

CHAPTER 25

ENERGY STORAGE SYSTEM PRICING

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Abstract

Comparing the costs of rapidly maturing energy storage technologies poses a challenge for customers purchasing these systems. There is a need for a trusted benchmark price that has a well understood and internally consistent methodology so comparing the different technology options across different power and energy levels produces a reliable answer. This chapter, including a pricing survey, provides the industry with a standardized energy storage system pricing benchmark so these customers can discover comparable prices at different market levels. The chapter also gives emerging energy storage technologies a widely accepted pricing benchmark.

Key Terms

balance of System (BOS), battery energy storage system (BESS), energy management software (EMS), energy storage, Energy Storage Pricing Survey (ESPS), energy storage system (ESS), original equipment manufacturer (OEM), power conversion system (PCS), Storage Module (SM)

1. Introduction

This chapter (or pricing survey) provides a reference price to those purchasing these systems for the different energy storage technologies. The price is the expected installed capital cost of an energy storage system. Because the capital cost of these systems will vary depending on the power (kW) and energy (kWh) rating of the system, a range of system prices is provided.

2. Evolving System Prices

It is often difficult to obtain capital costs for various energy storage technologies because grid energy storage is still a nascent industry. This type of information is required to perform an initial cost-benefit analysis related to a potential energy storage deployment, as well as to compare different energy storage technology options.

This chapter summarizes energy storage capital costs that were obtained from industry pricing surveys. The survey methodology breaks down the cost of an energy storage system into the following categories: storage module, balance of system, power conversion system, energy management system, and the engineering, procurement, and construction costs. Pricing data is presented for the following technologies: pumped hydro storage, compressed air energy storage, sodium battery storage, zinc battery storage, long- and short-duration flywheels, vanadium flow batteries, zinc bromide flow batteries, iron flow batteries, nickel batteries, lithium ion energy batteries, lithium ion power batteries, lead acid batteries, and advanced lead carbon batteries.

Energy storage technologies of all types are continuing to advance. This advancement is not only driving the technology to a more mature commercial level, but also lowering their price along three key avenues.

1. Many advancements are focused on directly lowering the capital cost of the energy storage unit. This comes about through improved manufacturing (lower material usage) and improved energy storage capacity. Initial capital costs continue to be the most

significant aspect of total cost of ownership, making these advancements critical for improving the competitive position of energy storage technologies. Significant technology improvements would be most evident here.

2. Other advancements are focused on lowering the lifetime cost of the technology. For example, if the original equipment manufacturer (OEM) can produce a battery with twice the cycle life of the previous release at the same price, the capital cost of the two systems would remain the same, but the lifetime costs of the second would be lower. Reducing lifetime costs is increasingly important as energy storage technologies focus on applications that require extended operation. Significant technology improvements are possible here, but typically these advancements are incremental.
3. Finally, cost improvements that reduce the balance of system (BOS) will also therefore result in a lower overall system cost and should not be overlooked. Although no dramatic price reductions are expected, slower but sustained cost reductions are expected, which will help reduce the entire system costs over time.

3. Purpose

The annual Energy Storage Pricing Survey (ESPS) is designed to provide a reference system price to market participants, government officials, and financial industry participants for a variety of energy storage technologies at different power and energy ratings. Because of impact of the myriad of possible design and usage profiles have on the capital equipment requirements, a price of an energy storage system to someone purchasing such a system can vary considerably. In addition, there are competitive market forces that will also impact the potential price, leaving the potential customer sometimes bewildered by the resulting offers. For this reason, the ESPS is designed to provide a realistic expectation of what the price of energy storage systems could be.

The system price provided is the total expected installed cost (capital plus EPC) of an energy storage system to a customer. Because the capital cost of these system will vary depending on the power (kW) and energy (kWh) rating of the system, a range of system prices has been provided for the reader. In order to ensure that the results are useful for customers as they evaluate systems at different scales, a key part of the Energy Storage Pricing Survey is an internally consistent analysis framework which allows for a reliable comparison of different system ratings (power / energy). The Energy Storage Pricing Survey accomplishes this by developing the pricing structure and forecast at the component level, and then scaling up to the requisite power & energy rating.

The goal of this series of reports is to set expectations for customers of the cost of energy storage systems at different power and energy levels. Estimating the system price of an energy storage can be difficult as there is no “standard” system configuration, and due to the nascent nature of the industry and the ongoing scarcity of equipment, different system sizes. These, and other reasons, make it difficult for customers to use the available published pricing for specific energy storage systems to extrapolate to a system that fits their needs.

This approach benefits the results in a number of ways. First, all technologies are broken down into the most basic component possible, allowing the different technologies to have a similar frame of evaluation where possible. Secondly, this approach allows a greater amount of precision on the components that are similar across technologies—balance of systems, power electronics, construction—using the same cost structure where appropriate. Third, the forecasted prices are thus developed at the component level which supports greater precision for each price estimate as

the future costs for the different components will change at different rates. Finally, this structure also allows for a systematic evaluation of systems at different power and energy ratings. By have a component level pricing relationship for power electronics (for example), then the overall system price for the same technology will have a more accurate relationship to other systems at different power and energy ratings.

3.1. Coverage

The Energy Storage Pricing Survey provides data on 14 different energy storage technologies based on similar design or operating characteristics:

1. Pumped Hydro Storage (PHS)
2. Compressed Air Energy Storage (CAES)
3. Sodium (Na)
4. Zinc (Zn)
5. Flywheel: Long Duration (FWLD)
6. Flywheel: Short Duration (FWSD)
7. Flow Battery: Vanadium (FBV)
8. Flow Battery: Zinc Bromide (FBZnBr)
9. Flow Battery: Iron (FBFe)
10. Nickel (Ni)
11. Lithium Ion: Energy (LiE)
12. Lithium Ion: Power (LiP)
13. Lead (Pb)
14. Lead Carbon (PbC)

The list of covered technologies for the ESPS will remain flexible in future editions of the Energy Storage Pricing Survey to address emerging new energy storage technologies with sufficient representation to justify a separate category. This flexibility will also take into account energy storage technology families that lose currently operating firms, rendering that technology non-viable and hence removal from the Energy Storage Pricing Survey.

