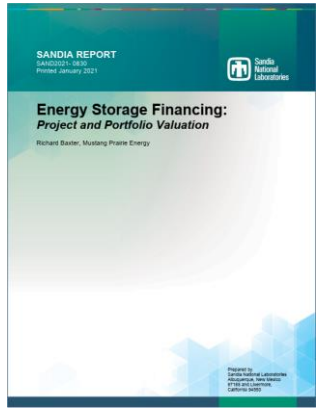
2021 DOE OE
Energy Storage Peer Review

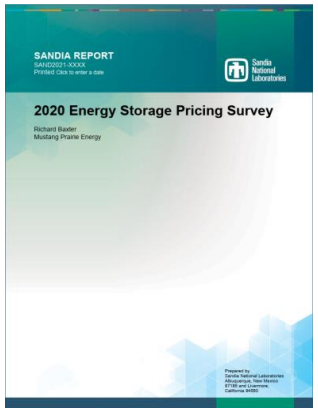
Richard Baxter
President
Mustang Prairie Energy

Energy Storage Financing Study



October 28th, 2021
5:00 pm – 5:15 pm

Energy Storage Pricing Survey



Acknowledgements

The author would like to acknowledge the support and guidance of Dr. Imre Gyuk, Director of the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability's Energy Storage Program, and Dr. Babu Chalamala and Dr. Ray Byrne of the Energy Storage Systems Program of Sandia National Laboratories.

Dr. Imre Gyuk, DOE – Office of Electricity

- Program Manager for the OE's Energy Storage Program

Dr. Babu Chalamala – Sandia National Laboratories

- Manager, Grid Energy Storage

Dr. Ray Byrne – Sandia National Laboratories

- Manager, Advanced Grid Modeling

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Presenter

Richard Baxter - President
Mustang Prairie Energy

Richard Baxter is President of Mustang Prairie Energy where he bridges the financial and technical sides of the energy storage industry for capital providers, project developers, and manufacturers. Richard has been active in the energy storage industry for 20 years, working across the industry, including at a storage OEM, investment bank, and as a strategy consultant.

Richard is the author of the U.S. DOE sponsored study series on Energy Storage Financing through Sandia National Laboratories. He is also the author of the Energy Storage Pricing Survey series and supports the Technology Cost and Performance Assessment for the DOE's Energy Storage Grand Challenge. Previously, he provided the cost surveys and capital pricing model for the Lazard Levelized Cost of Storage (LCOS) Survey 1.0, 2.0 and 3.0.

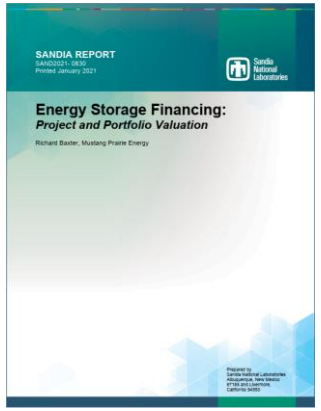
He has served on the Board of Directors for the Energy Storage Association, the Charitable Foundation of the Energy Bar Association, and NovoCarbon. He was also the founder and Executive Director of the Advancing Contracting in Energy Storage (ACES) Working Group where he led the development of the ACES Energy Storage Best Practice Guide.

Energy Storage Financing Study Series

MUSTANG PRAIRIE ENERGY

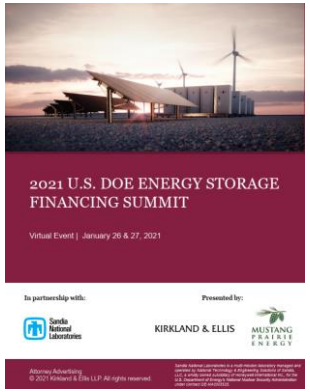
Outreach to Financial Industry

- Improve Risk Management for Energy Storage Project Development
- Promote Greater Technology and Project Risk Transparency
- Promote Wider Access to Low-Cost Capital
- Reduce Project & Transaction Costs



Study Components

- Workshops: Project Valuation Modeling
- Summits: Current Market Insights
- Reports: Document Lessons Learned



