Hydrogen Bromine Flow Battery for Grid Scale Energy Storage

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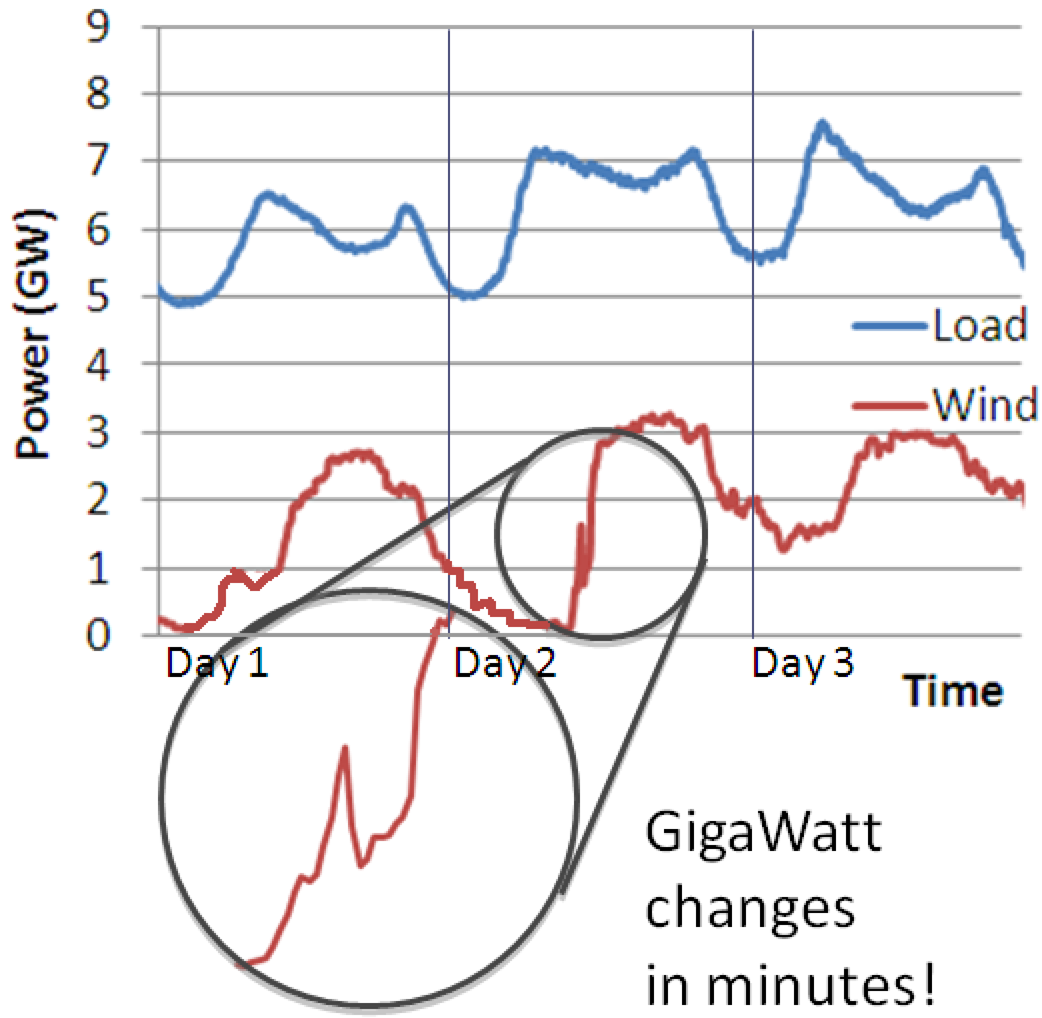
Cleantech to Market

