralph Masiello, Quanta Technology

Panelists

- Mark Rothleder, California ISO
- Thomas Overbye, Texas A&M University
- Venkat Banunarayanan, NRECA
- Efraín O'Neill, Agustín Irizarry, Univ. Puerto Rico, Mayagüez
- Bob Cummings, NERC

Four Questions

1. What is your vision for electric infrastructure in 2030?
2. What kinds of “boundary conditions” for today’s electric power system could increase in frequency by 2030?
3. What is your vision for the role that energy storage will play?
4. What are the gaps between where we are today and where we want to be in 2030?

Vision for Electric Infrastructure in 2030

What is your vision for electric infrastructure in 2030?

- Adaptation to accommodate high renewables & climate change (flexibility, G-T-D coordination, market design)
- Increased resilience (weather, natural disaster, cyber, physical attack)
- Smart grid (sensors, analytics, automation, IOT, demand side participation)

What is your vision for electric infrastructure in 2030?

Overbye

- My vision is for us to develop a truly resilient and sustainable electric infrastructure
- My concern we avoid thinking too narrowly about the future. Quoting Winston Churchill:
  - "It is wise to look ahead, but difficult to look further than you can see"
- From a research perspective we need to focusing on a wide range of possible scenarios:
  - We need to future-proof the grid so regardless we're prepared
  - A focus needs to be on preparing for High Impact, Low Frequency (HILF) events (Black Sky Days)

What is your vision for electric infrastructure in 2030?

Rothleder

- Aggressive renewable energy goals

33% by 2020 → 60% by 2030 → 100% by 2045

- Deep greenhouse gas (GHG) reduction goals

2020 Target		2030 Target		2050 Target
Reduce GHG emissions to 1990 levels	→	40% below 1990 levels	→	80% below 1990 levels

- Robust electric vehicles goal: 5.0 million by 2030, $2.5B investment in new charging stations

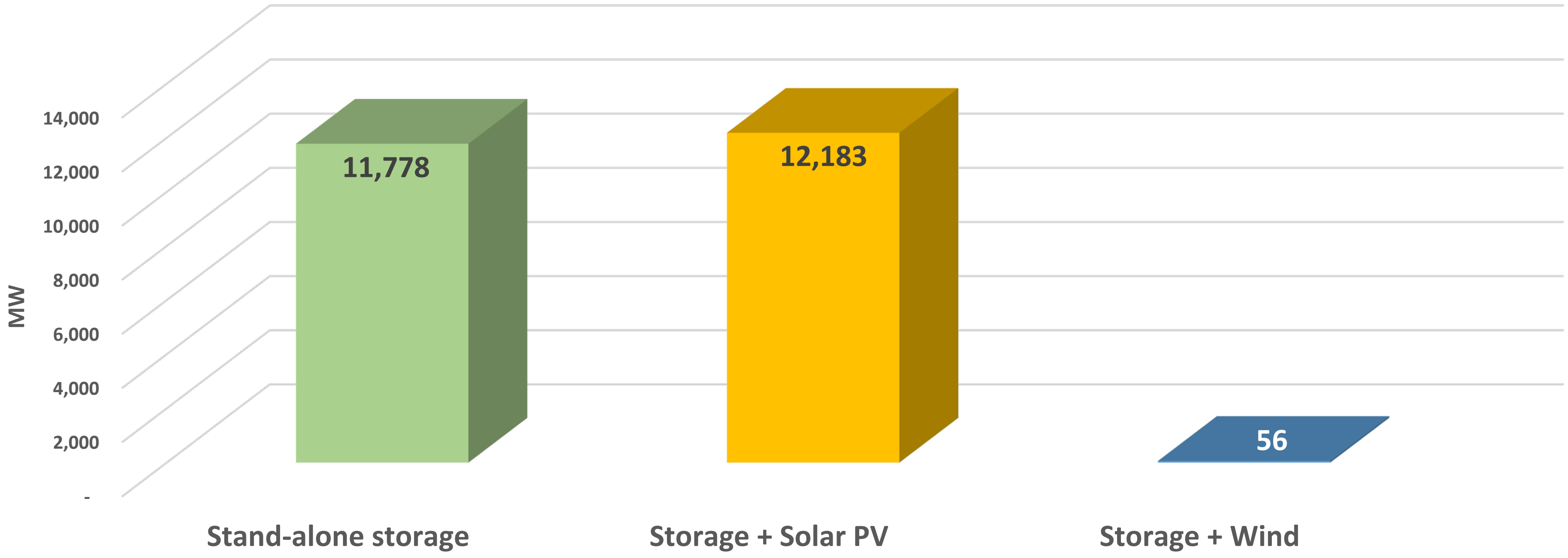
- 10,000 MW of distributed generation by 2021; 1.3 GW of battery storage by 2024

Decarbonization is creating opportunities to develop a high renewables and high DER energy service industry.

What is your vision for electric infrastructure in 2030?

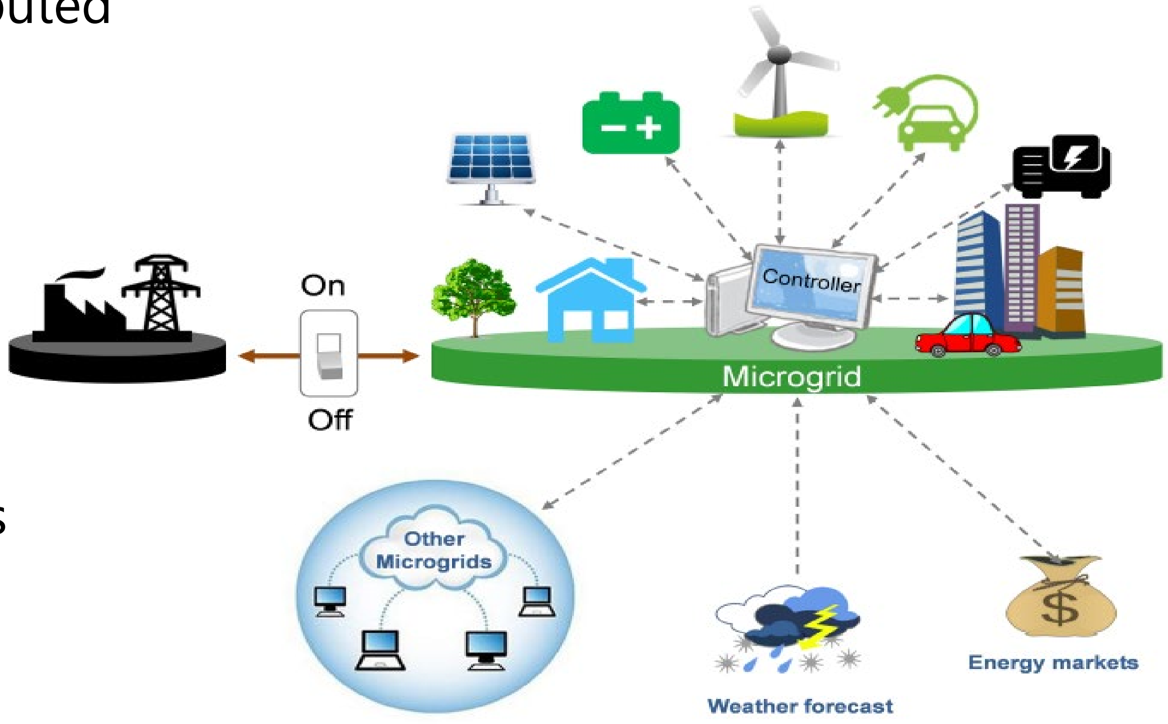
Rothleder

Types of Energy Storage Projects Active in CAISO's Generation Interconnection Queue (as of September 05, 2017)



What is your vision for electric infrastructure in 2030? Banunarayanan

- Agile, resilient grid
- Flexible, increasingly asynchronous distributed generation and load
- Digitalization of grid assets and information
- Automation of grid operations
- Data-driven decision making
- Increased use of data-driven technologies
- Increased consumer involvement



What is your vision for electric infrastructure in 2030?

O'Neill

A more distributed power system in island, coastal, and remote communities.

- Widespread use of onsite renewable energy to yield LOCAL economic, social and environmental benefits
- Solar communities and community microgrids
- A new role for conventional power system components
- Distributed energy for local resiliency
- Electric vehicles
- A trained workforce and informed citizenry

E. O'Neill, A. Irizarry, UPRM

What is your vision for electric infrastructure in 2030?

Cummings

- There will be a bulk power system: large cities cannot self-sustain on renewables
- Storage needed to optimize use of renewables
- Fast charging Electric Vehicles: distribution and transmission systems not ready to support
- Microgrids hold promise but are one-off designs: need to be predictable
- Distributed energy for local resiliency: storage near critical load (medical, fire, sewage, water supply)
- Re-thinking of supply to remote communities: microgrids, modular system designs
- A more brittle grid: little synchronizing torque to keep it together

Boundary Conditions

What kinds of “boundary conditions” for today’s electric power system could increase in frequency by 2030?

- Flexibility, controllability, stability
- Asset condition – age, vulnerability
- Complexity
- Adaptation – workforce, markets, systems

What kinds of “boundary conditions” for today’s electric power system could increase in frequency by 2030? Banunarayanan

- Cyber-physical safety and security
- Workforce sufficiency – especially in field operations
- Extended duration event-driven disruptions
- Increasing dependency and interdependency of infrastructures
- Community resilience
- A grid with time-varying asynchronous generation and load

What kinds of “boundary conditions” for today’s electric power system could increase in frequency by 2030? Rothleder

- Managing daily flexibility
- Manage multi-day weather events
- Ensuring sufficient capabilities exist to manage the grid
- Ensuring reliability and resilience
- Leveraging and optimizing new technologies
- Regional collaboration and coordination

Boundary conditions in the Caribbean

O'Neill

After a disaster you rely on your community

- Hurricanes and earthquakes
- Humid, hot, corrosive, drought conditions (in some areas), strong/extreme winds (storms)
- Dated, conventional, low-inertia power systems
- Resilience is not valued properly
- Context and solutions are different from continental locations
  - Market pushes unsuitable "solutions", causing implementation problems, maintenance issues and confusion
  - "Poison the well" effect for other sustainable solutions

Oases of Light deployed after hurricane María
https://epics.ieee.org/solar-power-aid-puerto-rico/

E. O'Neill, A. Irizarry, UPRM

What kinds of "boundary conditions" for today's electric power system could increase in frequency by 2030? Cummings

- Daily Use:
  - Security-constrained dispatch down to feeder levels: new multi-layered dispatch controls needed
  - Potential control interaction conflicts resulting in oscillatory system behavior
  - Potential conflicts between economics and reliability
- To accommodate "100%" renewables:
  - Need to rethink power supply from bottom up: integration of multiple technologies that work together, storage, wind, solar
  - Sufficient reserves must be built-in: system resource additions have to be modular
  - Ability to ride-through multi-day storage of energy needs will be essential
- For resiliency, emergencies, and disaster recovery:
  - Location of storage systems next to critical loads (water, sewer, emergency services, communications centers) with adequate capacity to run them for days
  - Storage system will have to adaptive; able to change charge/discharge strategies
  - Fly-in emergency power supplies, fuel supplies, and communications equipment (cell towers): standardized connection mechanisms will be necessary
  - Lack of spare parts and knowledge to rebuild after can be problems

What kinds of "boundary conditions" for today's electric power system could increase in frequency by 2030? Overbye

- It is likely we will be dealing with a much more complex electric grid infrastructure and control systems:
  - A highly optimized grid may not be a highly resilient grid
- The number, type and complexity of the devices connected to the grid is likely to increase
- Determining and mitigating hidden failure modes will be a key research challenge
- The coupling of infrastructures, including electric and transportation is likely to increase

Vision for Energy Storage Role

What is your vision for the role that energy storage will play?

- Operations and markets
- As a non-wires alternative
- Resilience and reliability
- Long term resource adequacy

E. O'Neill, A. Irizarry with collaboration from E. Rivera, G. Cosme, E. Parés

What is your vision for the role that energy storage will play?