The Energy Storage Pricing Survey provides pricing information on possible energy storage systems according to variable power and energy ratings. The ranges of these ratings provide potential customers with a framework for the resulting costs of the different systems.

3.2. System Scaling: Power

To provide an indicative pricing guide for potential customers, energy storage pricing is divided along different comparative metrics, with the first being the power rating of the system. The ESPS utilizes 5 different power ratings to help differentiate systems for customers. This approach provides some benefits in providing additional characteristic detail:

First, energy storage systems are used at all levels of the electric power system. Therefore, a power scaling rating of from 1 to 5 is used which broadly aligns the size of the unit with a potential usage in the market, although this is of course not a hard and fast rule. The scaling rating cover a variety of market uses, including wholesale (Size 1), utility (Size 2), distribution/microgrid (Size 3), commercial and industrial (Size 4), and residential markets (Size 5).

Table 1. System Power Rating Sizing

System Size	MW	Potential Market Segment
1	100	Wholesale
2	10	Utility
3	1	Distribution & Microgrid
4	0.1	Commercial & Industrial
5	0.01	Residential

Second, different energy storage technologies are typically available at different scales typically based on either engineering or economics reasons. A key distinction needs to be made about what energy storage technology system pricing is estimated at these different levels. Essentially, although a technology may be technically capable of supporting a certain market segment / system scale, the ESPS will endeavor to provide information on different systems based on the likely market usage. For instance, pumped hydro storage systems are generally only available over a power rating of 100 MW, while lead acid battery systems are not typically available much past 1 MW. Since this based on actual usage and available real data, and possible future uses based on OEM/developer marketing efforts, the filter as to what technologies are used at different scales, is assumed to possibly change over time.

Third, the price of a particular energy storage system will generally scale with size. This is due to a number of factors, including purchasing power of equipment and some fixed capital costs of components can be shared across larger scaled systems.

3.3. System Scaling: Energy

Different energy storage technologies are typically available with varying amounts of energy capacity based on design and economic drivers. Specifically, although the energy storage capacity of the most basic unit of energy storage can be scaled into a variety of designs, OEMs and system integrators typically build the energy storage systems into specific building blocks of discharge duration.

This will have a profound impact on the deployment of energy storage technologies, and their potential for market usage. For instance, most flow batteries are not available for shorter duration (less than 3 hours). Conversely, cell-based technologies are able to be designed into a wide range of deployment designs (1 through 8 hours) but are typically only deployed where there is current or near-term expected economically viable uses. Therefore, a particular technology, such as lithium ion can be deployed with a wide range of discharge durations, these different possible deployment options would have different cost ratings (\$/kWh) and thus a different economic profile.

4. Survey Methodology

This pricing survey provides a reference price to customers for the different energy storage technologies. The price is the expected installed capital cost of an energy storage system to a customer. Because the capital cost of these systems will vary depending on the power (kW) and energy (kWh) rating of the system, a range of system prices has been provided.

The pricing survey is based primarily on 70 interviews with key firms representing groups from across the energy storage industry. These interviews provided component and system level price quotes of different energy storage technologies. If complete AC system prices were provided, these were used fully. If the price quotes consisted of components, these were averaged together to arrive at a component price, which was then added to other component pricing to arrive at a full system price.

Because the data for the survey came from a variety of sources, care was taken to address the potential for variability in the responses for a particular component cost. The areas for greatest potential variability in responses were assumed to be in areas where there are fewer respondents, and where the technology in question is less mature. For components with fewer respondents (but mature markets) efforts continue to expand the survey group and ask them for pricing estimates. For areas where there a few direct respondents due to only a few OEMs, surveying project developers and integrators that are active in the market can help augment the results from these few OEMs in order to widen the survey pool.

4.1. Data Acquisition

The data was derived from interviews with companies from across the energy storage industry (see Table 1).

Participating Company Type	2018 ESPS
Energy Storage OEM	30
Government / Academia	3
System Integrator	6
Power Electronics	9
Project Developer	6
Financial Industry	4
Consultants	7
Balance of System	1
EPC	4
Total Interviews	70
Published Data Sources	3
Total All Data Sources	73
Individual System Price Quotes	197

Figure 1. Pricing Survey Participants for the Energy Storage Pricing Survey (ESPS)

4.2. Equipment Costs

To discuss the capital equipment costs between different energy storage technologies, we need a common system architecture framework and terminology to describe the different components of an energy storage system. While different system architectures exist, this chapter describes a structure that follows an emerging general consensus.