5/6/2011

Renewables Demand Storage

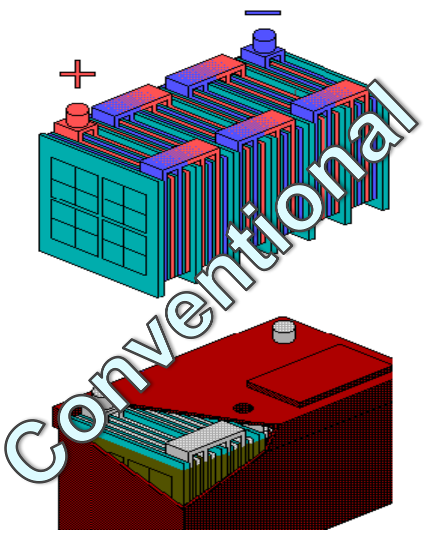


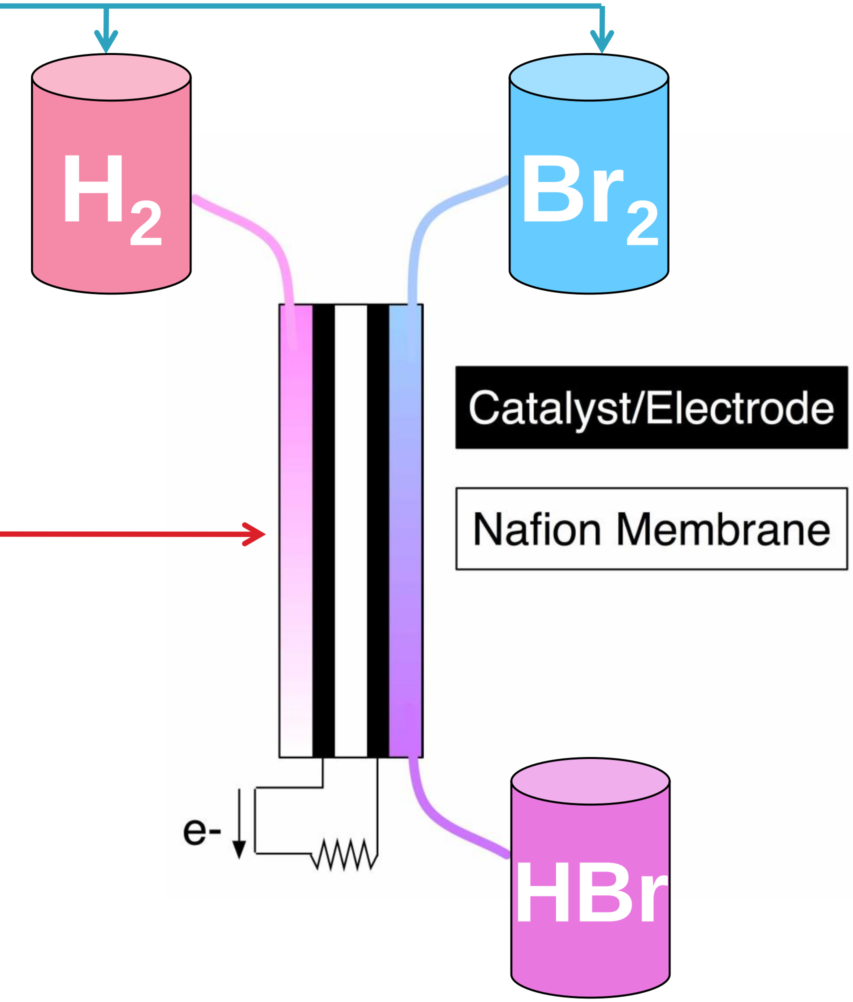
- Need to Control Renewable Generation
  - Lost value due to curtailment
  - Grid outage due to renewable variability
- ARPA-E Goal
  - Low cost storage that is dispatchable and rampable