O'Neill

In 2030

- Storage for control in microgrids and other distributed applications
- Excess storage could provide frequency control and perhaps some ramp control services:
  - Welcomed in a grid with less rotating inertia
- Essential to increase resilience in the Caribbean:
  - Community microgrids
  - Emergency energy hubs

Game changer now

- PR residential cost ~ 20 cents/kWh
- PV + storage already at grid parity
  - PV + batteries for standalone systems

E. O'Neill, A. Irizarry with collaboration from E. Rivera, G. Cosme, E. Parés

What is your vision for the role that energy storage will play?

Cummings

In 2030

- Non-traditional – charging in middle of day when solar available to charge
- Co-located with renewables or loads – avoid duplicative infrastructure
- High ramp rates for morning and evening net load ramps
- Load following/balancing, frequency control, frequency response, voltage support
- Get away from having to take in every renewable MW produced

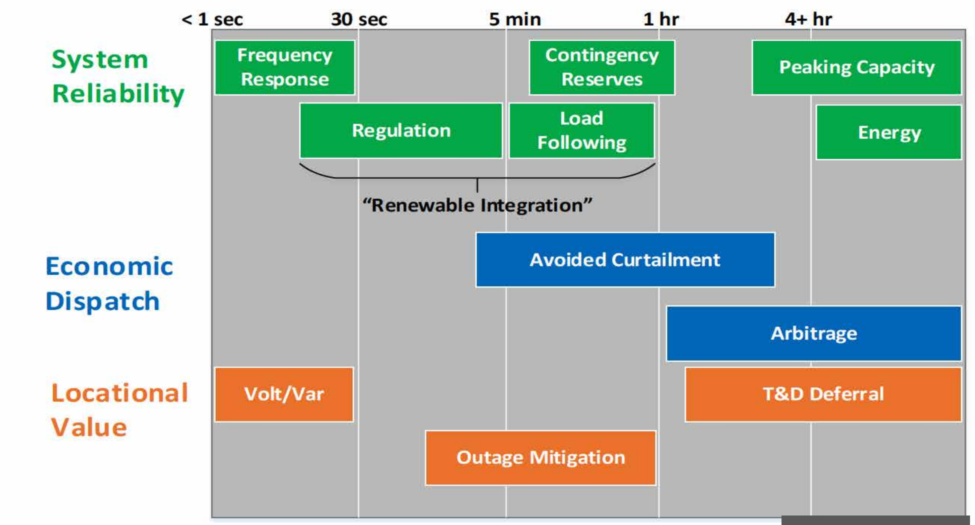
Game changer now/near future

- Key part of Distributed Energy Resource Management System tools
- Dispatchable to match demand
- Modularization
- Need – Utility-scale storage to meet needs of Duck Curve ramps

What is your vision for the role that energy storage will play?

Banunarayanan

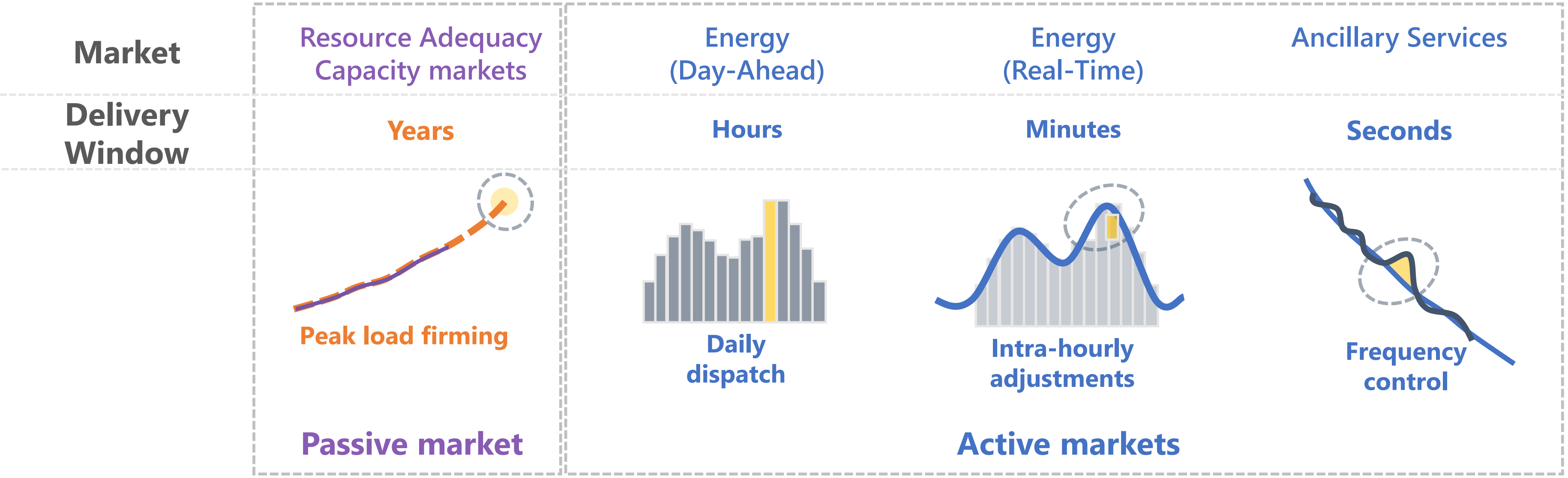
- Add flexibility to the grid
- Provide hedging for power supply constraints
- Provide resiliency to communities
- Enable integration of intermittent generation sources
- Enable optimization of grid performance



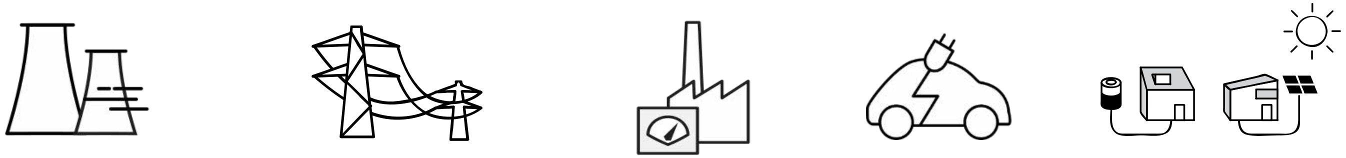
Source: EPRI

What is your vision for the role that energy storage will play?

Rothleder



Additional use-cases will add complexity and value



What is your vision for the role that energy storage will play?

Overbye

- Fast responding, higher capacity storage can play many positive roles:
  - From reducing frequency variations and damping oscillations to helping match supply and demand allowing for more renewable generation
- However, a concern is behavior during the outlier conditions in which the storage capacity is at a limit
- We could also run a risk during extreme event of a reduction in other traditional forms of energy storage associated with fossil fuels (e.g., coal piles, natural gas and gasoline storage)

Energy Storage Gaps: Now to 2030

What are the gaps between where we are today and where we want to be in 2030?

- Technology – performance, cost
- Markets and Operations – business models and operational tools
- Analytics – planning, economics
- Regulatory – business models, asset classification
- Practicality – workforce training, standards

What are the gaps between where we are today and where we want to be in 2030?

Rothleder

- Cost, affordability
- Optimization techniques to effectively and efficiently use storage
- Diverse set of storage technologies to cover diverse system needs
- Experience and learning at scale
- Harmonization of regulatory polices

What are the gaps between where we are today and where we want to be in 2030?

Overbye

- A societal challenge is figuring out exactly where we want to be, taking into account inherent technical limitations
- There are many economic considerations including fairness and the decreasing value of storage as more is available
- From a systems perspective a key operational challenge is how to effectively control the storage
- A key design (i.e., planning) challenge is how to model a system with lots of variable generation coupled with lots of storage, particularly hidden failure modes

What are the gaps between where we are today and where we want to be in 2030?

Banunarayanan

- Understanding opportunities and limitations of energy storage
- Infrastructure needs for optimizing large scale distributed energy storage
- Treatment as a grid asset in planning and operations
- Transparency in cost and performance
- Maturity in market offerings and project experience

What are the gaps between where we are today and where we want to be in 2030?

O'Neill

- Policy, regulatory and business models
  - Must make sense for the Caribbean
- Less cost, more cycles, less maintenance
- Financing
- Battery recycling and maintenance services / market
- Better energy control and monitoring
- Workforce development

- User side considerations
  - Selection, maintenance, safety
  - Citizens are used to "infinite supply of energy", but will adapt (they always do)

Community leaders during a Solar Communities Colloquium Bayamón, Puerto Rico, April 2017.

E. O'Neill, A. Irizarry with collaboration from E. Rivera, G. Cosme, E. Parés

What are the gaps between where we are today and where we want to be in 2030?

Cummings

- Depending on yet-to-be-developed storage technologies: better storage mediums
- Need cohesive, system control and dispatch algorithms; aggregators needed: DERMS
- Need to integrate distribution and transmission operations (not just dist.)
- Recognition of physical limitations: batteries are a problem in urban areas
- Misconceptions abound
- Domestic manufacturing capabilities
- Modular design and connections: plug-and-play concept
- Workforce development and training: installation, operations, maintenance
- Spare parts inventory (locational)
- Safe and smart integration into system

Questions

Please submit your questions
in the Chat box to the host. Reference the speaker or topic.

Panel 2: Technology Pathways

Concept to Commercialization

Moderator

Deepak Divan, Georgia Tech

Panelists

- Cliff Ho, Sandia National Laboratories
- Sanjoy Banerjee, Urban Electric Power
- Alex Huang, University of Texas at Austin
- Paul Albertus, University of Maryland
- Frank Jakob, Black & Veatch (EPC)

Overview

Deepak Divan, CDE

Georgia Tech

Energy Storage - Drivers

Energy storage is the key to a sustainable energy future

Mobile Applications:

- EVs, trucks, buses, semis, ships and aircraft

Stationary Applications:

- Dynamic grid balancing: non-storage (DR) OR storage (hydro)
- Time shifted generation (security): minutes, hours, days, seasons

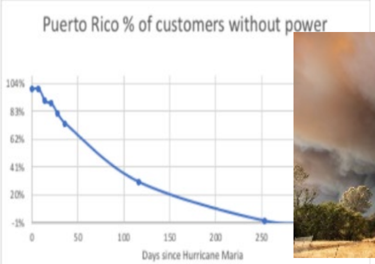
Key metrics: MW, MWHr, cost, cycles, LCOE, scale, commission time