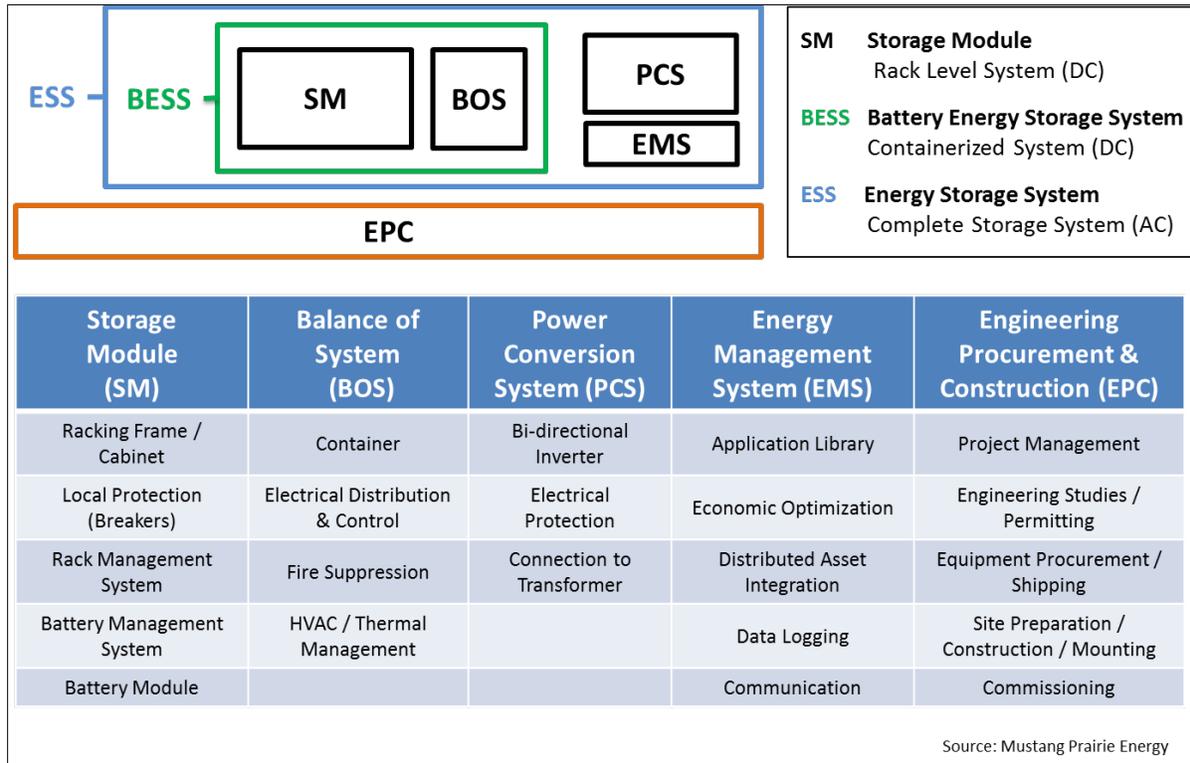


Figure 2. Energy Storage System diagram

To ensure a transparent and consistent evaluation of the different energy storage technologies, a standardized component framework is critical. The following are the definitions of the different segments of an energy storage system starting with the central energy storage component and working outwards.

- **Storage Module (SM):** An assembly of energy storage medium components (battery) built into a modular unit to construct the energy storage capacity (kWh) of an energy storage system. Example: A complete rack (or tower, or cabinet), consisting of the battery modules, battery management system (BMS), and associated electrical cabling.
- **Balance of System (BOS):** The equipment needed to combine a series of the storage modules into a complete DC level system, including electrical cabling, switchgear, thermal management, fire suppression, plus the enclosure, ranging from a special purpose enclosure, container, or a building.
- **Battery Energy Storage System (BESS):** The complete DC level energy storage system and comprises one or more storage modules with the accompanying BOS so the unit can be electrically connected with other electrical components.

- **Power Conversion System (PCS):** Converts and manages the power (kW) flow between the BESS's DC power output and the external AC power circuit—typically a step-up transformer to an AC distribution system. PCS components include the bi-directional inverter, any protection equipment to help isolate the DC system if needed, and the required cabling or busbar.
- **Energy Management Software (EMS):** Controls the operations of the energy storage system. The degree of the sophistication of this system is generally dictated by the range of expected market roles or applications the unit is expected to perform, and at what level in the market. Typically, the EMS includes communication equipment to connect to the utility supervisory control and data acquisition (SCADA) and data management systems.
- **Energy Storage System (ESS):** The complete equipment list for an AC-level energy storage system, comprising all the equipment up to, but not including, the step-up transformer. For ease of comparing different energy storage technologies, this total system price does not include certain electrical equipment such as metering equipment, which can vary from location.

4.3. System Scale Availability by Technology

Energy storage technologies are used at all levels of the power system. They are priced according to five different power ratings to provide a relevant system comparison and a more precise estimate. The power rating of an energy storage system impacts system pricing, where larger systems are typically lower in cost (on a \$/kWh basis) than smaller ones due to volume purchasing, etc.

5. Planned Future Improvements

There are several improvements planned by Mustang Prairie Energy for future enhancements of the energy storage pricing survey.

Capital Costs

- Improve BOS and power conversion system cost estimates through more detailed pricing analysis
- Add additional required components to improve safety and environmental conditioning requirements
- Improve deployment-specific cost requirements by enhancing the component specification for different operating environments.

Operating Costs

- Improve collection of fixed and variable O&M costs. Breaking out these costs from a simple, single metric is becoming more achievable, as more projects are deployed and the industry gains more experience.
- Incorporate a declining round trip efficiency of the energy storage system over time to better estimate the increasing thermal management requirement of the system.

Warranty Costs

- Improve structuring of warranty costs. As operating experience is gained, warranty coverage and costs are becoming more specific to usage profiles. Future pricing analysis that considers usage profiles must have a better understating of their effect on operating lifespans.
- Warranty analysis can be used as a proxy for operating lifespan.

Engineering, Procurement and Construction (EPC) Costs

- Develop US regional- and deployment-specific (urban, suburban, and rural) cost structure. There are a wide range of factors driving variability in EPC costs for energy storage projects including:
 - EPC firms’ lack of experience
 - Energy storage projects being deployed in both greenfield and brownfield situations
- As the industry expands, these costs are expected to decline as EPC firms gain experience. This experience will lower EPC costs through efficiency of scale and reduce the potential for overage costs after the contract begins.

6. Survey Results

Each of the following sections contains results for the 2018 pricing survey.

6.1. Pumped Hydro Storage

Table 2. Pumped Hydro Storage (PHS) installed system costs

Pumped Hydro Storage Costs					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kW	1633.2				

Table 3. Pumped Hydro Storage (PHS) performance characteristics

Pumped Hydro Storage Performance Characteristics	
Lifespan	40 Yrs.
Round-Trip Efficiency (AC)	82%
Operating Range (Depth of Discharge %)	100%
Capacity at End of Life (% of Original)	100%
Operation & Maintenance (O&M)	1%
Extended Warranty	0%

6.2. Compressed Air Energy Storage

Table 4. Compressed Air Energy Storage (CAES) installed system costs

Compressed Air Storage Costs					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kW	1614.3				

Table 5. Compressed Air Energy Storage (CAES) performance characteristics

Compressed Air Storage Performance Characteristics	
Lifespan	40 Yrs.
Round-Trip Efficiency (AC)	55%-80%
Operating Range (Depth of Discharge %)	100%
Capacity at End of Life (% of Original)	100%
Operation & Maintenance (O&M)	1%
Heat Rate (DT/MWh)	4.1%

