



July 6, 2011

# The role of RD&D investments in utility-scale energy storage to support the integration of variable renewable generation

30<sup>th</sup> International Energy Workshop, Stanford University

Audrey J. Lee

Fellow, Energy Technology Innovation Policy group

Laura Diaz Anadon, Gabe Chan, Tom Alfstad, Paul Friley, Savvas Politis

# Outline

- Motivation
  - Energy Research, Development, Demonstration, and Deployment (ERD3) Policy Project
- Methodology:
  - Expert elicitation instrument
  - Integrated energy system modeling: MARKAL
- Findings and results
  - Experts
  - Budget and allocation recommendations
  - Cost reduction, benefits estimates
  - Qualitative responses
  - Stakeholder interviews
  - Relationship between storage and other technologies

## ERD3 Project Aim and Research Areas

***“producing a set of recommendations for accelerating the pace of energy technology innovation in the U.S.”***

- Making recommendations about allocating federal funds for energy RD&D
- Identifying gaps in private sector innovation and learning about the levers to encourage more
- Understanding energy innovation systems in other countries, their priorities, and recommending international collaboration
- Improving the U.S. energy innovation system and the effectiveness of its institutions catalyzing change
  - Cross-institutional and cross-sectoral analysis

# Methodology

1. Expert elicitation
2. Stakeholder interviews
3. Latin Hypercube Sampling
4. Energy system modeling
5. Recommendations

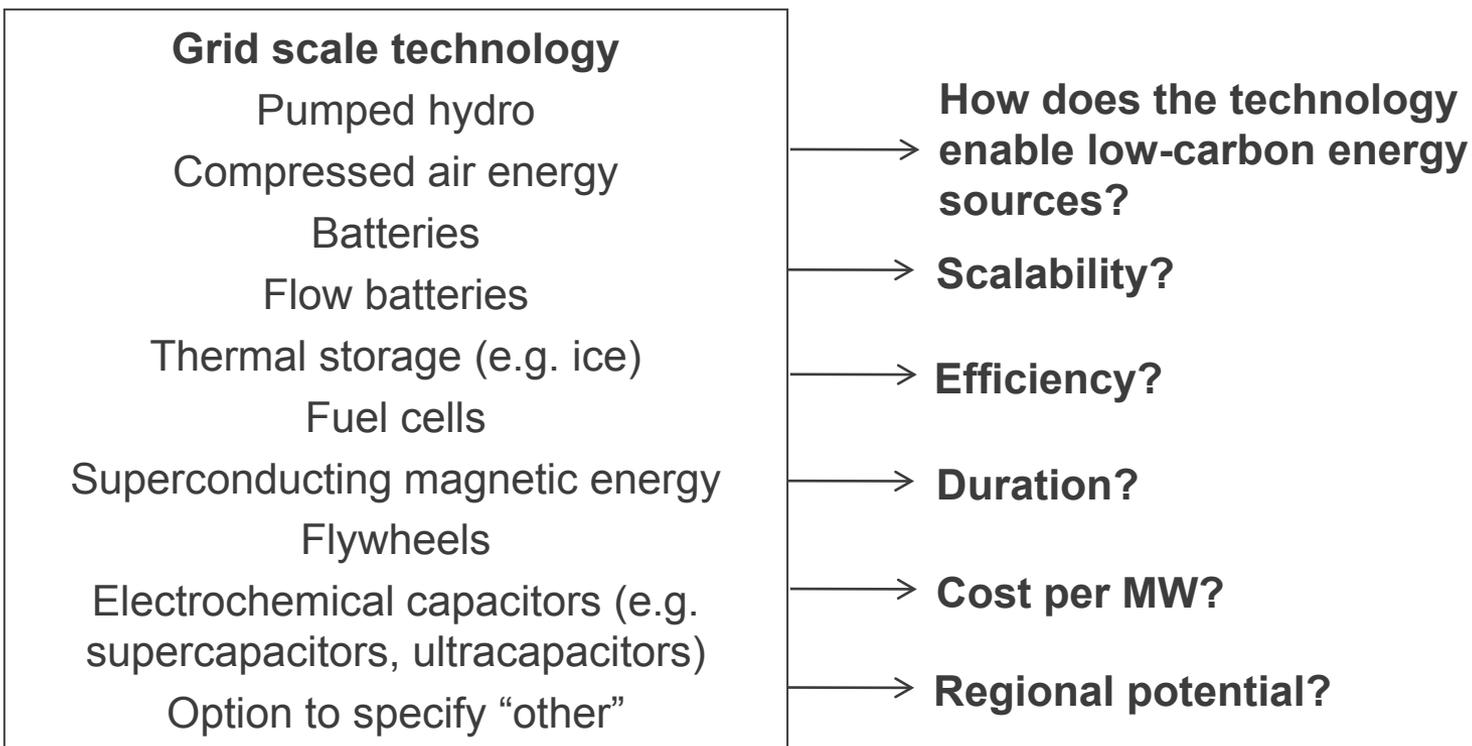
## Seven Technology Areas

- Grid-scale energy storage
- Fossil energy
- Bioenergy
- Nuclear energy
- Solar energy (PV)
- Vehicle technologies
- Building technologies

## The need for energy storage RD&D

- Spans many applications from ensuring grid power quality to supporting variable generation to electric vehicles. (EPRI, 2003)