PV & WIND

2019: Wind + 4 hours storage: $24/MWHr

PV + 4 hours storage: $32/MWHr

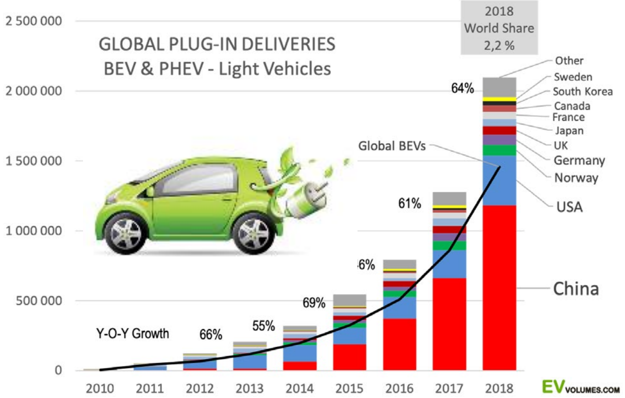
Renewables



Resiliency

1.6 GW Raccoon Mountain PHS

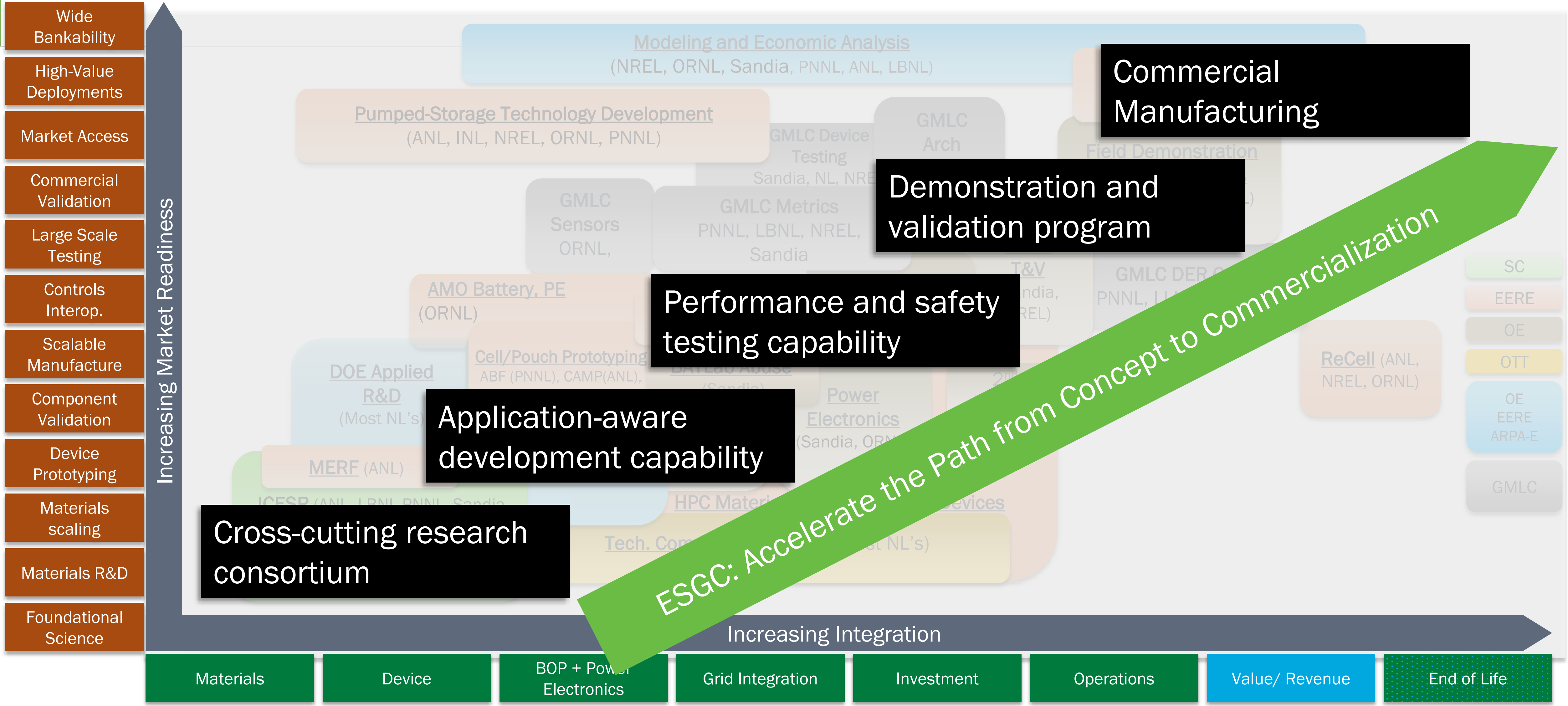
840 MW Hydrogen Plant - MHPS



E-Transportation: 60% YoY Growth

100 MW BESS Plant - Tesla

Technology Pathways: Concept to Commercialization



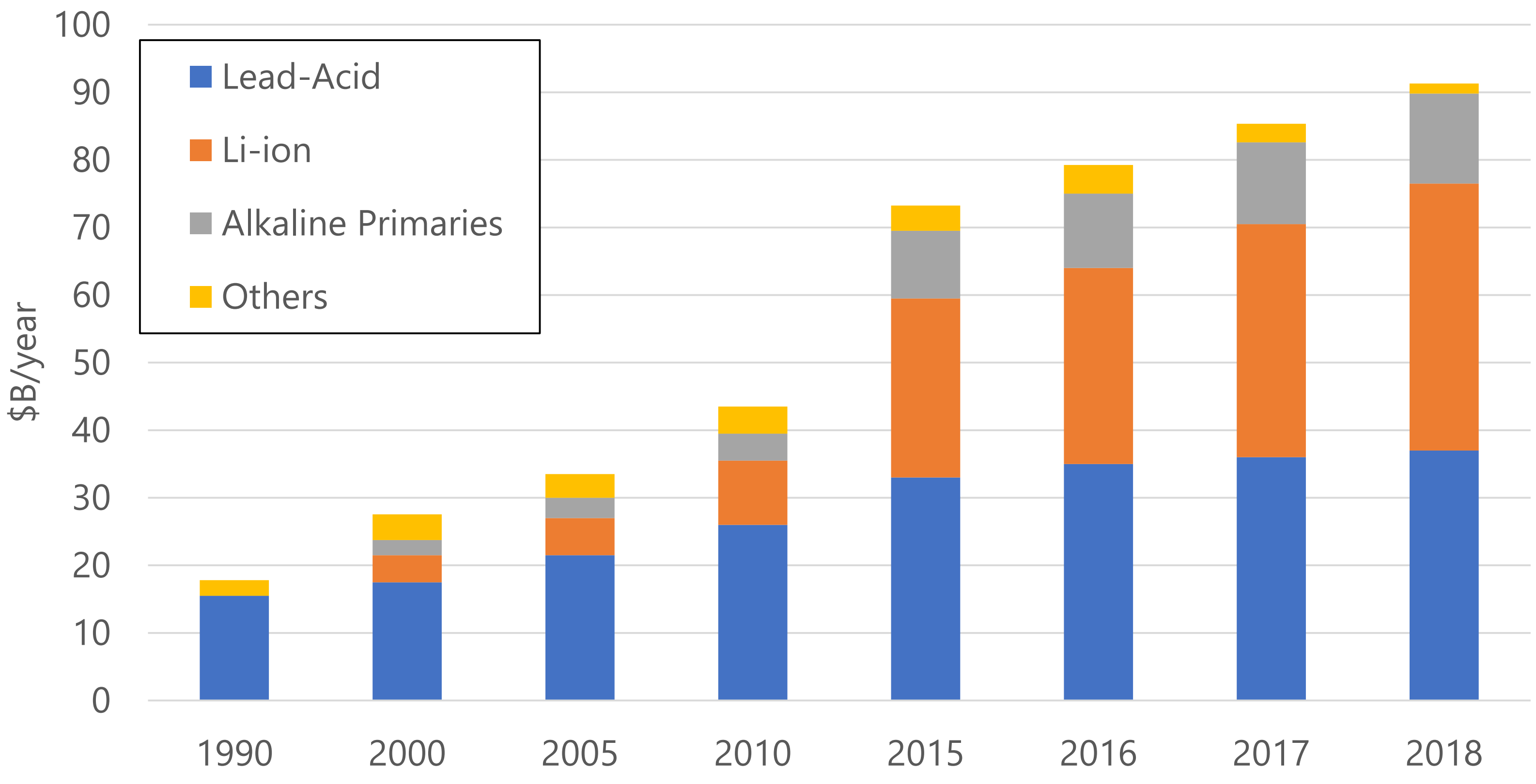
Electrochemical Energy Storage

Sanjoy Banerjee

Urban Electric Power

Energy Storage Grand Challenge Panel: Technology Pathways

Global Battery Sales

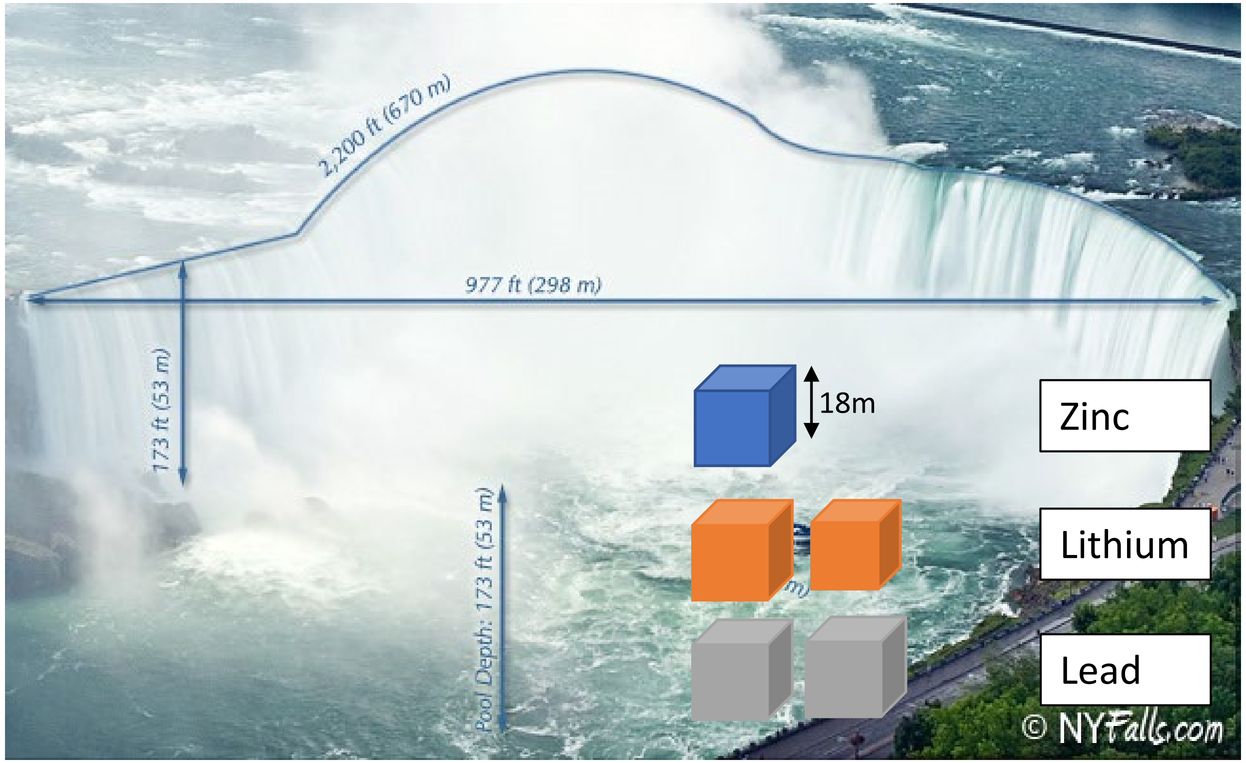


Where are we today?

- Li-ion sales ~$40B/yr growing
- Lead-Acid sales~$38B/yr stable
- Zn primary cell sales ~ $13B/yr growing
- Other battery sales (NiCd, NiMH, Flow batteries, NAS, …) ~$1.5B/yr decreasing

How much material is theoretically needed to store electricity produced by Niagara Falls in a day?