Rapidly growing need for storage

Solution: HBr Flow Battery

- Independently optimize for **energy** and for **power**
- Low cost reactants



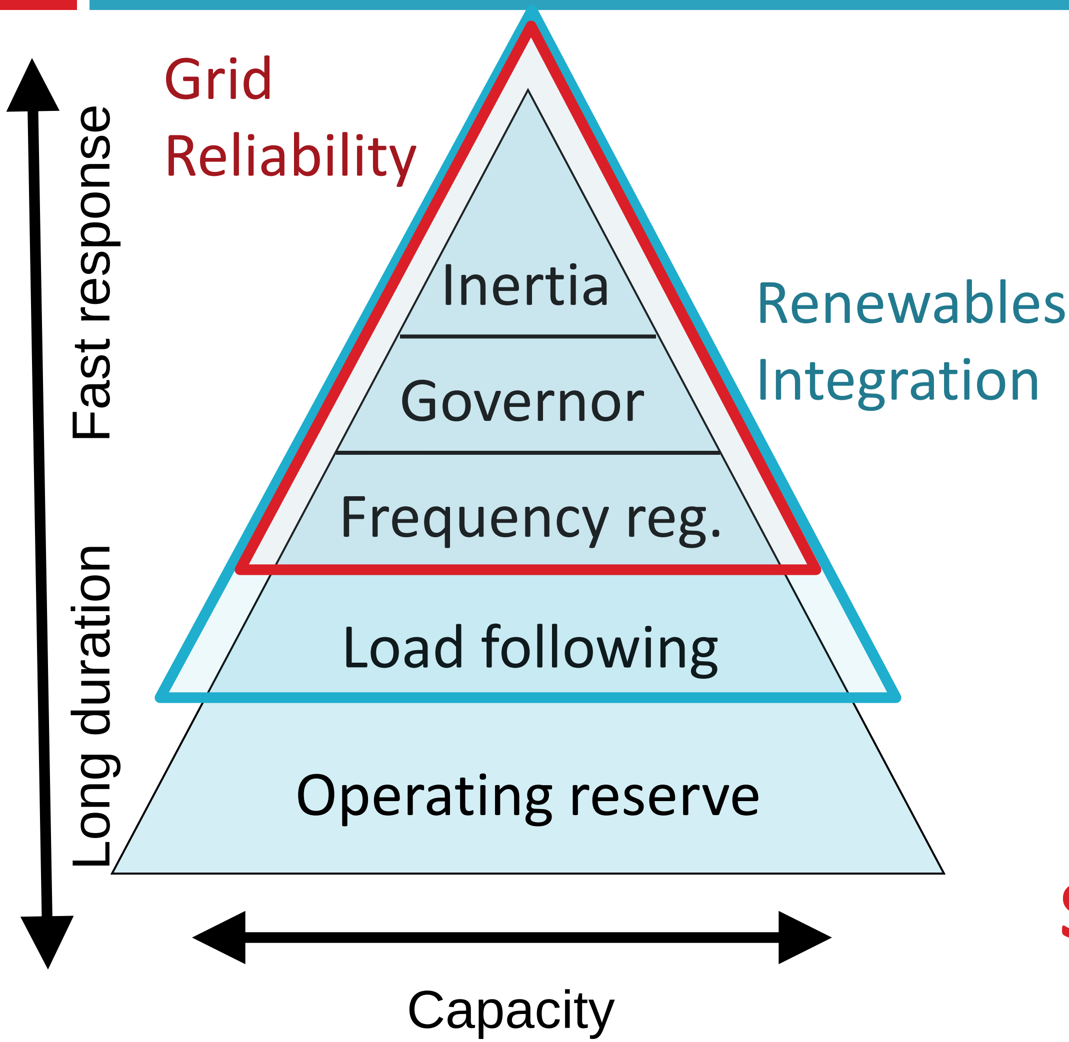


Distinct Technology Advantages

Competitors	Pumped Hydro, CAES	Natural Gas, CAES	Other Batteries	Other Flow Batteries, Flywheels
Limitations	Site Limited	Carbon-emitting Slow to Ramp	Energy Depends on Power	Higher Cost

HBr flow battery offers unique advantages

Best Applications for Storage



- **High power,** fast storage stabilizes grid frequency
- **High energy,** low cost storage shifts generation and follows load
- **High availability** generation (hydro, coal, nuclear) provides base load