Reports: Available at https://www.sandia.gov/ess-ssl/

- Energy Storage Financing: *A Roadmap for Accelerating Market Growth* SAND2016-8109
- Energy Storage Financing: *Performance Impacts on Project Financing* SAND2018-10110
- Energy Storage Financing: *Advancing Contracting in Energy Storage* SAND2019-14896
- Energy Storage Financing: *Project & Portfolio Valuation* SAND2021-0830
- Energy Storage Financing: *Operations & Market Strategy* SAND2021-xxxx
- Energy Storage Financing*: Cost & Revenue Certainty (Underway)* SAND2022-xxxx

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Sandia National Laboratories

Hosts:

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Energy Storage Financing: Cost & Revenue Certainty *(Current Study)*

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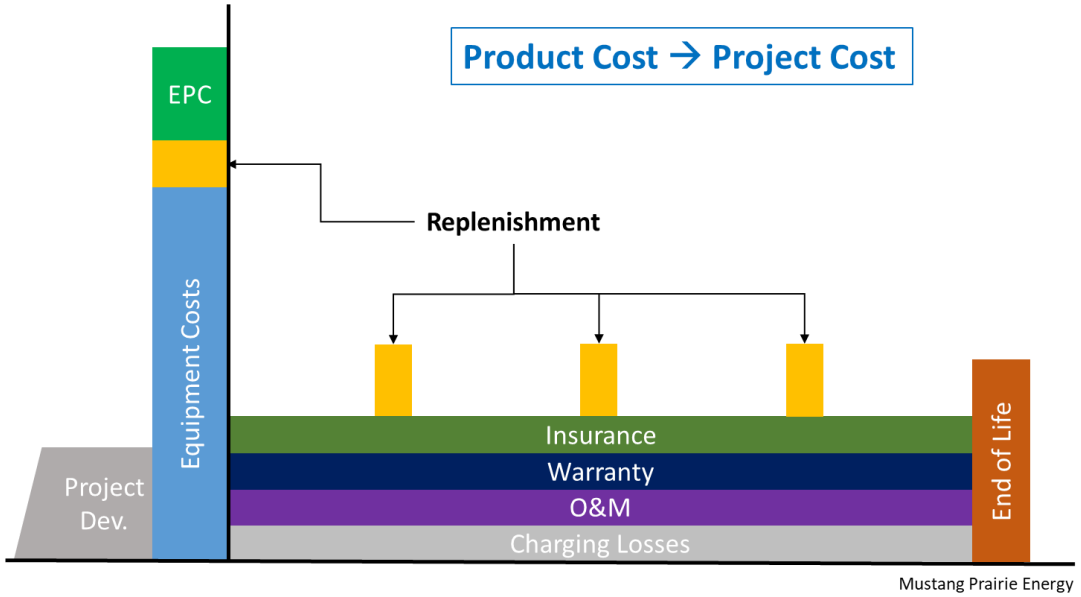
Cost Certainty

Project Development
- Market Modeling
- Equipment / System Design
- Interconnection / Permitting
- EPC (Installation & Commissioning)
- Legal / Financing Costs

Capital Equipment
- Cost Reductions
- Performance Improvements
- Application Specific Cost Estimate

Operations
- O&M
- Replenishment
- Insurance / Warranties
- End of Life

Long Duration Energy Storage
- Capital Costs
- Installation
- Operations



Li-Ion	Slowing Average Cost Decline in Near Term Greatest Decline in Larger Systems Significant Upside Cost Pressure for Many Customers

Storage Module	BOS	PCS	EPC
Materials Manufacturing Vehicle Demand	Steel HVAC Safety	Copper Steel Software	Scale Location Experience

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Energy Storage Financing: Cost & Revenue Certainty *(Current Study)*

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Revenue Certainty

Market Modeling
- Existing Applications
- Future Possible Applications
- Visibility: Clearing / Bilateral / ????

Off-Take
- Contract (PPA)
- Hedge
- Spot Market

Impact from Operations
- Lifespan Performance
- Hybrid Systems
- Dynamic Operation

Incentives
- Deployment (ITC)
- Usage (Green/Firm PPA?)