Niagara Falls: 60,000 MWh/day

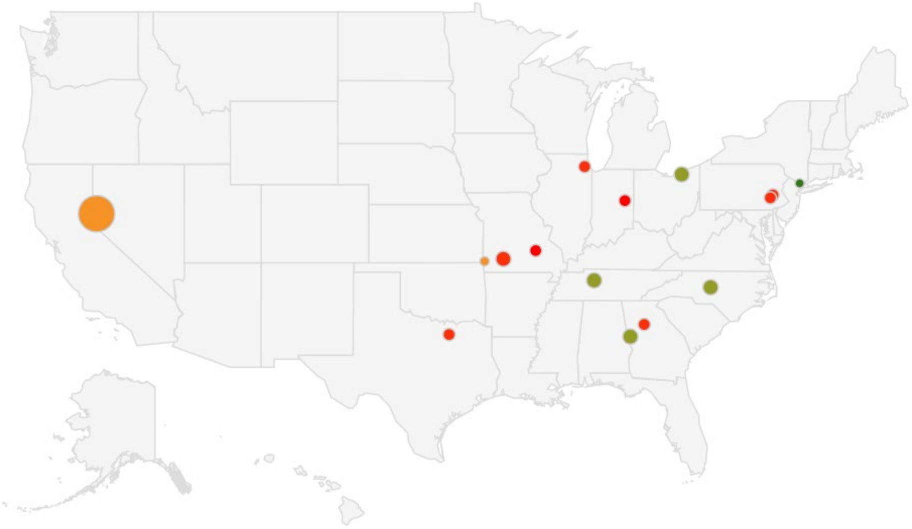


Anode (*)	Cost $M	GHG Produced Mt CO_2	Volume (m^3)	Mass (tonnes)
Zinc	93	1.5	6,200	44,000
Lithium	370	6	10,200	5,300
Lead	230	4	12,000	120,000

(*) Based on the anode theoretical capacity against a hypothetical air cathode

Battery Manufacturing in the US:
Technology, Plant Locations & Relative Sizes

Technology	Applications	Manufacturing & Supply chain	Material Cost ($/kWh)
Li-ion	EV, portable, Power applications	US supply chain? Only 2 plants in the US (9% of Worldwide capacity)	>$100 1000 cycles
Lead-Acid	SLI, Backup, UPS Some solar	Supply depends on price and availability of recycled lead	~$100 (mature) 1000 cycles
Zn Primary	Consumer electronics	$5B sales US. Established supply	~$5 (primary) 1 cycle
Zn rechargeable	Grid-Resilience & Recovery Evolving Grid	Established supply chain. Manufacturing investment required	Now: $200 (early) To: $15-$30 1000 cycles



Urban Electric Power	Secondary Alkaline
Duracell	Primary Alkaline
Duracell	Primary Alkaline
Energizer	Primary Alkaline
Zochem, Inc	Zinc Battery Recycle
Tesla	Li-ion
Eagle Picher	Li-ion

Northstar	Lead Acid
Trojan Battery	Lead Acid
East Penn Manufacturing	Lead Acid
Exide Technologies	Lead Acid
EnerSys, Inc	Lead Acid
Crown Battery	Lead Acid
Exide Recycling	Lead Acid Recycle
Doe Run's	Lead Acid Recycle

Electrochemical Storage Technologies:
Potential & Necessary Developments

Incremental (5 years)	Intermediate (10-15 years)	Disruptive (15+ years)	
Personal Electronics, Start-stop & hybrid vehicles	Resilience and Recovery, Electric Vehicles Evolving and Modernizing Grid Infrastructure,	Electric Flight Autonomous Robots	**Application**
Li-ion: Si-C, low Co electrodes. Pb-acid: Adv. Pb-C & Bipolar.	$Zn\text{-}MnO_2$: primary to high-cycle rechargeable. Adv. Li ion & $Zn\text{-}MnO_2$: gel/solid electrolytes. High voltage & dual electrolyte systems. Additive manufacturing of Zn metal anodes.	Beyond Li-ion: Li-S, Li-Air Mg & Al Ion High voltage Zn metal	**Technology**
Increased recycling capability. Ongoing additions to manuf. facilities and workforce	Li-ion: secure US supply chain $Zn\text{-}MnO_2$: Evolve facilities from primary to rechargeable cell manufacturing Work force for adv. manufacturing technology		**Manufacturing & Workforce**
Resolvable: venture investments	Hi V electrolytes and ion selective separators Hi cycle electrochemical conversion reactions Dendrite control: high rate electrodeposition		**Technology Barriers**
Modest	Significant	High	**Risk**
Private	Public-Private	Public	**Funding Source**

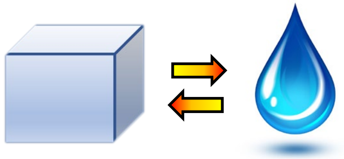
Thermal Energy Storage

Cliff Ho

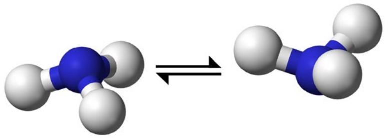
Sandia National Laboratories

Types of Thermal Energy Storage

- **Sensible (single-phase) storage**
  - Use temperature difference to store heat
  - Molten salts (nitrates <600 °C; carbonates, chlorides 700 – 900 °C)
  - Solids storage (graphite, concrete, ceramic particles), >1000 °C

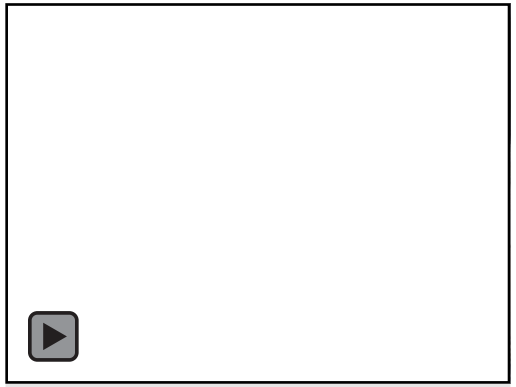


- **Phase-change materials**
  - Use latent heat to store energy (e.g., molten salts, metallic alloys)



- **Thermochemical storage**
  - Converting thermal energy into chemical bonds (e.g., decomposition/synthesis, redox reactions)

Molten-salt storage tanks at Solana CSP plant in Arizona. Credit: Abengoa



Falling particles for direct solar heating Sandia National Laboratories

Applications

Sensible

Molten Salt Storage

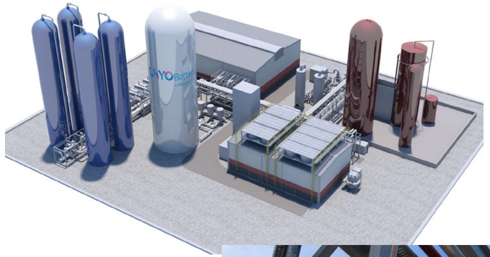
photo credit: Mary Grikas, Wiki commons, 10/9/15

Crescent Dunes CSP, Nevada
100 MW/1 GWh

https://en.wikipedia.org/wiki/Solana_Generating_Station

Solana CSP, Arizona
280 MW/1.7 GWh

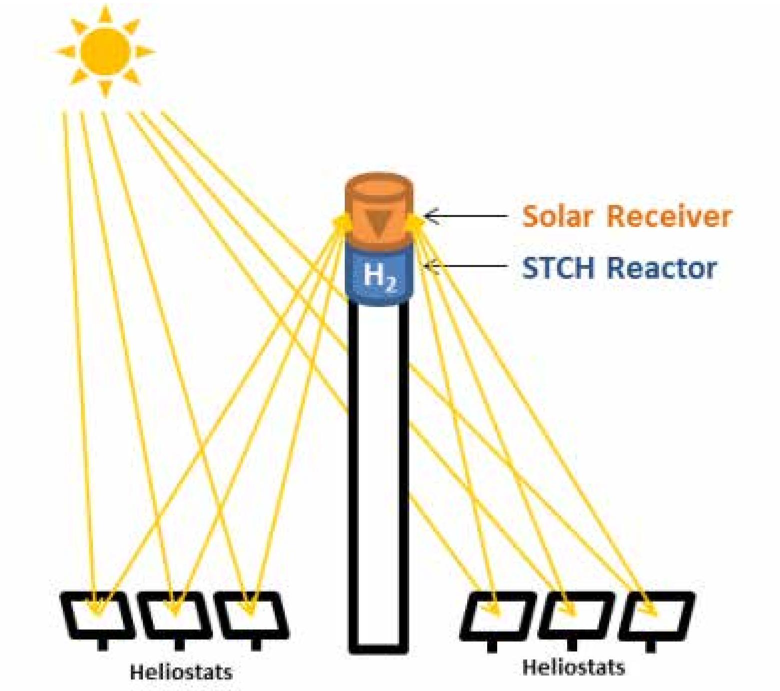
Latent



Images: Highview Power

Highview Power Liquid Air Energy Storage
50 MW/400 MWh
(Vermont - planned)

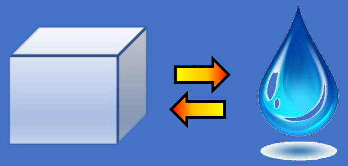
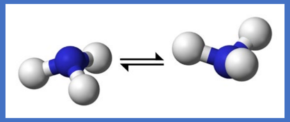
Thermochemical



https://www.energy.gov/eere/fuelcells/hydrogen-production-thermochemical-water-splitting

Solar thermochemical hydrogen production (pilot demonstration)

Summary and Needs

Thermal Storage	Method/Materials	Advantages	Challenges/Needs
Sensible 	Temperature difference (e.g., molten salts, rock, sand)	• Mature technology • Demonstrated large capacity with CSP (~GWh) • Low cost	• Heat loss • Large volumes required
Latent 	Phase-change (e.g., salts, metals, silicon, liquefied air)	• Large energy density • Liquid-air and molten-silicon commercialized (sensible plus latent)	• Low maturity • Heat loss • Air and silicon require extreme temperatures
Thermochemical 	Chemical bonds (e.g., carbonates, metal hydrides, oxides ammonia, sulfur)	• Large energy density • Potential for long-duration storage	• Low maturity • High cost • Material durability and kinetics

CSP = Concentrating Solar Power

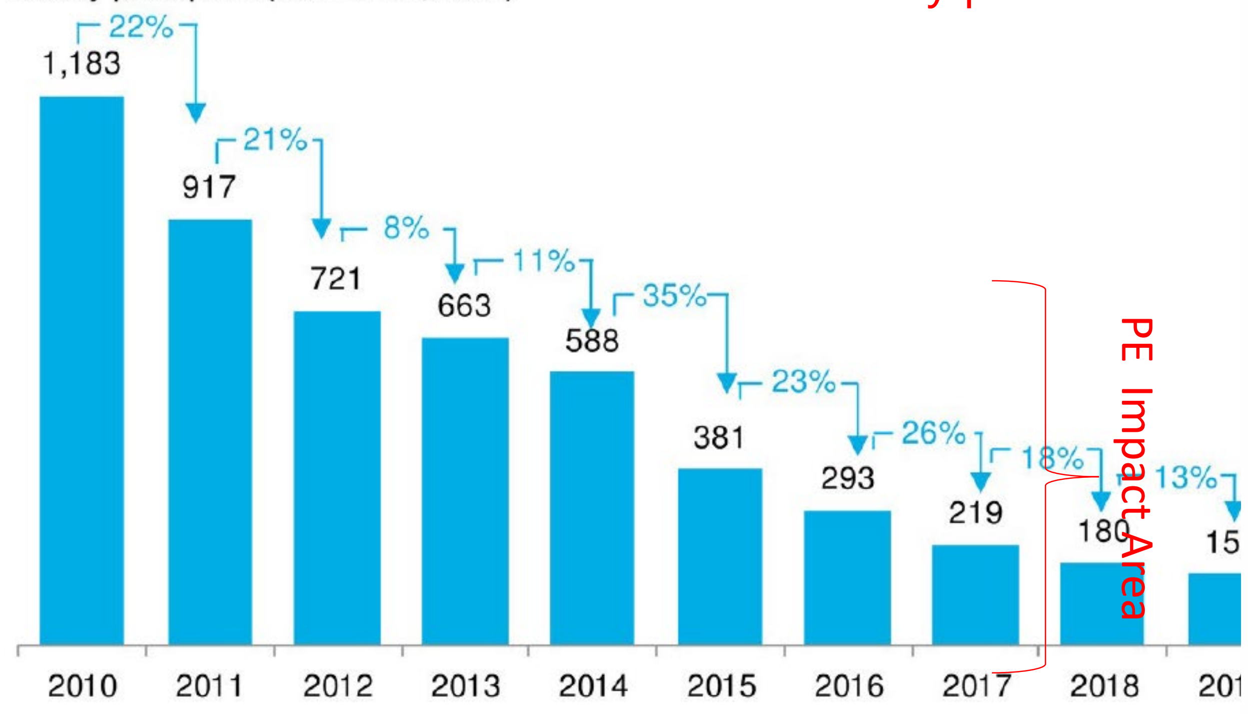
Power Electronics: Enabling Technology For Energy Storage System