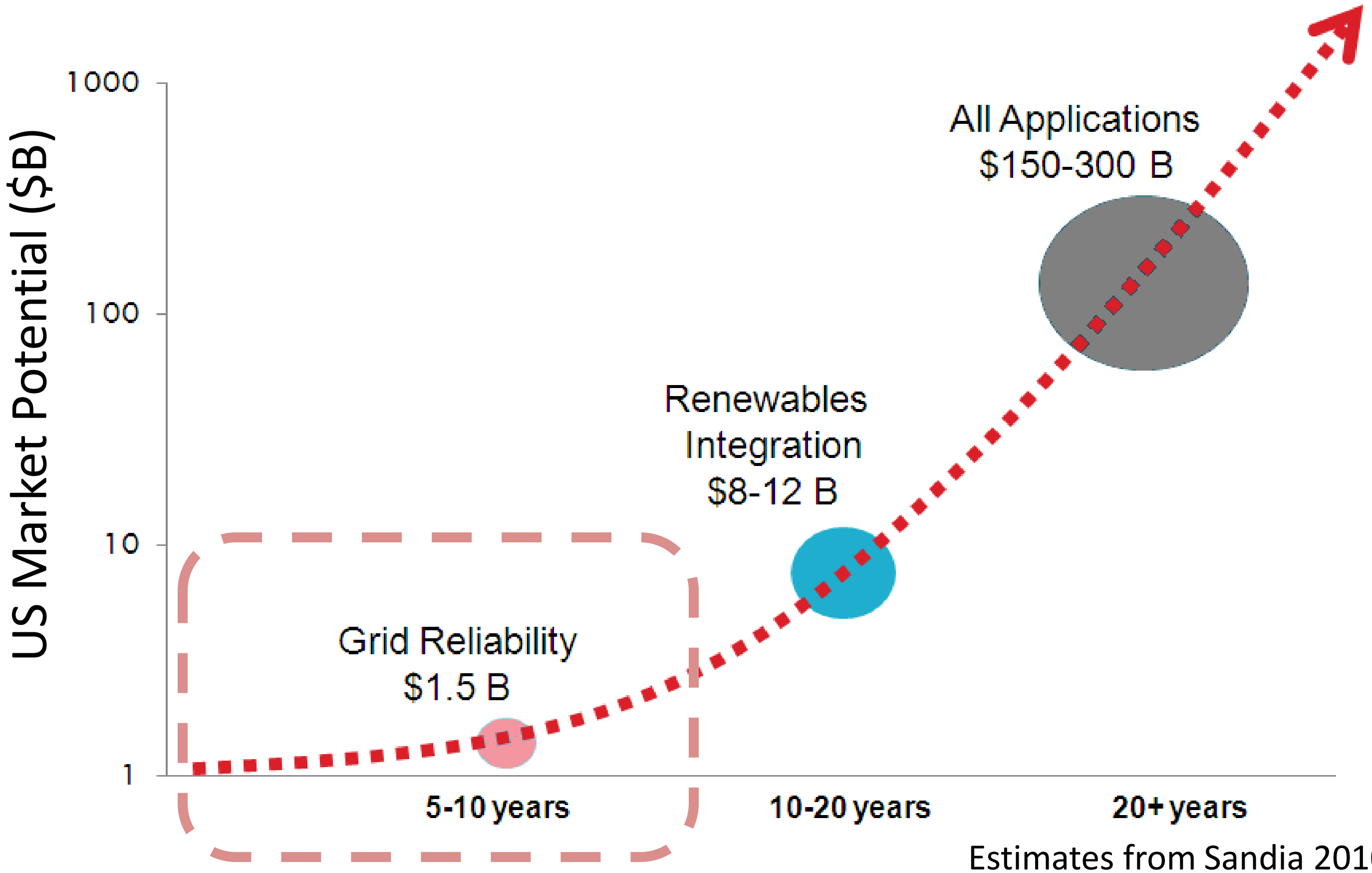
Seek premium markets

Market Screens

	Transmission & Distribution Deferral	Retail Time of Use	Grid Reliability	Renewables Integration
Market size	$4B	$80B	$1.5B	$10B
Premium power	✓✓✓	✓✓	✓✓	✓
Fast response	✓	✓	✓✓	✓✓
Large capacity	✓	✓	✖	✓
Regulatory hurdles	✖	✓	✓	✓
Safety	✓	✖✖	✓	✓
Time to market	✖	✓	✓	✖