6.3. Sodium

Table 6. Sodium (Na) installed system costs

Sodium Costs / 6-Hr					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kWh	378.5	400.7	439.9		

Table 7. Sodium (Na) Performance characteristics

Sodium Characteristics	
Lifespan	15 Yrs.
Round-Trip Efficiency (AC)	75%
Operating Range (Depth of Discharge %)	80%
Capacity at End of Life (% of Original)	80%
Operation & Maintenance (O&M)	2%

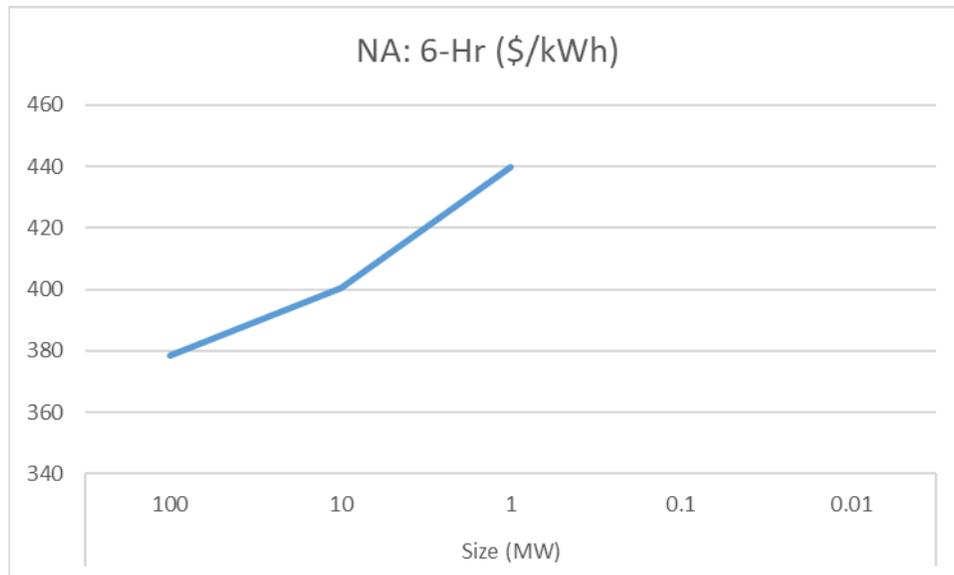


Figure 3. Sodium (Na) installed system costs

6.4. Zinc

Table 8. Zinc (Zn) installed system costs

Zinc Costs / 4-Hr					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kWh	252.1	268.0	310.7	366.1	

Table 9. Zinc (Zn) performance characteristics

Zinc Characteristics	
Lifespan	10 Yrs.
Round-Trip Efficiency (DC)	75%
Operating Range (Depth of Discharge %)	80%
Capacity at End of Life (% of Original)	80%
Operation & Maintenance (O&M)	2%

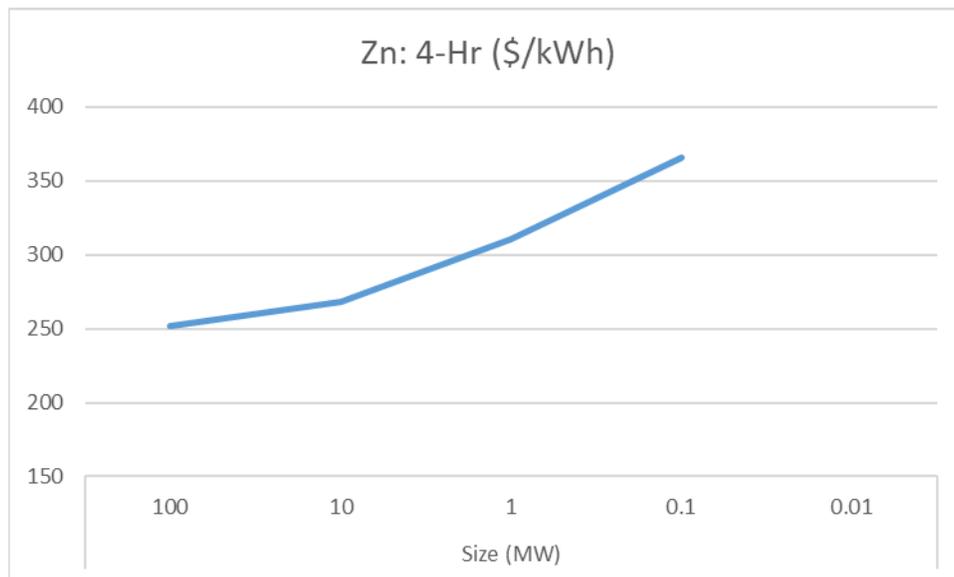


Figure 4. Zinc (Zn) installed system costs

6.5. Flywheel: Long Duration

Table 10. Flywheel: Long Duration (FWLD) installed system costs

Flywheel: Long Duration Costs / 4-Hr					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kWh		676.0	753.3		

Table 11. Flywheel: Long Duration (FWLD) performance characteristics

Flywheel: Long Duration Characteristics / 4-Hr					
	Size (MW)				
	100	10	1	0.01	0.001
\$/kWh		676.0	753.3		