- This work focuses **bulk energy storage technologies at the grid scale**, particularly for integration of low-carbon power generation, like renewable energy.
  - Climate change mitigation (Yang and Williams, 2009)
  - Energy security and diversity concerns (Stirling, 1994; Flavin et al., 2006; Grubb et al., 2006)
  - Economic drivers for energy storage with fast discharge are already stronger and growing faster than those with longer term discharge characteristics. (The Electricity Advisory Committee, 2008; NERC, 2009b)
- Scalable (MW)
- Long durations (> 30 min)
- High ramp rates (MW per second)

# Elicitation for Grid-Scale Energy Storage Technologies



# Energy Storage Experts

300 experts invited, 50 accepted, 25 returned survey

<i>Name</i>	<i>Affiliation</i>	<i>Name</i>	<i>Affiliation</i>
Dale T. Bradshaw	National Rural Electric Cooperative Association (NRECA)	Matt Lazarewicz	Beacon Power Corp.
Scott Brown	New Energy Capital	Eric D. Lougher	Southwest Solar Technologies, Inc.
Nancy Clark	Sandia National Laboratory	Jason Makansi	Pearl Street, Inc.
Garth Corey	Sandia National Laboratory	Michael J. McGill	Electricity & Air Storage Enterprises, LLC
Paul Denholm	NREL	Sekari Mtingwa	MIT
Christopher J. Grieco	Gravity Power, LLC	Karen D. Parysek	Praxair, Inc.
Bill Gray	Velkess, Inc.	Bradford P. Roberts	S&C Electric Company
David E. Gushee	Retired from Congressional Research Service	Samir Succar	NRDC
Chad Hall	Ioxus, Inc.	Charles Vartanian	A123 Systems
Tim F. Havel	Energy Compression, Inc.	Robert Webster	Magnum Energy
Timothy D. Heidel	MIT	Steve Willard	PNM Resources
Eric Ingersoll	General Compression	Chi-Jen Yang	Duke University
Bernard Lee	retired president and CEO of the Inst. of Gas Technology		

# Budget Recommendations: Energy Storage

## *DOE Energy Storage Budget*

FY2009: \$208 million		FY2010: \$63 million	
\$185 million ARRA	\$23 million EFRCs, OE R&D	\$31 million ARPA-E	\$32 million EFRCs, OE R&D