Enter grid reliability and renewables integration markets

Recommendation: Grid Reliability First



Estimates from Sandia 2010

Nearest opportunity is grid reliability

Grid Reliability - Features to Beat

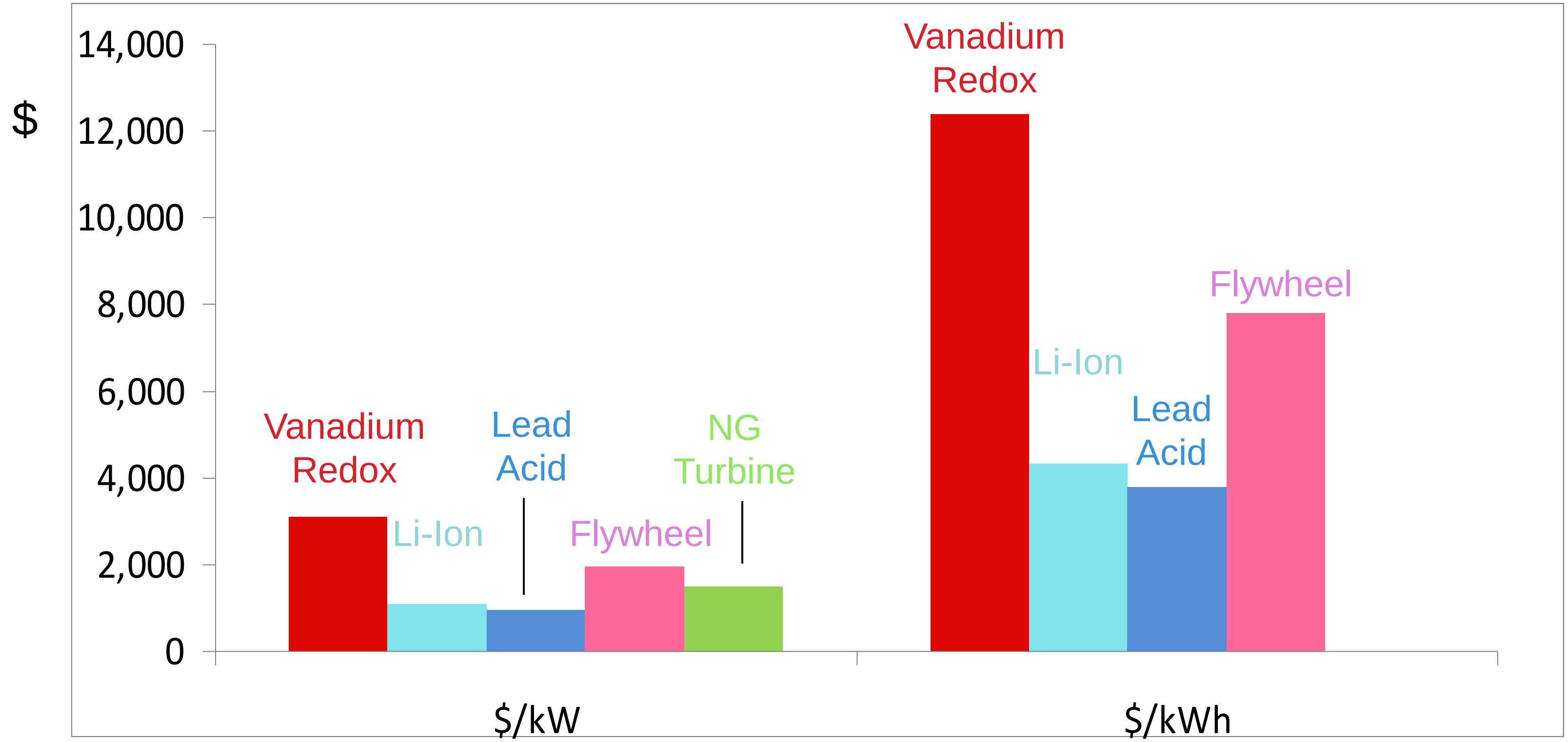
	Vanadium Redox	Lead Acid	Lithium Ion	Flywheel	Natural Gas	HBr Flow
Ramp Rate	Full Ramp in Seconds	Full Ramp in Seconds	Full Ramp in Seconds	Full Ramp in Seconds	20 MW/min	✓ ✓
Discharge Time	4-5 hour	15 min-4 hour	15 min-4 hour	15 min	n/a	✓
Power Capacity	50 MW	100 MW	100 MW	20 MW	100 MW	✓
Efficiency	70%	85%	90%	87%	n/a	✓
Lifetime	10-20 years	7-10 years	7-10 years	15-20 years	20 years	???