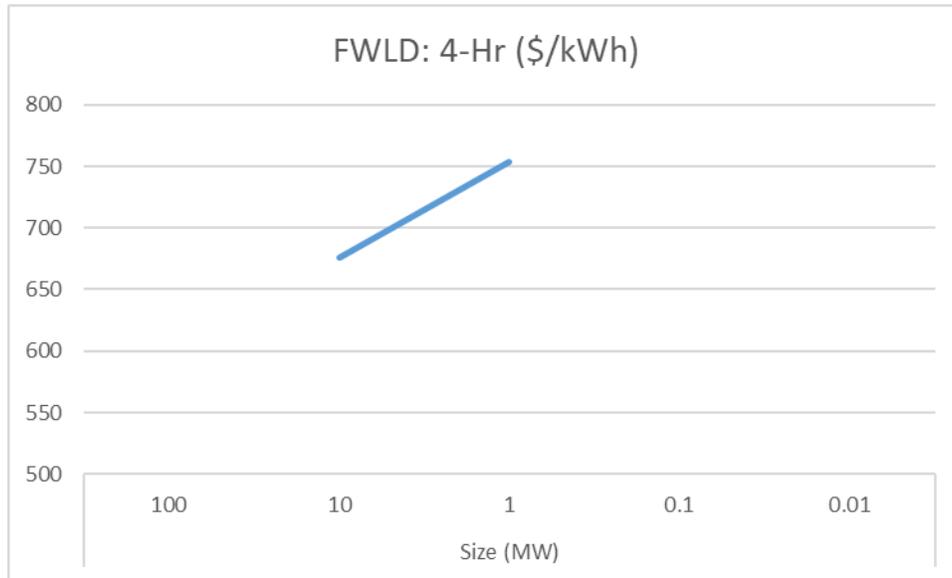


Figure 5. Flywheel: Long Duration (FWLD) installed system costs

6.6. Flywheel: Short Duration

Table 12. Flywheel: Short Duration (FWSD) installed system costs

Flywheel: Short Duration Costs					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kW		880.0	1146.5	1250.0	

Table 13. Flywheel: Short Duration (FWSD) performance characteristics

Flywheel: Short Duration Characteristics	
Lifespan	20 Yrs.
Round-Trip Efficiency (AC)	80%
Operating Range (Depth of Discharge %)	100%
Capacity at End of Life (% of Original)	100%
Operation & Maintenance (O&M)	2%

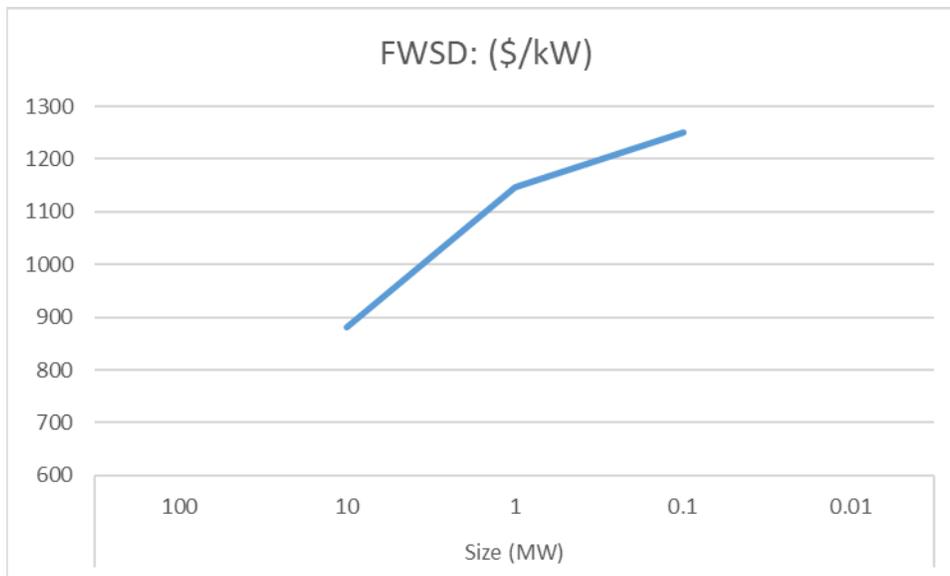


Figure 6. Flywheel: Short Duration (FWSD) installed system costs

6.7. Flow Battery: Vanadium

Table 14. Flow Battery: Vanadium (FB V) installed system costs

Flow Battery: Vanadium Costs					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
FB V: 4-Hr	409.9	424.2	520.1	617.3	
FB V: 6-Hr	345.5	379.1	432.1	522.5	
FB V: 8-Hr	304.6	343.1	402.4	487.2	

Table 15. Flow Battery: Vanadium (FB V) performance characteristics

Flow Battery: Vanadium Characteristics	
Lifespan	20 Yrs.
Round-Trip Efficiency (AC)	70%-80%
Operating Range (Depth of Discharge %)	100%
Capacity at End of Life (% of Original)	100%
Operation & Maintenance (O&M)	3%

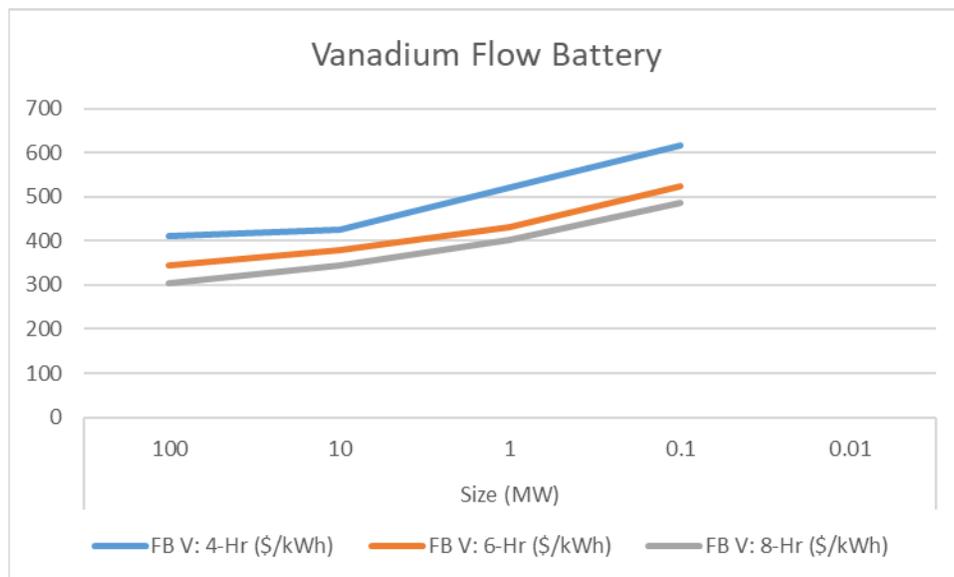


Figure 7. Flow Battery: Vanadium (FB V) installed system costs

6.8. Flow Battery: Zinc Bromide

Table 16. Flow Battery: Zinc Bromide (FB ZnBr) installed system costs

Flow Battery: Zinc Bromide Costs					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
FB ZnBr: 3-Hr				746.5	
FB ZnBr: 4-Hr	472.2	506.0	555.3	630.3	
FB ZnBr: 5-Hr	417.2	429.5	452.0	493.9	
FB ZnBr: 6-Hr	413.5	425.7	447.3	485.9	