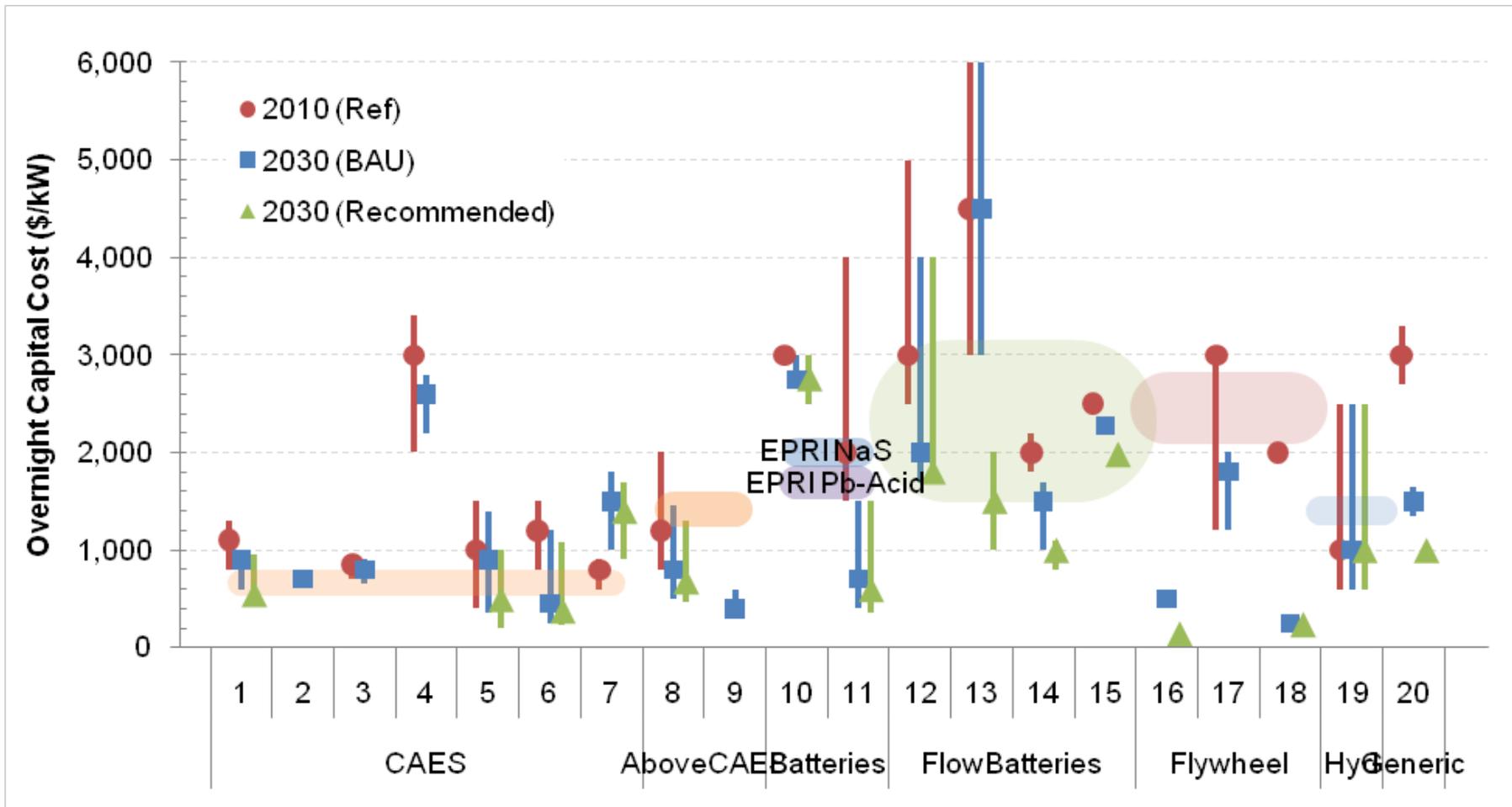
Experts' Recommended Budgets	
(millions 2010\$)	No. of Experts
50	2
70-80	3
100	6
120	3
200-250	5
500	2
2,000-20,000	1
240	Average