Must extend lifetime to 20 years

Estimates from EPRI 2010

Grid Reliability: Cost to Beat

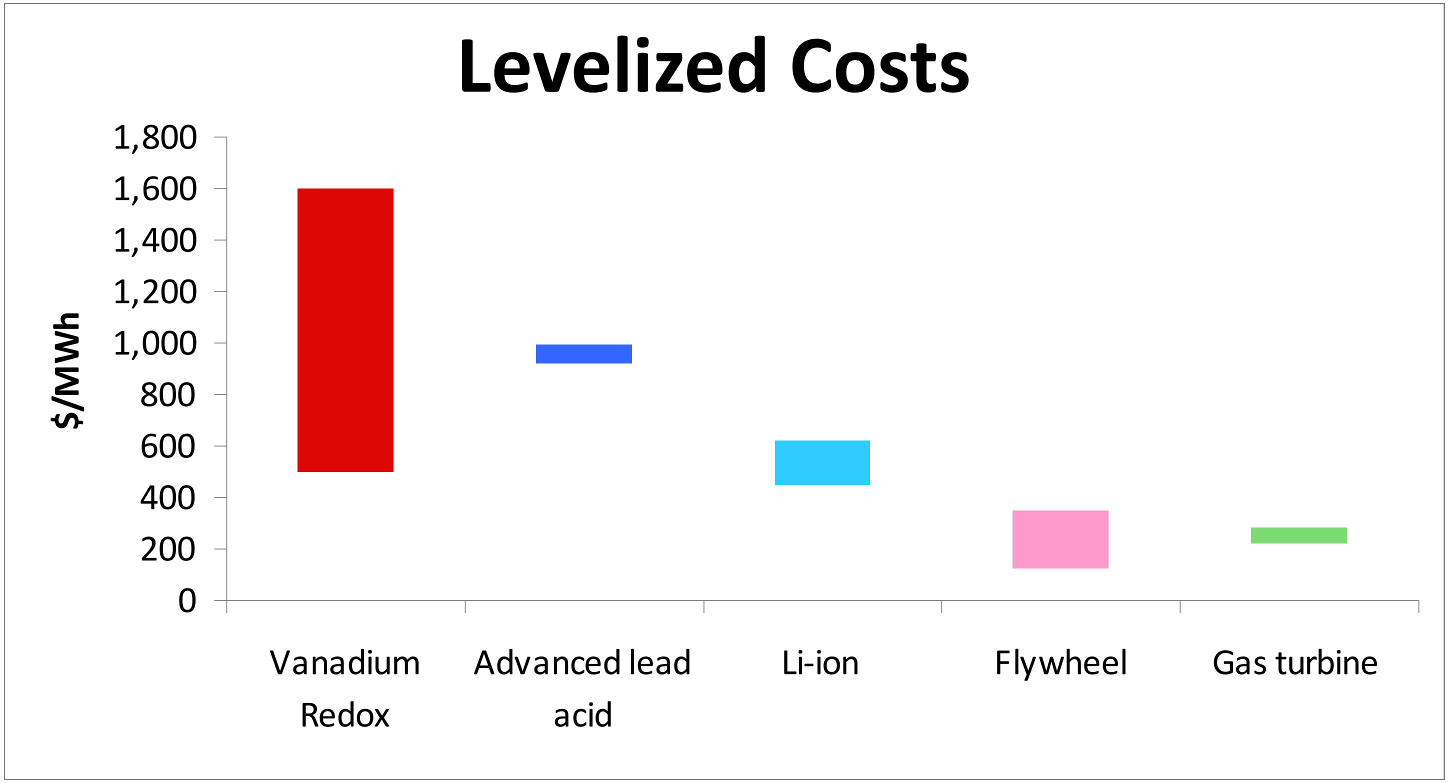
Installed Costs



Assumption: 15-min discharge times, gas turbine figures averaged from PJM, CAISO & NYISO (Source: EPRI)

Need better metric

Grid Reliability: Cost to Beat



Assumption: 15-min discharge times, cycle lifetimes from EPRI 2010, 5-17% capacity factor, gas turbine figures averaged from PJM, CAISO & NYISO (Source: EPRI)