Table 17. Flow Battery: Zinc Bromide (FB ZnBr) system costs

Flow Battery: Zinc Bromide Characteristics	
Lifespan	20 Yrs.
Round-Trip Efficiency (AC)	70%
Operating Range (Depth of Discharge %)	100%
Capacity at End of Life (% of Original)	100%
Operation & Maintenance (O&M)	3%

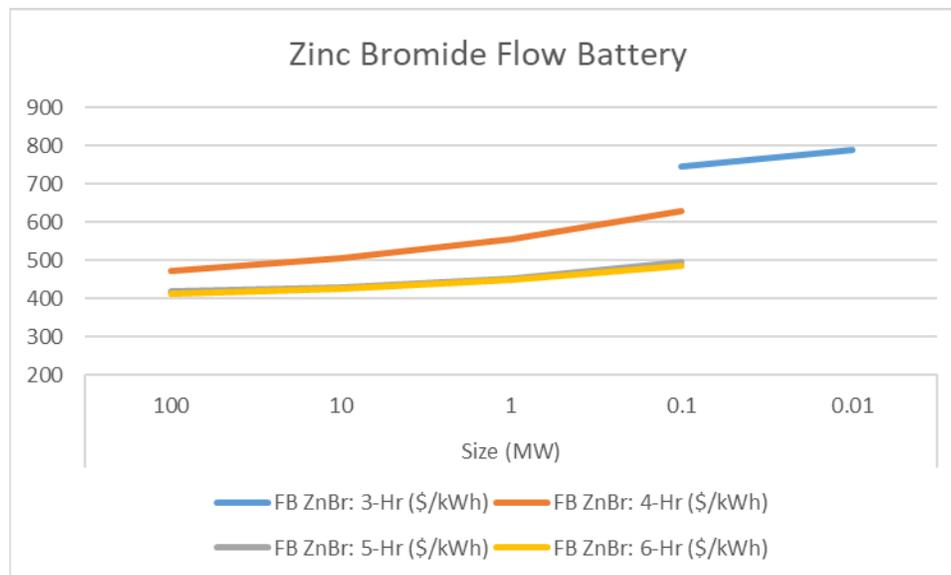


Figure 8. Flow Battery: Zinc Bromide (FB ZnBr) installed system costs

6.9. Flow Battery: Iron

Table 18. Flow Battery: Iron (FB Fe) installed system costs

Flow Battery: Iron Costs / 4-Hr					
	Size (MW)				
	100	10	1	0.1	0.01
\$/kWh	404.5	416.4	443.8	505.1	

Table 19. Flow Battery: Iron (FB Fe) system costs

Flow Battery: Iron Characteristics	
Lifespan	20 Yrs.
Round-Trip Efficiency (AC)	70%
Operating Range (Depth of Discharge %)	100%
Capacity at End of Life (% of Original)	100%
Operation & Maintenance (O&M)	3%

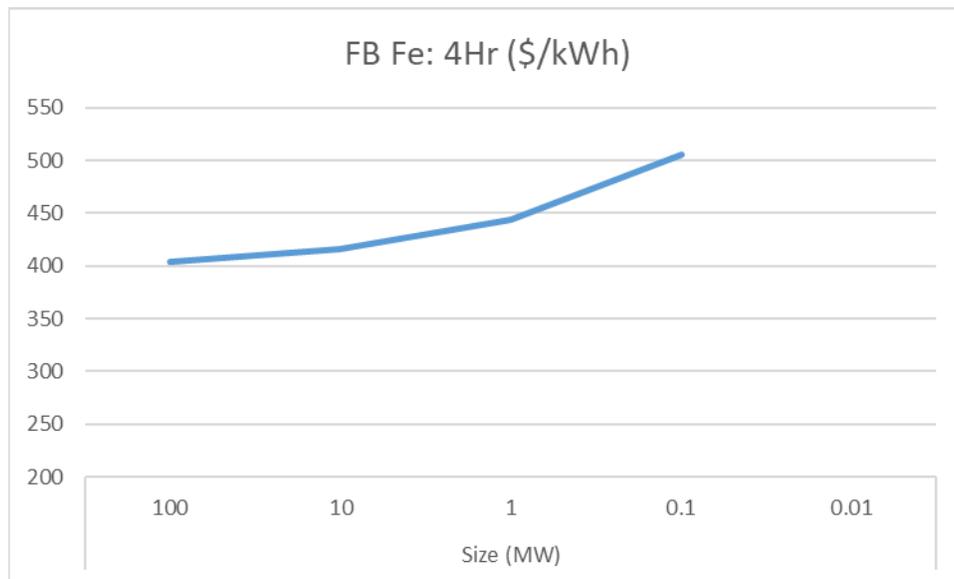


Figure 9. Flow Battery: Iron (FB Fe) installed system costs

6.10. Nickel

Table 20. Nickel (Ni) installed system costs

Nickel (Ni) Costs					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
Ni: 2-Hr			339.6	466.4	835.2
Ni: 3-Hr			320.5	434.4	741.6
Ni: 4-Hr			311.0	418.5	694.8

Table 21. Nickel (Ni) performance characteristics

Nickel (Ni) Characteristics	
Lifespan	10 Yr.
Round-Trip Efficiency (AC)	75%
Operating Range (Depth of Discharge %)	80%
Capacity at End of Life (% of Original)	80%
Operation & Maintenance (O&M)	2%