Dr. Alex Huang

University of Texas at Austin

Battery Energy System BOS Cost

Automotive battery pack cost



Drivers: Technology & Market Adoption (Volume)

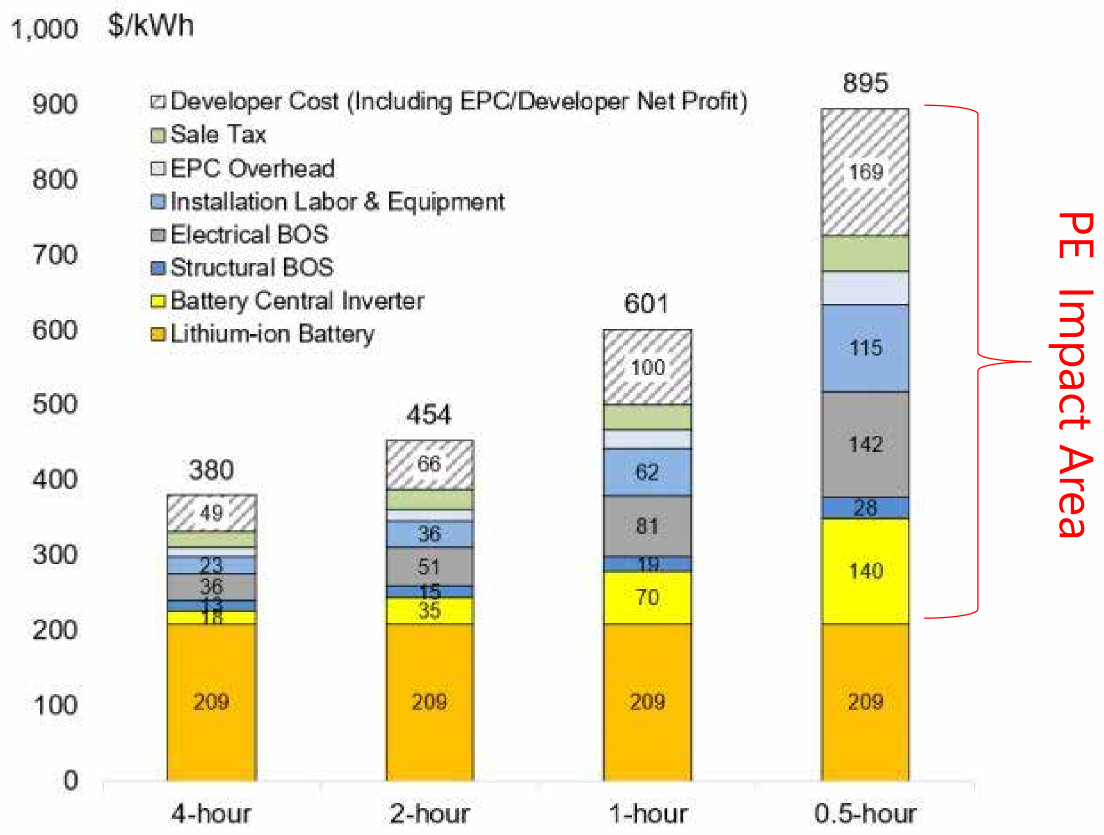
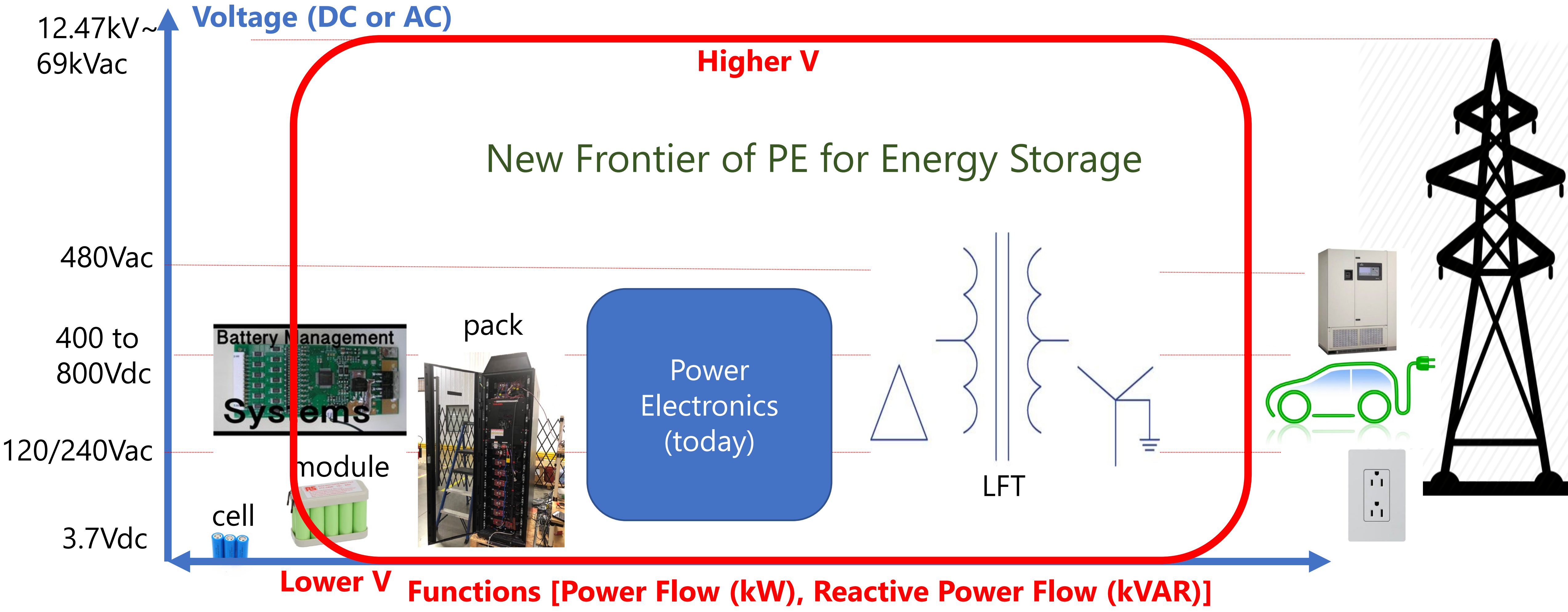


Figure ES-1. 2018 U.S. utility-scale lithium-ion standalone storage costs for durations of 0.5–4 hours (60 MW_{DC})

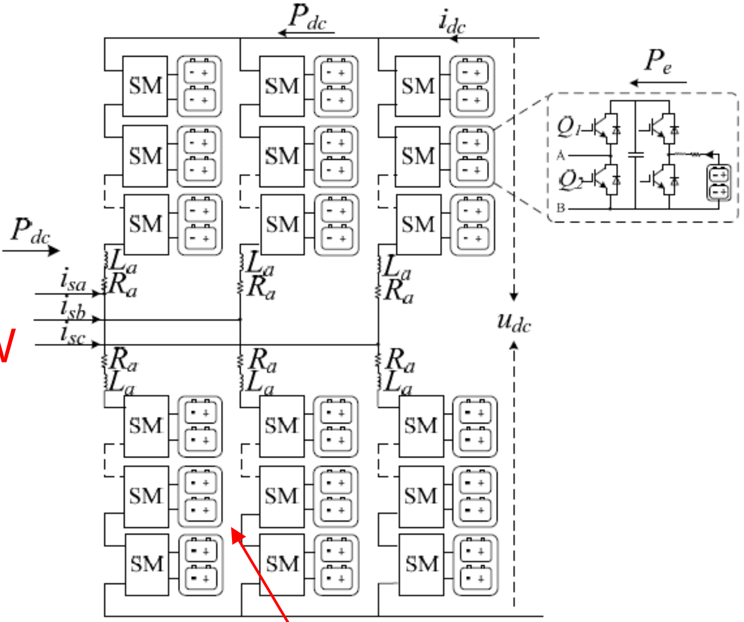
Power Electronics: Conversion, Control and BOS Cost Reduction