Long Duration Energy Storage
- New Regulatory Structures
- New Off-Take Contracts

Market	Role	Applications	Oversight
Wholesale	Stand Alone Hybrid Operation	• Arbitrage • Peak Capacity Deferral • Reserves • Frequency Regulation • Ramping • Synthetic Inertia	NERC, FERC
Utility	Transmission Distribution Island / Microgrid Behind the Meter	• Transmission Deferral • Transmission Congestion Relief • Blackstart • Voltage Support • Microgrid / Islanding • Distribution Deferral	PUC, NERC, FERC
Behind the Meter	Industrial Commercial Hybrid Generation Residential	• TOU Energy Management • Demand Charge Management • Backup Power • Working Storage • Distribution Energy Management • Power Quality	PUC, FERC

Some BTM Units Active in Wholesale Markets

Discrete	Definable	Indeterminate
Formal Markets, Price Visibility, Multiple Parties	Bilateral Contract, Location Specific, Contract Specific	Individuals Value Application Differently, Highly Variable
Frequency Regulation	Black Start	Reliability

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Energy Storage Financing Study Series: Summits & Workshops

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Financing Summits

- Outreach to the Financial Industry
- Allows DOE to engage directly with those shaping the storage industry
- Promotes financial industry networking with storage industry leaders
- Platform to promote DOE programs and resources

Valuation Workshops

- Valuation Models
- Compare Modeling Approaches
- Revenue Recognition / Value Stacking
- Results from Project Analysis

Event Dates

2021 – Sept 28 & 29	Virtual	240 Attendees
2021 – Jan 26 & 27	Virtual	300 Attendees
2020 – Sept 22 & 23	Virtual	150 Attendees
2020 – Jan 14th	NY, NY	170 Attendees
2019 – Oct 22nd	SF, CA	74 Attendees
2019 – Jan 23rd	NY, NY	146 Attendees
2018 – Oct 6th	SF, CA	104 Attendees
2018 – Jan 18th	NY, NY	124 Attendees
2017 – June 7th	D.C.	84 Attendees
2017 – Jan 11th	NY, NY	68 Attendees
2014 – Dec 16th	NY, NY	65 Attendees

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Energy Storage Financing Summit: September 28th & 29th, 2021

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Day 1: Valuation Workshop

Welcome	Rohit Chaudhry, Kirkland & Ellis LLP
Chairman	Richard Baxter, Mustang Prairie Energy
Keynote	Imre Gyuk, U.S. Department of Energy
Keynote	Bobby Jeffers, Sandia National Laboratories
Workshop	Moderator: Ray Byrne, SNL • Tu Nguyen, SNL • Di Wu, PNNL • Giovanni Damato, EPRI • Patrick Balducci, ANL

Recordings will be available at:
https://www.sandia.gov/ess-ssl/

Day 2: Industry Panels

Welcome	Rohit Chaudhry, Kirkland & Ellis LLP
Chairman	Richard Baxter, Mustang Prairie Energy
Keynote	Michael Pesin, U.S. Department of Energy
Keynote	Mike Gravely, California Energy Commission
Panel 1: Market Overview	Moderator: Robert Fleishman, Kirkland & Ellis • Alicia Barton, FirstLight Power • Jack Farley, Apex Compressed Air Energy Storage • Troy Miller, GE Renewable Energy • Salvatore Minopoli, Largo Clean Energy • Russ Weed, Advanced Rail Energy Storage
Panel 2: Capital Providers	Moderator: Tatiana Monastyrskaya, Kirkland & Ellis • Cassidy Deline, Cypress Creek Renewables • Tom Dickson, New Energy Risk • Roman Fontes, Western Area Power Administration • Mike Lorusso, CIT • Sondra Martinez, Nord/LB

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Next Summit & Workshop

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2022 U.S. DOE Energy Storage Financing Summit (NYC)

Event

- **January 20th, 2022**
- Hosted by Kirkland & Ellis & Mustang Prairie Energy
- Hybrid Event: In-Person & Virtual Event
- Free Event / Invitation Required to Register

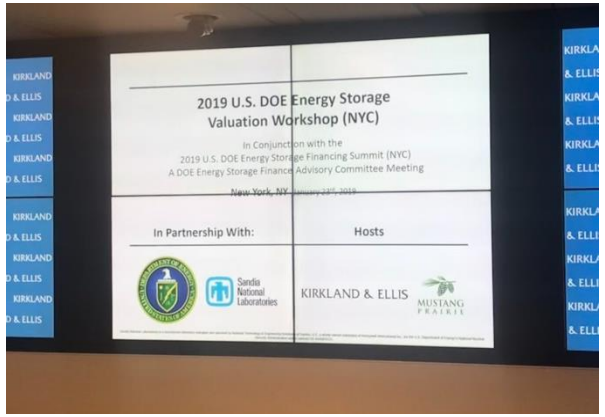
Energy Storage Valuation Workshop

Panel 1: Market Overview

Panel 2: Capital Providers

Panel 3: Revenue Certainty

Invitations to the live feed will be sent to all DOE-OE Energy Storage Peer Review Participants