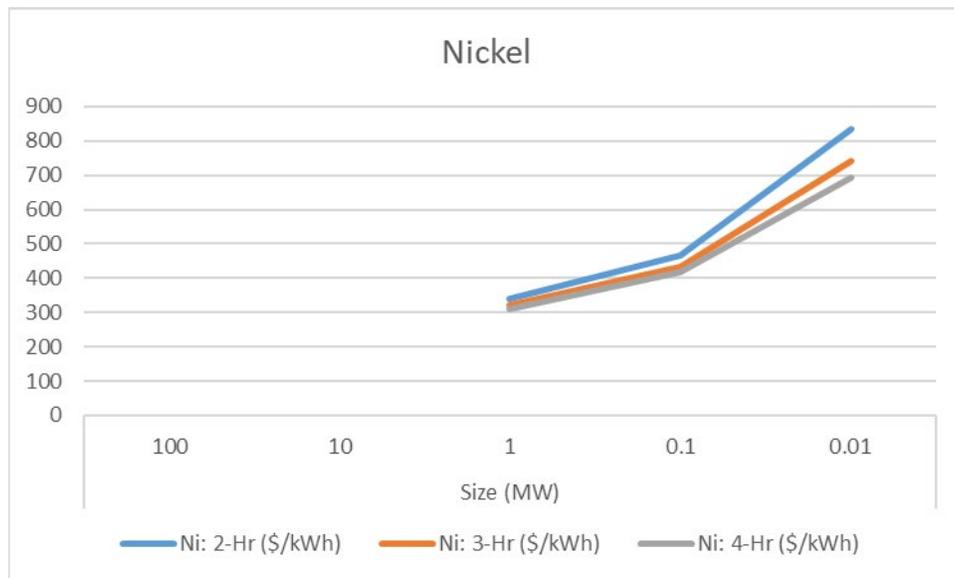


Figure 10. Nickel (Ni) installed system costs

6.11. Lithium-Ion: Energy

Table 22. Lithium Ion: Energy (Li) installed system costs

4					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
Li: 2-Hr	451.8	474.6	558.9	719.4	1057.8
Li: 3-Hr	429.3	449.9	535.5	679.5	930.9
Li: 4-Hr	420.1	440.6	523.8	659.6	867.4
Li: 5-Hr	410.5	435.0	516.8	647.6	829.3
Li: 6-Hr	406.8	431.2	512.1	639.6	803.9
Li: 7-Hr	404.2	428.6	508.8	633.9	785.8
Li: 8-Hr	402.2	426.6	506.3	629.6	772.2

Table 23. Lithium Ion: Energy (Li) performance characteristics

Lithium-Ion: Energy Characteristics	
Lifespan	10 Yrs.
Round-Trip Efficiency (AC)	85%-90%
Operating Range (Depth of Discharge %)	80%-100%
Capacity at End of Life (% of Original)	70%-80%
Operation & Maintenance (O&M)	2%

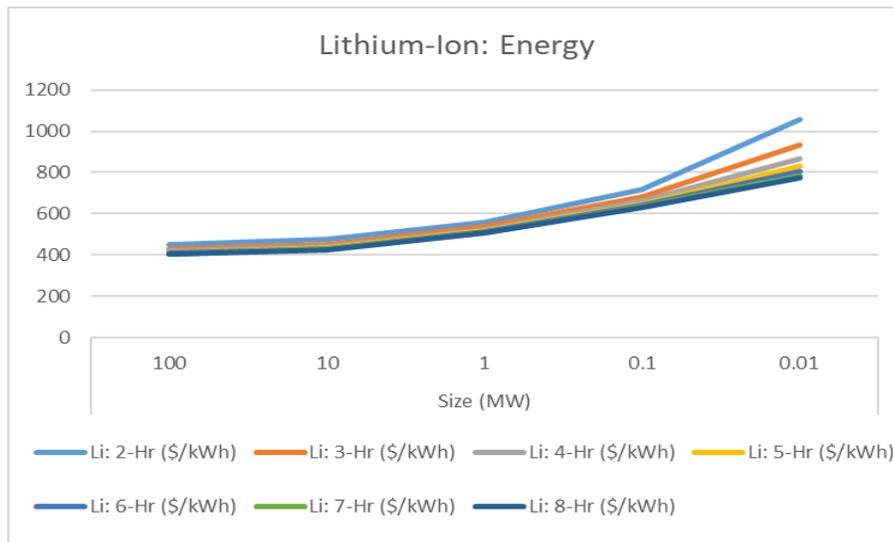


Figure 11 Lithium Ion: Energy (Li) installed system costs

6.12. Lithium-Ion: Power

Table 24. Lithium-Ion: Power (Li) installed system costs

Lithium-ion: Power Costs					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
Li: 0.5-Hr	808.5	849.8	1007.3	1398.9	
Li: 1-Hr	466.3	485.5	592.3	755.2	

Table 25. Lithium-Ion: Power (Li) performance characteristics

Lithium-ion: Power Characteristics	
Lifespan	10 Yrs.
Round-Trip Efficiency (AC)	80%-85%
Operating Range (Depth of Discharge %)	80%-100%
Capacity at End of Life (% of Original)	70%-80%
Operation & Maintenance (O&M)	2%