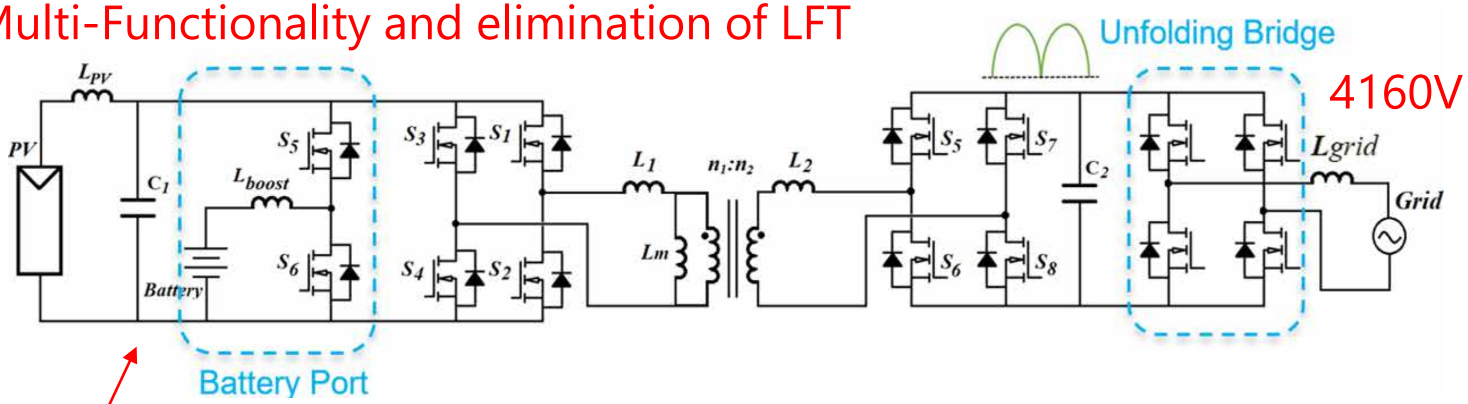
Impact Example

Architecture and topology innovation

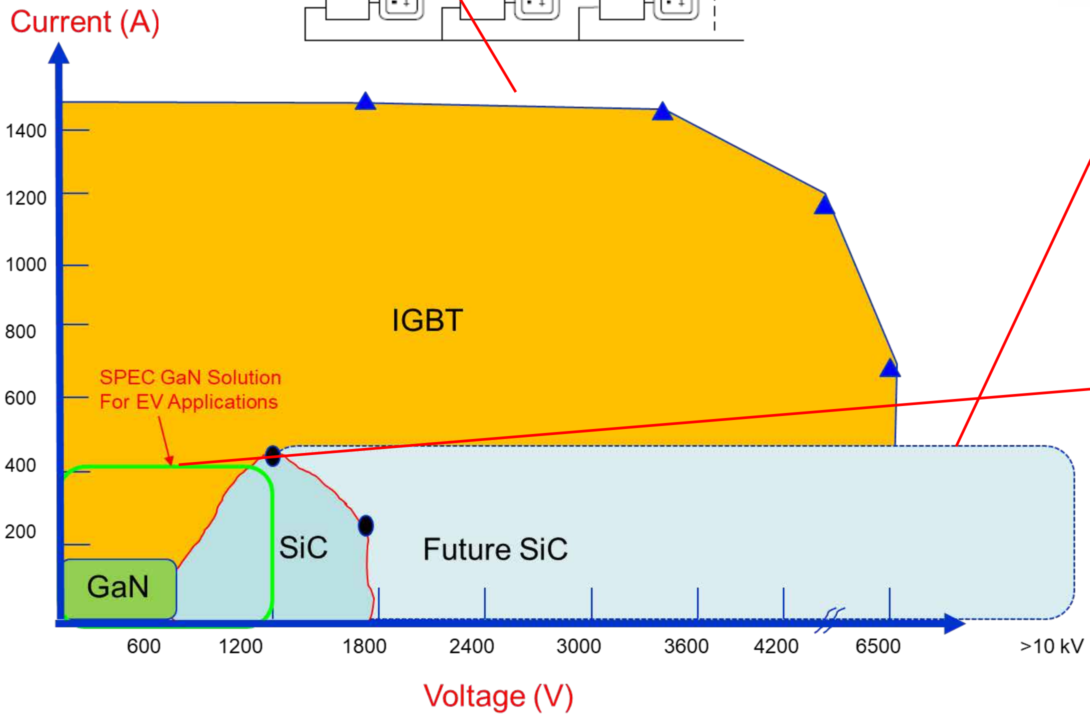
69kV/
100MW



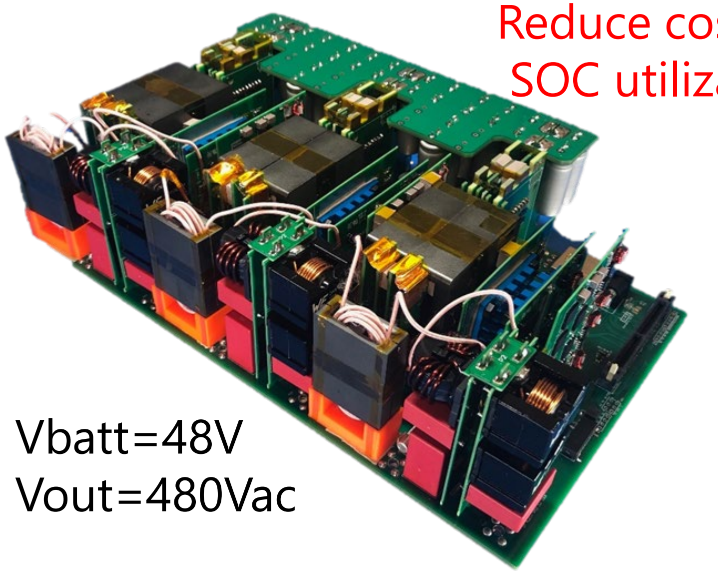
Multi-Functionality and elimination of LFT



4160V

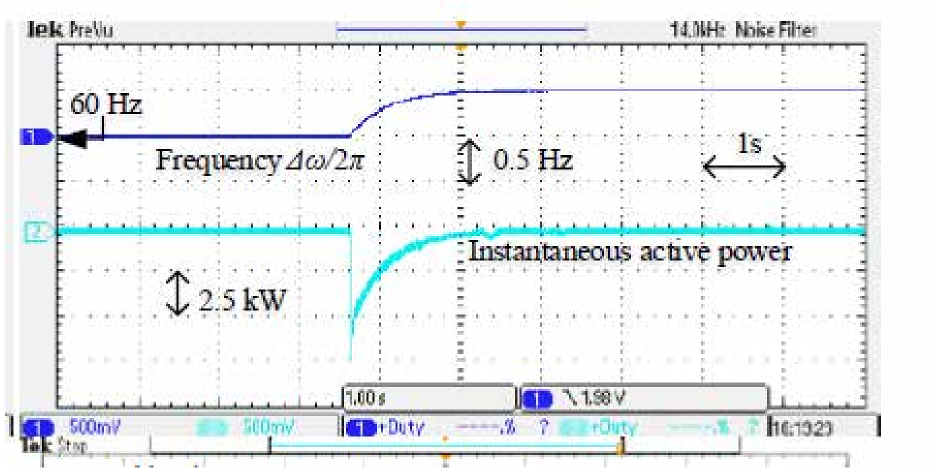


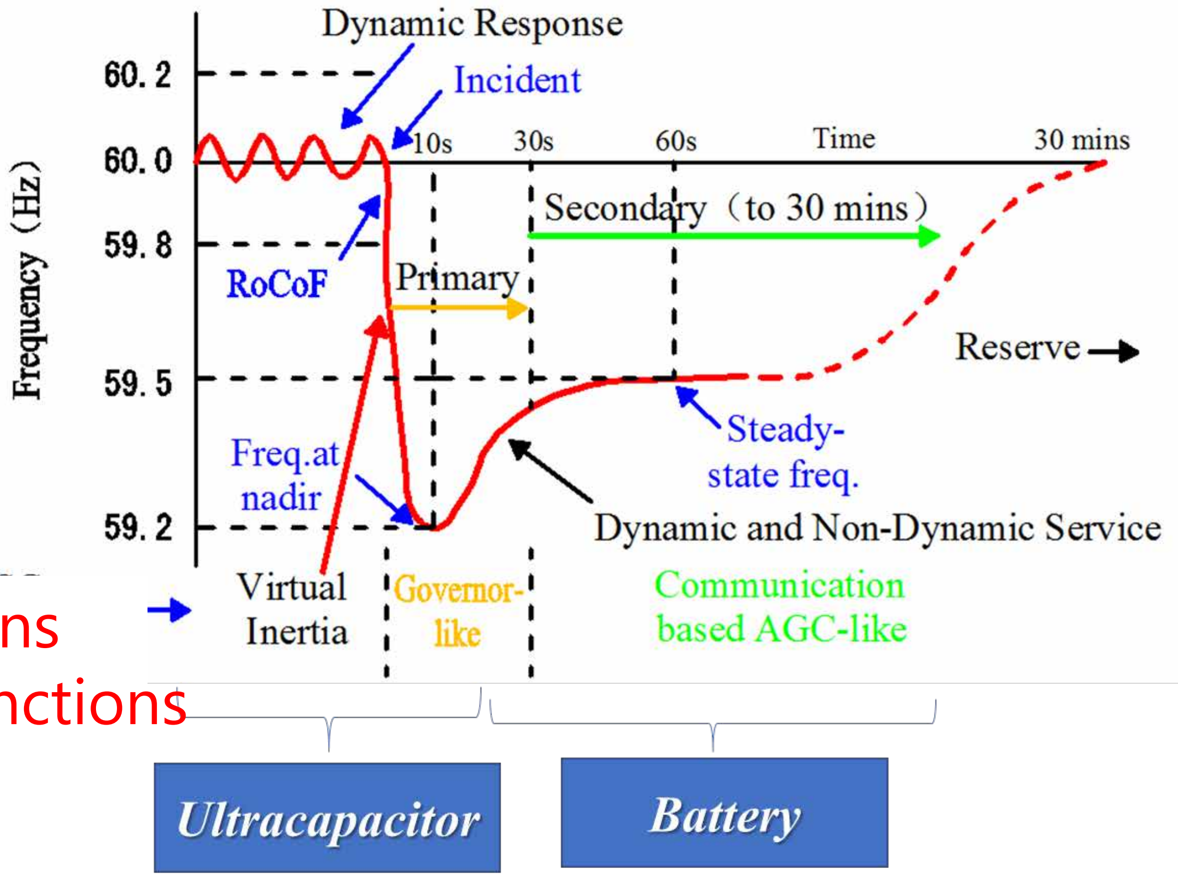
Reduce cost of BMS/better
SOC utilization



Vbatt=48V
Vout=480Vac

Impact Example





Power Control Innovations
Grid forming inverter functions

$$p_g = G_{\omega p}(s)\Delta\omega_g = \frac{-As}{s^2 + Ak_{i\theta}s + Ak_{i\omega}}\Delta\omega_g = \frac{-As}{(s+p_1)(s+p_2)}\Delta\omega_g$$

R&D Recommendations

- Emphasize the BOS cost reduction as part of the ESGC
- Investment in Medium Voltage and High Voltage Power Electronics to support large energy storage system
- Tighter integration of BMS and Power Electronics technology
- National or Regional Center of Excellence on Energy System Integration Issues from components to system:
  - Module/pack level testing and model validation
  - BMS/power electronics integration
  - System architecture and control innovation

Long Duration Electricity Storage

Paul Albertus

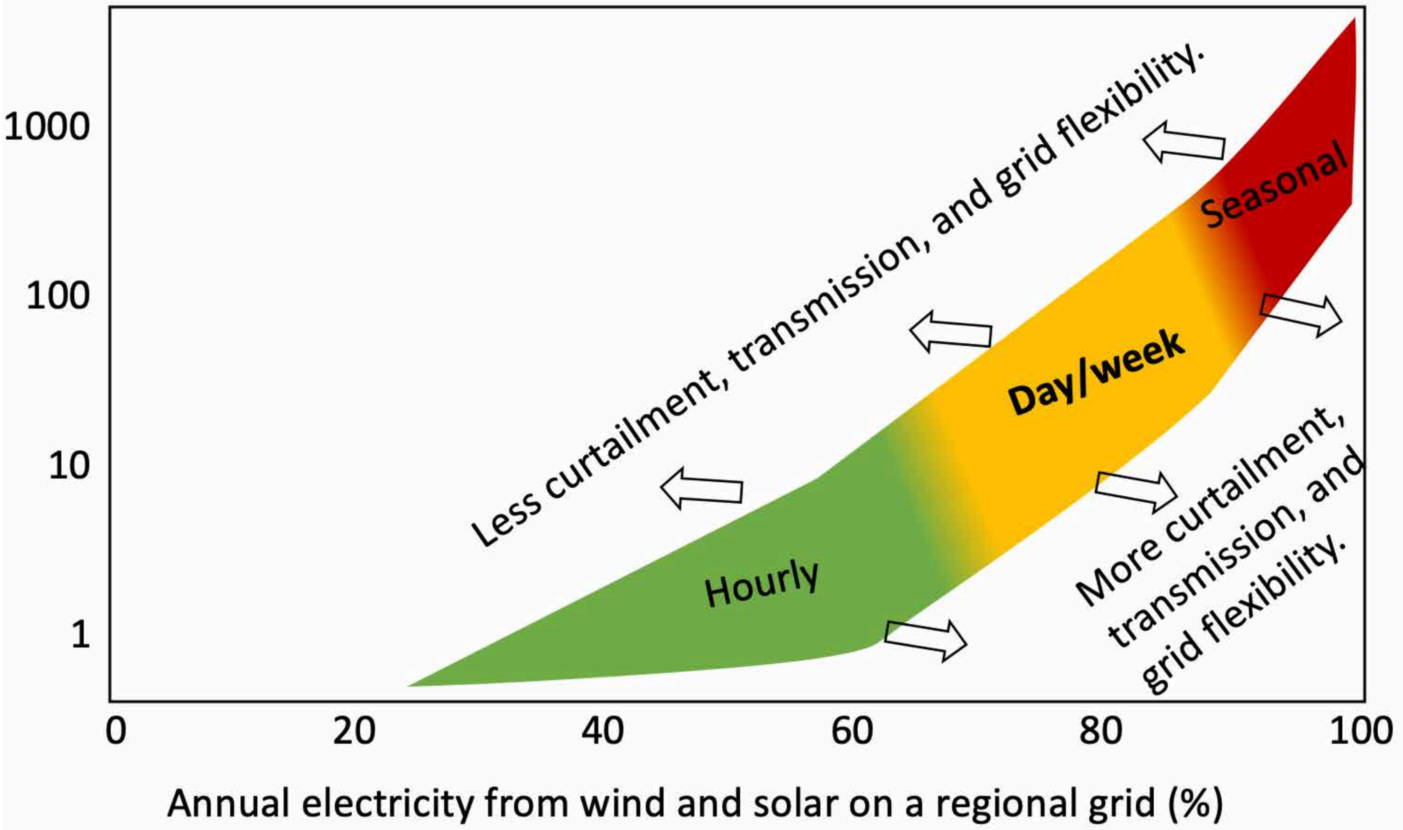
University of Maryland

Long-duration electricity storage (10 to 100h)

- The vast majority of electricity storage projects today are for applications that require <10 hours at rated power.
- Storing electricity for 10 to 100 hours has potential applications:
  - Load customers: ensure reliability, from backup generation to isolated grids to capacity markets.
  - Delivery customers: increase utilization and defer investments, from microgrids to load pockets to transmission scale markets.
  - Generation customers: reducing curtailment and hedging price, from self consumption to generation smoothing to utility scale firm generation.
- The ARPA-E DAYS program ($30M, 3 years, from 2018) is focused on development of long-duration electricity storage approaches.