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Energy Storage Pricing Survey Series

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Energy Storage Pricing Survey Overview

Provides
- Realistic Expectation for System Price
- Standardized Reference Benchmark Price
- Range of System Costs Based on Range of Power / Energy Ratings

Technologies Covered
- 15 Technology Families Currently Covered
- Provides Support for Non-Lithium Technologies
- Grid Applications of 2 Hours to Long Duration
- UPS Technologies Not Covered

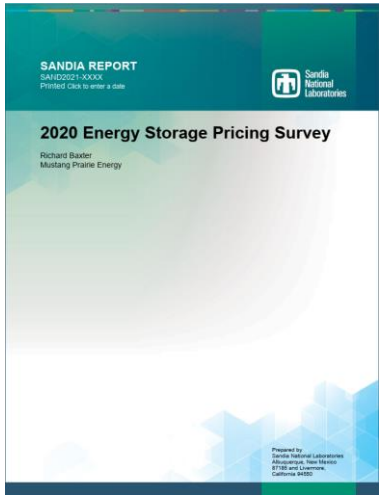
Data Acquisition
- Primary – OEM & Customers
- Secondary – Market Reports
- Weighting of Data Allows to Promote Market Accuracy
- Survey Options
- U.S. Based Deployment

Anonymity
- Component and System Price Quotes
- Specific OEM Price Quote Remains Confidential

Key Takeaways

Lithium
- Slowing Average Cost Decline in Near Term (Lithium)
- Greatest Decline in Larger Systems
- Significant Upside Cost Pressure for Many Customers

Non-Lithium
- Project Development / EPC Costs Lacking Experience
- Exposure to Commodity Prices



Energy Storage Pricing Survey (ESPS)

Available at https://www.sandia.gov/ess-ssl/

2018 ESPS	SAND2019-14896
2019 ESPS	SAND2021-0831
2020 ESPS	SAND2021-XXXX
2021 ESPS (Underway)	SAND2022-XXXX

Energy Storage Pricing Survey: Technology Coverage / Data Sourcing

Participating Groups	2018	2019	2020
Energy Storage OEM	30	29	26
Gov / NGO / Edu	3	4	7
System Integrator	6	9	5
Power Electronics	9	2	2
Developer / IPP	6	7	11
Financial / Insurance	4	11	9
Consultant / Engineering	3	6	12
Balance of System	1	1	3
EPC / ECI	4	2	7
Utility	4	1	1
Total Interviews	**70**	**72**	**83**
Published Data Sources	**3**	**7**	**15**
Total All Data Sources	**73**	**77**	**98**
Unique Component Price Quotes	**197**	**234**	**277**
Synthetic Price Quote	**96**	**114**	**136**

	2020 ESPS Technology	
1	Pumped Hydro Storage	PHS
2	Compressed Air Energy Storage	CAES
3	Advanced Compressed Air Energy Storage	ACAES
4	Liquid Air Energy Storage	LAES
5	Gravity Energy Storage	GES
6	Sodium	Na
7	Flow Battery: Vanadium	FBV
8	Flow Battery: Zinc Bromide	FBZnBr
9	Flow Battery: Iron	FBFe
10	Flywheel: Long Duration	FWLD
11	Flywheel: Short Duration	FWSD
12	Lithium Ion: NMC	LiNMC
13	Lithium Ion: LFP	LiLFP
14	Zinc	Zn
15	Lead	Pb

Energy Storage Pricing Survey: Methodology

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Data Collection

Technology Specific
- Price not Cost
- Includes Est. Profit Margin
- Technology Specific
- Rating (Power/Energy)
- Component Level
- Full Systems
- Performance Metrics
- Operating Costs

Weighting
- Component Level
- Direct / Indirect
- Commercial Position

Primary - Interviews
- Direct
- Indirect

Secondary - Published
- Published Price Quotes
- Reports
- Media

System Ratings

Power
- Technology Specific
- 100 MW: Wholesale
- 10 MW: Utility
- 1 MW: Distribution / Microgrid
- 100 kW: Commercial & Industrial
- 10 kW: Residential