# Allocation of Recommended Budgets: Energy Storage (Average Percentage of Budget)

<ul style="list-style-type: none"> <li>• Average</li> <li>• % of total budget</li> <li>• Annual</li> <li>• 2010-2030</li> </ul>	Pumped Hydro	Compressed Air Energy	Batteries	Flow Batteries	Thermal	Fuel Cells	Superconducting Magnetic Energy	Flywheels	Electrochemical Capacitors	Other
Basic Research	0.2	1.8	4.5	4.0	0.5	1.3	1.9	1.5	2.3	1.1
Applied Research	0.7	3.7	4.9	4.9	1.4	1.1	1.1	2.5	2.4	1.7
Experiments and Pilots	0.7	3.7	4.2	7.1	2.0	0.6	0.4	2.2	2.3	2.4
Commercial Demonstration	1.4	8.3	4.6	7.8	1.6	0.7	0.6	1.9	2.1	1.7

Total	3.0	17.5	18.2	23.9	5.5	3.7	4.0	8.1	9.2	7.0
-------	-----	------	------	------	-----	-----	-----	-----	-----	-----

# Overnight Capital Costs under Different RD&D Budgets



Compared to EPRI estimates (colored bars)



## Qualitative responses

Technology	Major Hurdles
CAES	Materials cost-effectiveness, eliminated fuels use, ubiquitous storage, geological risk, heat exchange of compressed air, compressor efficiency, heat recovery
Batteries	Energy density, controls for smart grid capability, manufacturability, electrode mechanical stability
Flywheels	Scalability of manufacturing
Electrochemical capacitors	Scalability of manufacturing. Control systems for capacitors
Flow batteries	Application control algorithms, low cost ZnBr

- Demonstration of long-term reliability and safety, lifetime, maintenance, operation, stability, reliability, cost reduction
- Grid modeling and simulation to show value
- Need standards, guidelines

# Stakeholder Meetings to Review Results

**Kleiner Perkins**

**House Comm. on Science & Technology**

**DOE/OE**

**DOE/ARPA-E**

## **Remarks:**

Long-term: high roundtrip efficiency and fewer moving parts

Modularity, scalability, and ubiquity are important

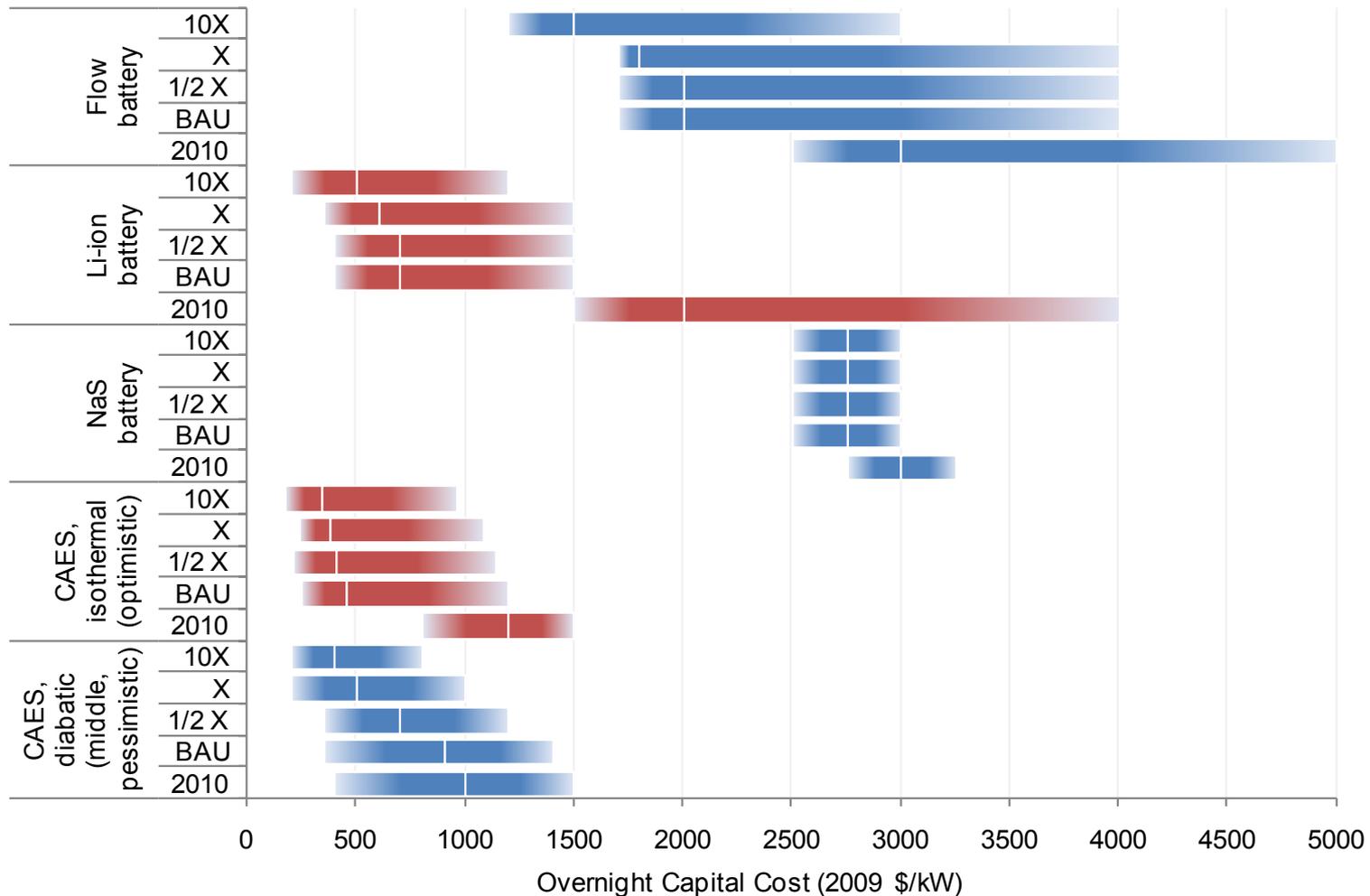
The more technically mature and capital intensive, the more funding needed for commercial demonstration