Must beat $300/MWh

Grid Reliability: Optimal Locations

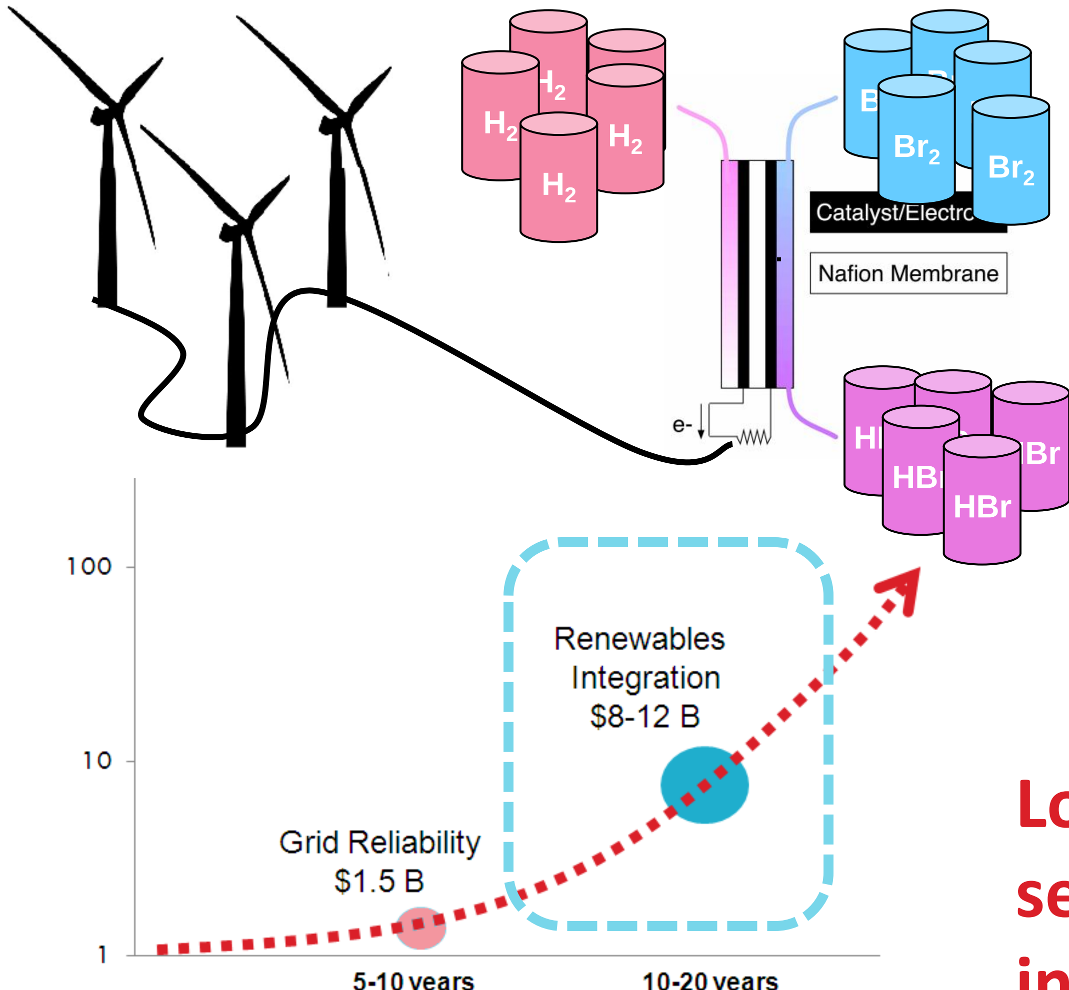
	NYISO	PJM	ISO-NE	CAISO
Market Size	Neutral → Leader	Leader	Laggard	Neutral → Leader
Tariff Favorability	Leader	Neutral → Leader	Neutral	Laggard → Neutral
Regulation Dynamics	Leader	Neutral → Leader	Leader	Laggard → Neutral
Government Support	Leader	Neutral	Leader	Neutral → ?
Wind Queue*	9 GW	7 GW	3GW	11.3GW