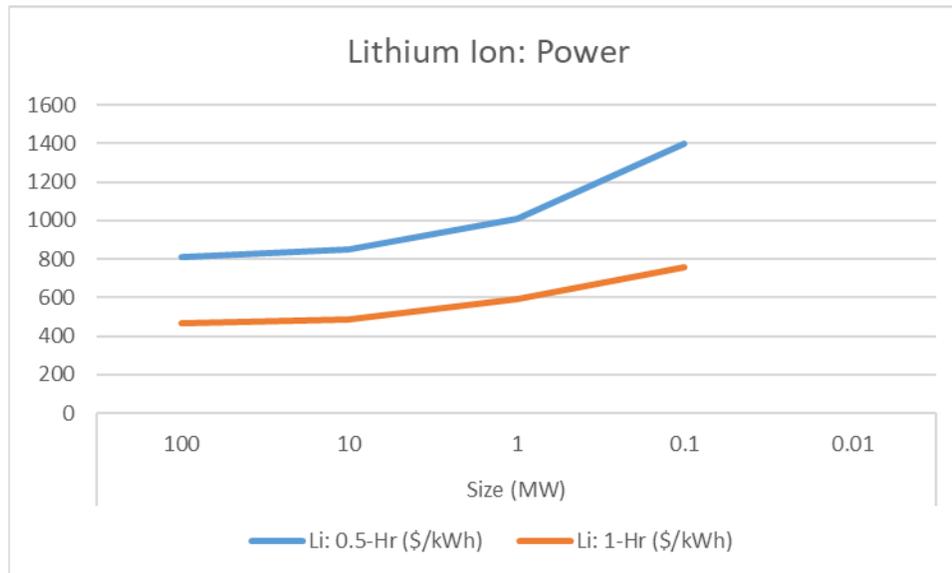


Figure 12. Lithium-Ion: Power (Li) installed system costs

6.13. Lead

Table 26. Lead (Pb) installed system costs

Lead (Pb) Costs					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
Pb: 2-Hr			445.8	550.4	810.6
Pb: 2-Hr			375.5	461.8	633.2
Pb: 2-Hr			338.4	415.4	542.3

Table 27. Lead (Pb) performance characteristics

Lead (Pb) Characteristics	
Lifespan	5 Yrs.
Round-Trip Efficiency (AC)	80%
Operating Range (Depth of Discharge %)	50%
Capacity at End of Life (% of Original)	80%
Operation & Maintenance (O&M)	3%

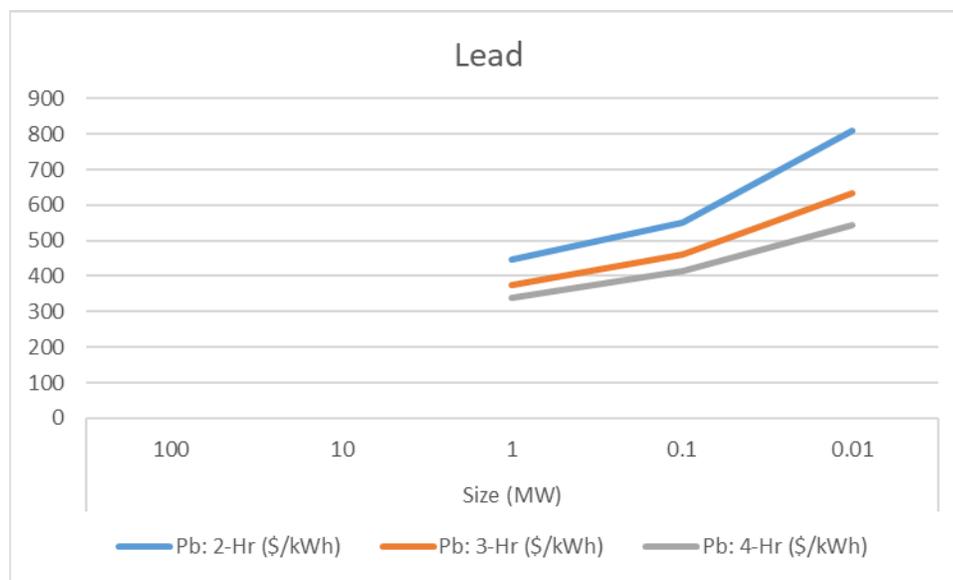


Figure 13. Lead (Pb) installed system costs

6.14. Lead Carbon

Table 28. Lead Carbon (PbC) installed system costs

Lead Carbon (PbC) Costs					
\$/kWh	Size (MW)				
	100	10	1	0.1	0.01
PbC: 2-Hr			720.9	877.8	1201.6
PbC: 3-Hr			598.1	738.4	973.8
PbC: 4-Hr			547.5	664.4	855.0

Table 29. Lead Carbon (PbC) performance characteristics

Lead Carbon (PbC) Characteristics	
Lifespan	5-10 Yrs.
Round-Trip Efficiency (AC)	80%
Operating Range (Depth of Discharge %)	70%
Capacity at End of Life (% of Original)	80%
Operation & Maintenance (O&M)	3%

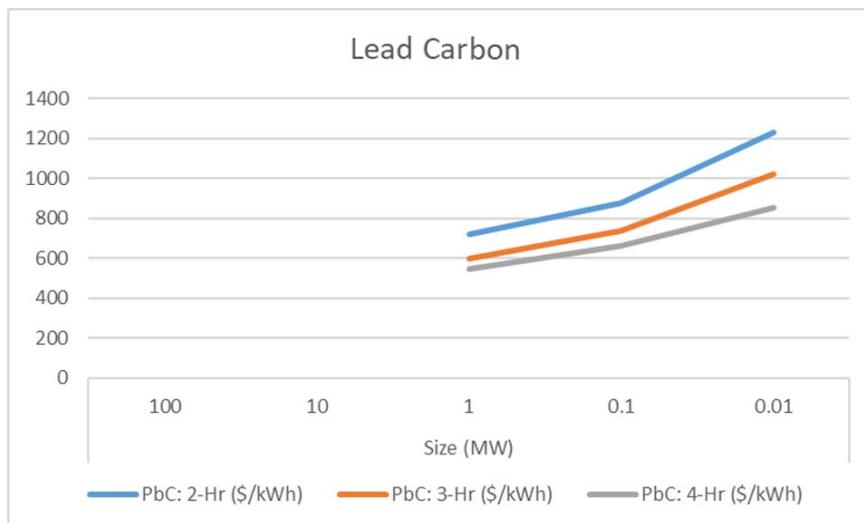


Figure 14. Lead Carbon (PbC) installed system costs



Richard Baxter is President of Mustang Prairie Energy where he bridges the financial and technical sides of the energy storage industry for investors, lenders, project developers, and manufacturers. Richard has been active in the energy storage industry for 20 years, holding a variety of positions across the value chain. Richard is the author of the study series on Energy Storage Financing, and the annual Energy Storage Pricing Survey, both published through Sandia National Laboratories. He has served on the Board of Directors of the Energy Storage Association, and the Charitable Foundation of the Energy Bar Association. Richard holds a BS in Materials Engineering from Virginia Tech, and an MS in Energy Policy from the University of Pennsylvania.



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