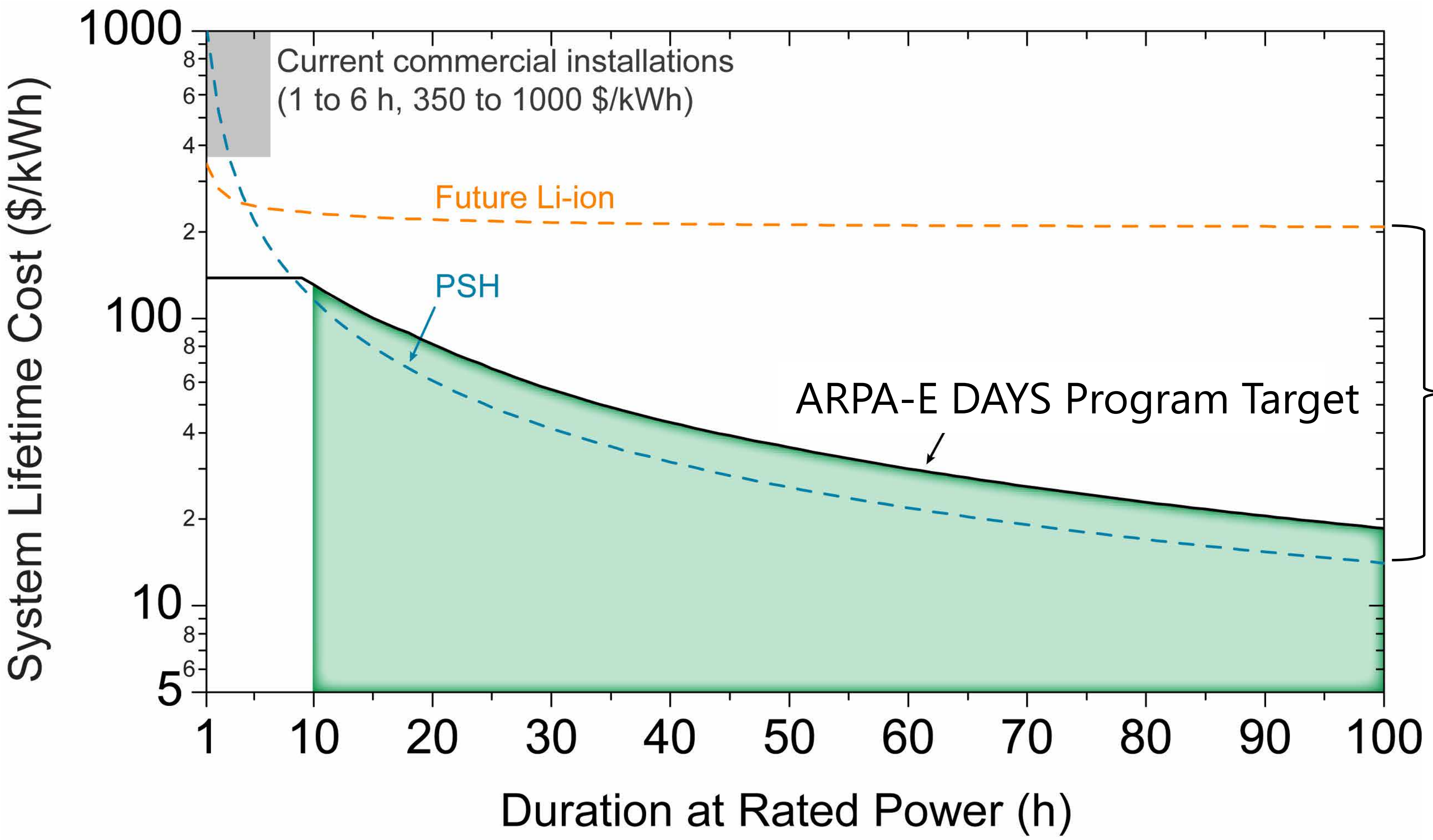
Example: Long duration storage on a large grid (e.g. PJM) bridges daily and seasonal durations

Maximum required storage duration to meet all hours of load (hours at rated power)



Reference: Albertus et al., Joule *4*, 21-32, January 15, 2020.

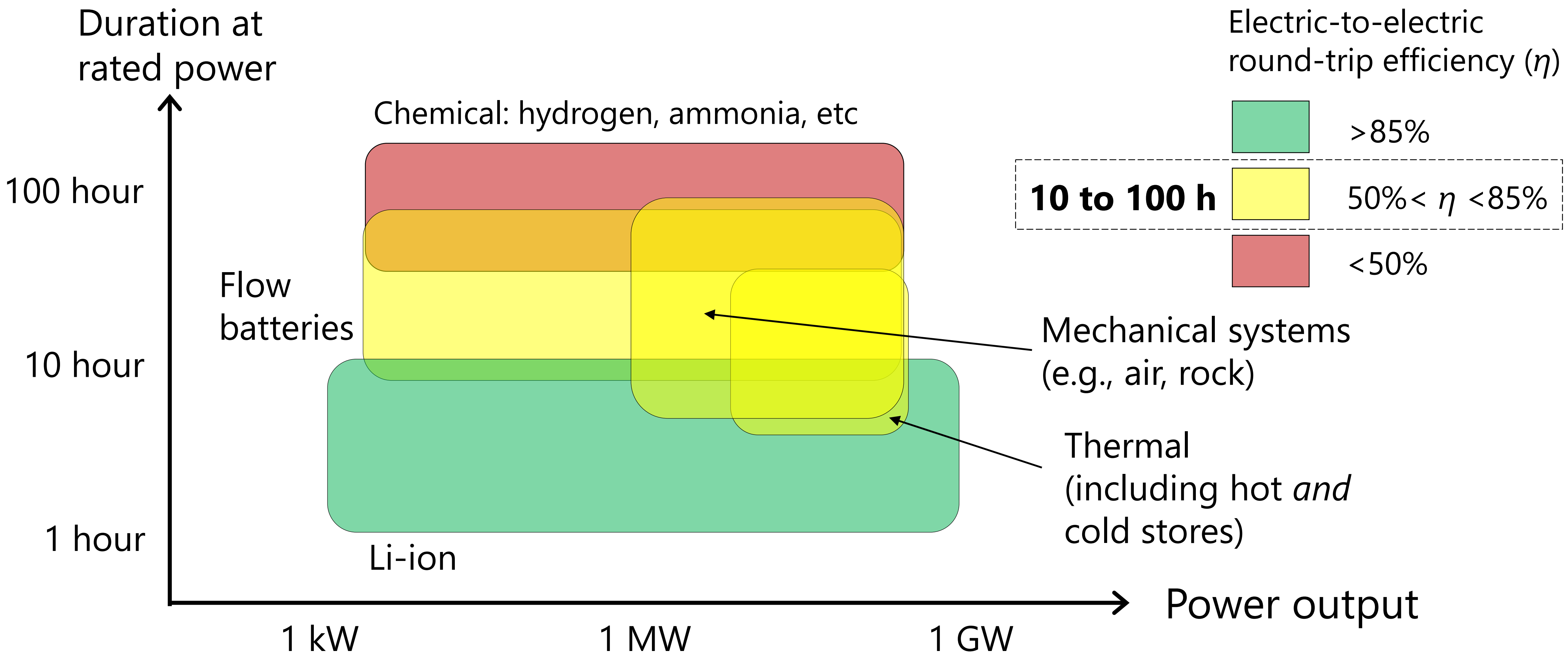
Long duration storage technologies have economics more like Pumped Storage Hydro than Li-ion



Marginal cost of adding energy to a PSH system is much lower than to a Li-ion system.

Reference: Albertus et al., Joule *4*, 21-32, January 15, 2020.

Long duration technologies should have better efficiency than power to gas, and low-cost scaling pathways



A high-level comparison of a "generic" long duration electrochemical and thermal technology

An electrochemical technology (e.g., a Zn-based or flow battery):

- Materials and prototype: ~$10M, lab scale. Long-term degradation testing should be done.
- Demonstration: $10s of M. Need a company to make a pilot line and do careful cost analysis. Failure often happens here because it doesn't beat (rapidly improving) Li-ion by >30%, and/or in technical aspects.
- Commercial deployment / manufacturing: $100s of M. Best to use existing processes and supply chains!

A turbine-based thermal technology (e.g., a high-temperature rock-based unit with a fluidized bed heat exchanger):

- Materials and prototype: ~$10s of M. Component testing must be done at sub-scale.
- Demonstration: ($10s to 100s of M) Turbines perform best at large scale (100s of MW), so demonstrations are typically sub-scale. An at-scale first-of-a-kind demonstration project may be in the $Billions (e.g., CCS).
- Commercial deployment / manufacturing: ($B) The optimal project size is usually 100s of MW. Use of existing components and supply chains is helpful. Concentrating solar power has many lessons here.