*As of March 2010

Leader
Neutral
Laggard

New York ISO is the most favorable first market

Second Market: Renewables Integration

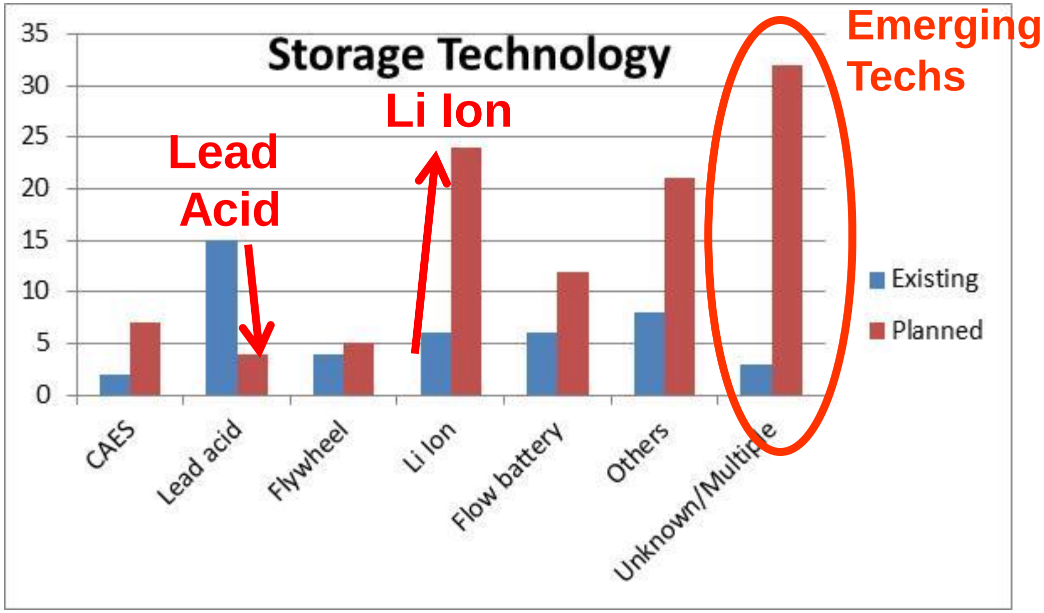


- **Similarities to grid reliability:**
  - High power
  - Long lifetime (20 years)
- **Difference:**
  - More tanks (4–8 hour discharge)

Low cost of added energy sets up renewables integration

Dynamically Changing Environment

Aggressive Competition



Pilot projects: 44 existing; 105 planned
Source: EPRI 2010

Evolving Regulations

- National convergence
- Renewable and storage portfolio standards
- Valuing quality and accuracy of electricity delivery

Watch dynamic factors

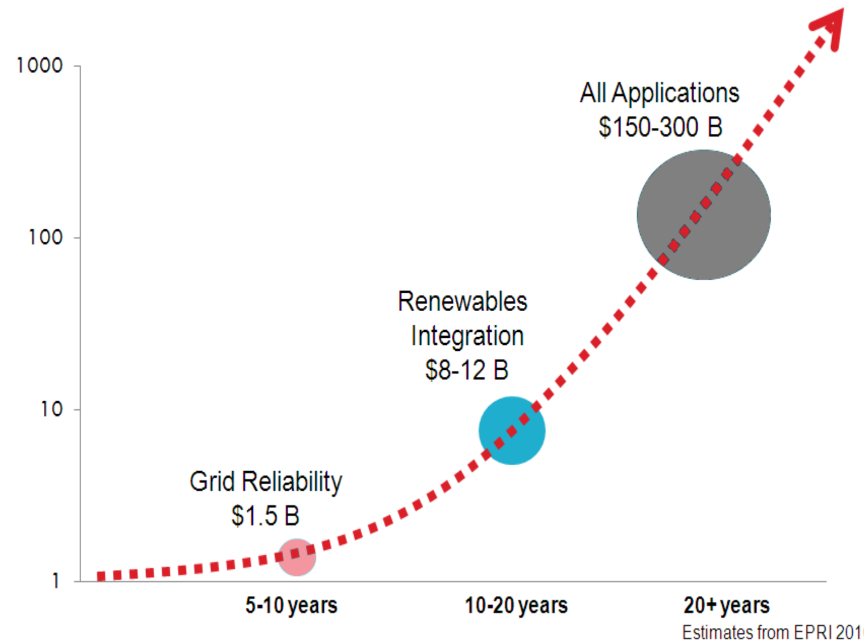
Long Road to Commercialization

Today	2016	2017	2019
Prototyping 5 years	Testing 1 year	Expanded pilot 2 year	Roll out to grid

- Key takeaways
  - Must prove reliability for direct-to-grid
  - Utility partners are crucial but risk averse
  - HBr development timeline aligns with storage need

Recommendations and Research Focus

- Best applications
  - Grid reliability
  - Renewables integration
- Best location: NYISO
- Regulatory tailwinds
  - Storage portfolio standards
  - Pricing power quality
- Address challenges
  - Long Lifetime
  - Bromine Toxicity



Thank You

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  - Proton Energy Systems
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