Rush to pilot/demo, to quickly prove whether it will fail.

Funding also needed for systems policy, regulatory review, rationalization, to understand economics.

Federal role for energy storage is binary. In 5-6 years, it either works, or will never work.

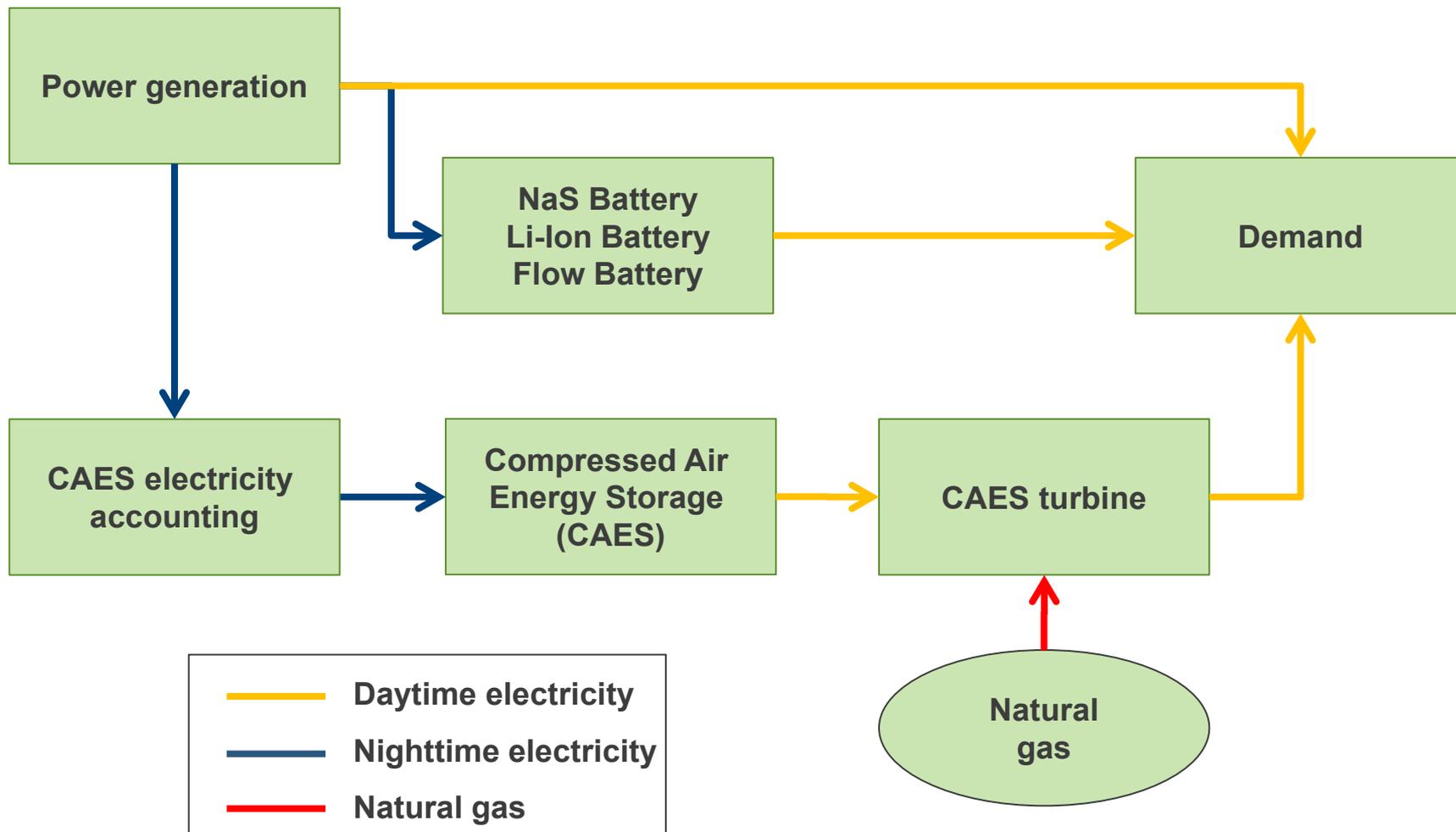
# Selected experts' cost projections (10<sup>th</sup>, 50<sup>th</sup>, and 90<sup>th</sup> percentile estimates)



# Integration of Technology Expert Elicitations into Energy System Model - MARKAL

Tool	<ul style="list-style-type: none"><li>• U.S. Ten-Region MARKAL Model (BNL)</li></ul>
Inputs	<ul style="list-style-type: none"><li>• Technology costs, performance metrics</li><li>• Probability distribution functions</li><li>• Correlation between technologies</li></ul>
Metrics	<ul style="list-style-type: none"><li>• Greenhouse gas emissions</li><li>• Petroleum consumption reductions</li><li>• CO2 credit prices</li></ul>
Scenarios	<ul style="list-style-type: none"><li>• Recommended Federal RD&amp;D spending</li><li>• Middle, optimistic, pessimistic</li><li>• CO2 cap-and-trade</li><li>• Sectoral policies</li><li>• Oil prices, natural gas prices</li></ul>

# Incorporation of storage technologies in MARKAL



## Conclusions

- NaS and flow batteries not deployed, based on experts' projections.
- Li-ion battery deployment increases with storage RD&D funding.
- Storage is **negatively correlated** with photovoltaics, natural gas combustion turbines, and power sector CO2 emissions
- **Correlations** in 2030 are stronger when RD&D funding for storage (only) is increased to ten times the experts' recommended level
- Storage deployment is dependent on cost differential between **peak and off-peak electricity**. As buildings' (peakier) electricity demand grows over time, that cost differential could increase. Deployment of storage is higher under increased RD&D funding, especially in 2050.
- Significant **system cost reductions** under increased storage funding.
- Storage is primarily used for **inter-temporal arbitrage**, thus it helps **non-dispatchable electricity**, like nuclear and wind.
- Renewable electricity **variability** was not the focus of the elicitation and is not captured in MARKAL, therefore storage's ability to mitigate variability is not present.



Thank you for your attention,  
the ERD3 Advisory Board and the rest of the team for advice,  
and the Doris Duke Charitable Foundation for financial support.