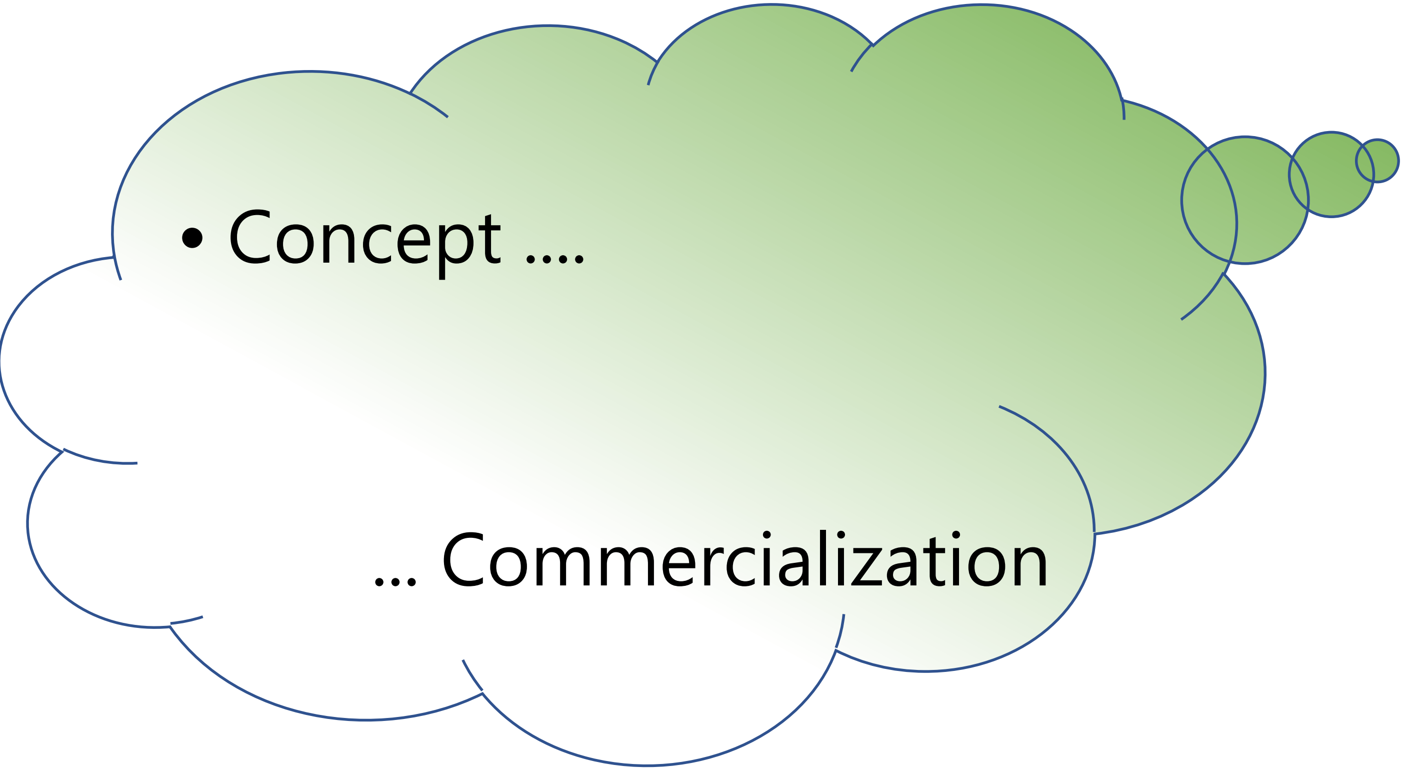
Commercial Opportunities

Frank Jakob

Black & Veatch

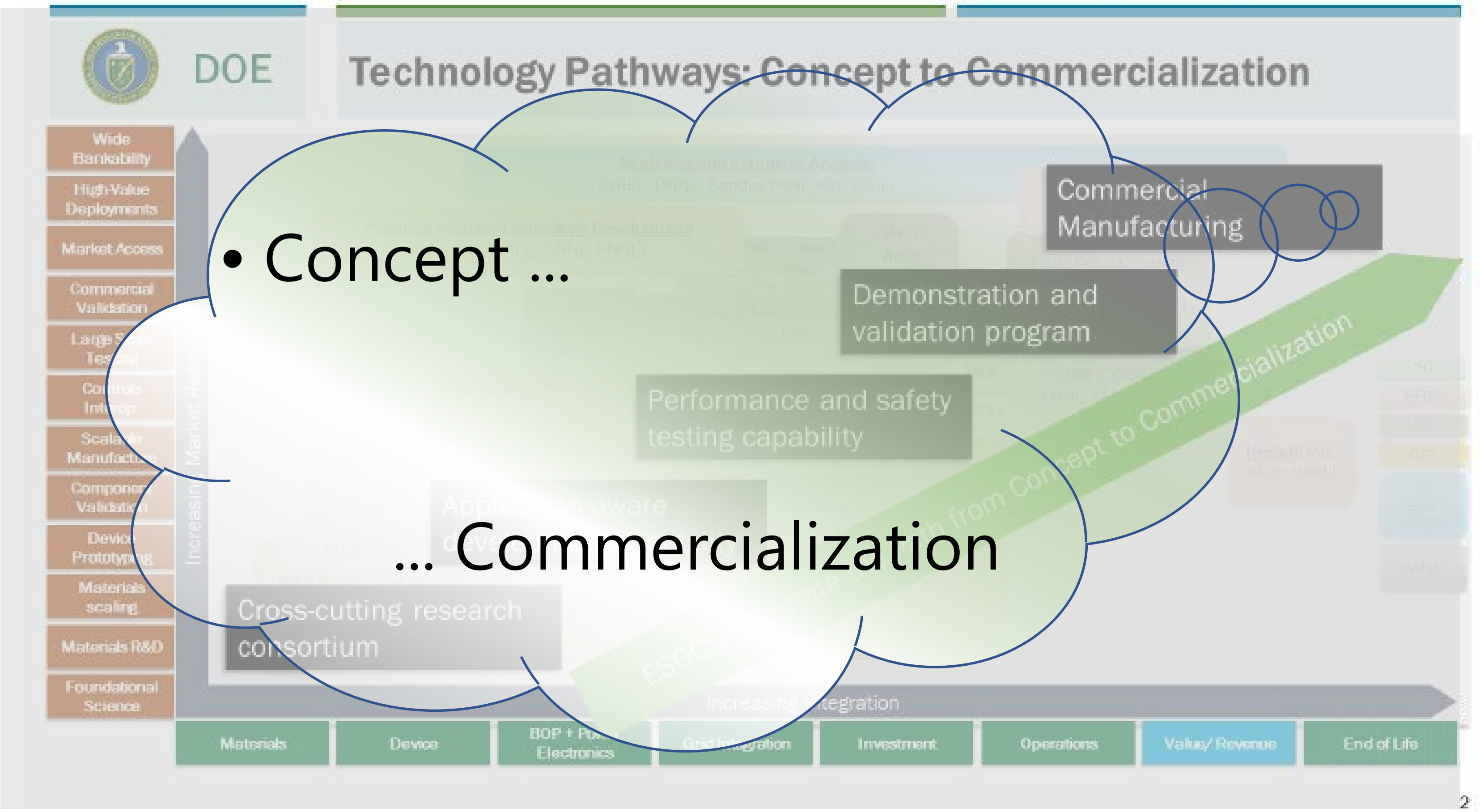
Long-duration Storage: Gaps to Commercialization

Gaps to be filled before EPC project execution begins



- Bankable
- AHJ alignment (permitting)
- Equipment warrantees
- Performance guarantees
- All-risk mitigations

Steppingstones to Successful Commercialization Through EPC



Long term SUCCESS

Operator > Operator**s**

Experience

Walk > Jog > Run

FOAK

DEPLOYMENT GAPS

Announcements for Energy Storage

Big plans for BIG energy storage (Power or Energy or Both)

2018

California,

LADWP,

Pumped hydro storage *added* to the existing Hoover Dam

Uncertainty of energy prices for long lived asset

2019

Utah,

Intermountain PP,

Hydrogen storage for seasonal energy storage

Uncertainty of storing hydrogen in salt dome for seasonal storage

2020

Minnesota,

Great River Energy,

New **electro-chemical** technology, 150 hr

Traditionally long development times,
Li-ion 1970 > 1990 > 2010

Questions

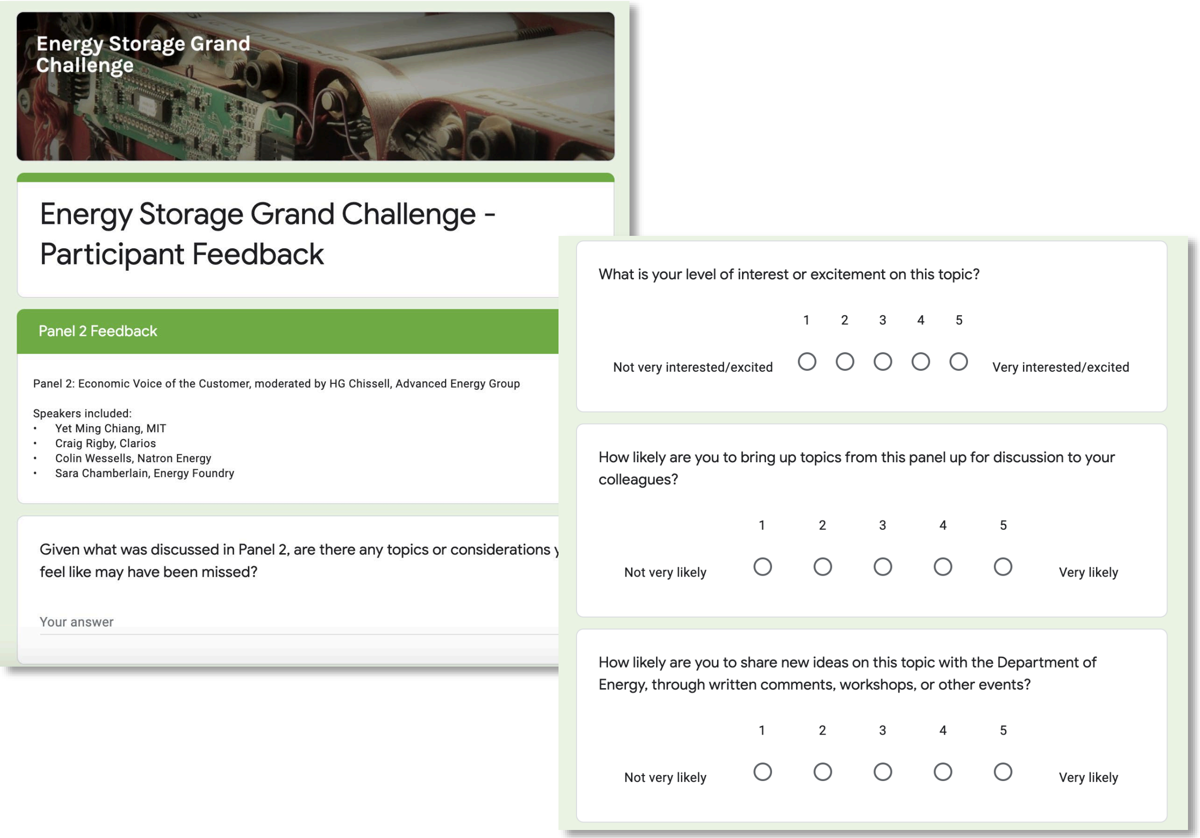
Please submit your questions in the Chat box to the host. Reference the speaker or topic.

Workshop Feedback Form

After this workshop, we invite you to share your additional thoughts and comments about the presentations you heard today. This may include additional questions, concerns, considerations, or suggestions for the Department of Energy.

This is an opportunity to provide us with feedback on how interesting and relevant the material from the panels were. You are also able to opt-in to be involved in future Department of Energy events.

The link is available through the chat function in WebEx.



Energy Storage Grand Challenge

Energy Storage Grand Challenge - Participant Feedback

Panel 2 Feedback

Panel 2: Economic Voice of the Customer, moderated by HG Chissell, Advanced Energy Group

Speakers included:

- Yet Ming Chiang, MIT
- Craig Rigby, Clarios
- Colin Wessells, Natron Energy
- Sara Chamberlain, Energy Foundry

Given what was discussed in Panel 2, are there any topics or considerations y feel like may have been missed?

Your answer

What is your level of interest or excitement on this topic?

Not very interested/excited 1 2 3 4 5 Very interested/excited

How likely are you to bring up topics from this panel up for discussion to your colleagues?

Not very likely 1 2 3 4 5 Very likely

How likely are you to share new ideas on this topic with the Department of Energy, through written comments, workshops, or other events?

Not very likely 1 2 3 4 5 Very likely

U.S. DEPARTMENT OF ENERGY

Closing Remarks

Andy McIlroy

Associate Laboratories Director,
Integrated Security Solutions
Sandia National Laboratories

Thank you.

Our next workshops:

- Pacific/Northwest Regional Workshop, May 20
- Midwest/Northeast Regional Workshop, May 27

For more information, visit:
https://www.energy.gov/energy-storage-grand-challenge

Appendix

Appendix 1: Panel 2 Participant Bios

Dr. Paul Albertus is currently an Assistant Professor of Chemical and Biomolecular Engineering at the University of Maryland, and Associate Director of the Maryland Energy Innovation Institute; his research group focuses on electrochemical energy storage. Dr. Albertus previously served as a Program Director at ARPA-E (2015 to 2018), where he initiated and managed the $30M DAYS program focused on long duration (10 to 100 hours) electricity storage.

Sanjoy Banerjee is CUNY Distinguished Professor and Director of the Energy Institute at the City University of New York (CUNY), and serves as Executive Chairman of Urban Electric Power, a CUNY spinoff which manufactures batteries for grid applications in Pearl River, NY. He recently received the 2019 ACS/EPA Green Chemistry Challenge Award.

Deepak Divan is Director of the Center for Distributed Energy and Professor at Georgia Tech. He is member of the National Academy of Engineering and has four companies that he has started and/or run in the area of power electronics and the grid.

Dr. Cliff Ho is a Fellow of the American Society of Mechanical Engineers and a Senior Scientist at Sandia National Laboratories, where he has works on problems involving solar energy and energy storage. He holds 15 patents, has published over 200 scientific papers, and is the recipient of two R&D 100 Awards. He received his B.S. in Mechanical Engineering from the University of Wisconsin-Madison in 1989, and his MS and Ph.D. from the University of California at Berkeley in 1990 and 1993.

Dr. Alex Huang is Professor of Electrical Engineering at UT Austin. He is member of the National Academy of Inventors and has several companies that he has started in the area of power electronics and the grid, the areas of his research.

Frank Jakob, Black & Veatch – Frank is a Mechanical Engineer, with 40 years of experience in energy and power systems. Starting in Research & Development at Battelle. Now in Deployment with Black & Veatch as "Technology Manager for Energy Storage" in the Power Division.