Energy
- Technology Specific
- Short Duration
- 2 – 8 Hr
- Long Duration

Calculated System Price

Equipment
- System Builds from Components
- ESS = SM + BOS + PCS + EMS
- ESSI = ESS + EPC
- Rating (Power/Energy)
- Component Level
- Full Systems
- Performance Metrics
- Operating Costs

Data Anonymity
- OEMS
- Developers
- Customers
- Competitors

Forecast
- 10 Year
- Hi / Low Banding

Replenishment (2021)

Usage
- Use Case Usage Profile
- Tech Specific Degradation
- Capacity Requirements
- Forward Price Curve

Avenues
- Oversize
- Augmentation
- Replacement

Energy Storage Pricing Survey: Energy / Power Filter

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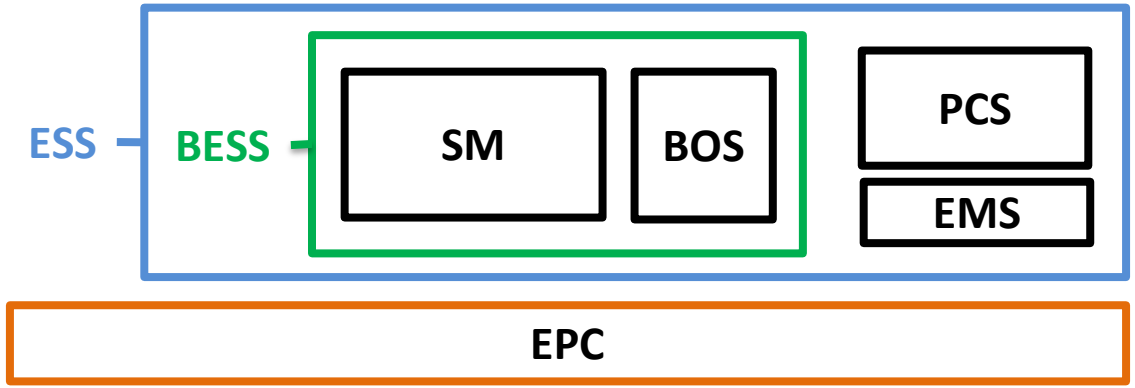
System Cost Structure Built Around Data Availability

Power (MW)							Energy (Hours of Duration)						
100	10	1	0.1	0.01			2	3	4	5	6	7	8
					Pumped Hydro Storage	PHS							
					Compressed Air Energy Storage	CAES							
					Advanced Compressed Air Energy Storage	ACAES							
					Liquid Air Energy Storage	LAES							
					Gravity Energy Storage	GES							
					Sodium	Na							
					Flow Battery - Vanadium	FB V							
					Flow Battery - Zinc Bromide	FB Zn							
					Flow Battery - Iron	FB Fe							
					Flywheel - Long Duration	FW LD							
					Flywheel - Short Duration	FW SD							
					Lithium NMC	Li							
					Lithium LFP	Li							
					Zinc	Zn							
					Lead	Pb							

System Capital Cost Structure



SM **Storage Module**
Rack Level System (DC)

BESS **Battery Energy Storage System**
Containerized System (DC)

ESS **Energy Storage System**
Complete Storage System (AC)

Storage Module (SM)	Balance of System (BOS)	Power Conversion System (PCS)	Energy Management System (EMS)	Engineering Procurement & Construction (EPC)
Racking Frame / Cabinet	Container	Bi-directional Inverter	Application Library	Project Management
Local Protection (Breakers)	Electrical Distribution & Control	Electrical Protection	Economic Optimization	Engineering Studies / Permitting
Rack Management System	Fire Suppression	Connection to Transformer	Distributed Asset Integration	Site Preparation / Construction
Battery Management System	HVAC / Thermal Management		Data Logging	Foundation / Mounting
Battery Module			Communication	Commissioning

	Description	Relationship
SM	Storage Module	
BOS	Balance of System	
BESS	Battery Energy Storage System	BESS = SM + BOS
PCS	Power Conversion System	
EMS	Energy Management System	
ESS	Energy Storage System	ESS = BESS + EMS + PCS
EPC	Engineering Procurement & Construction	
ESSI	Installed Complete System	ESSI = ESS + EPC

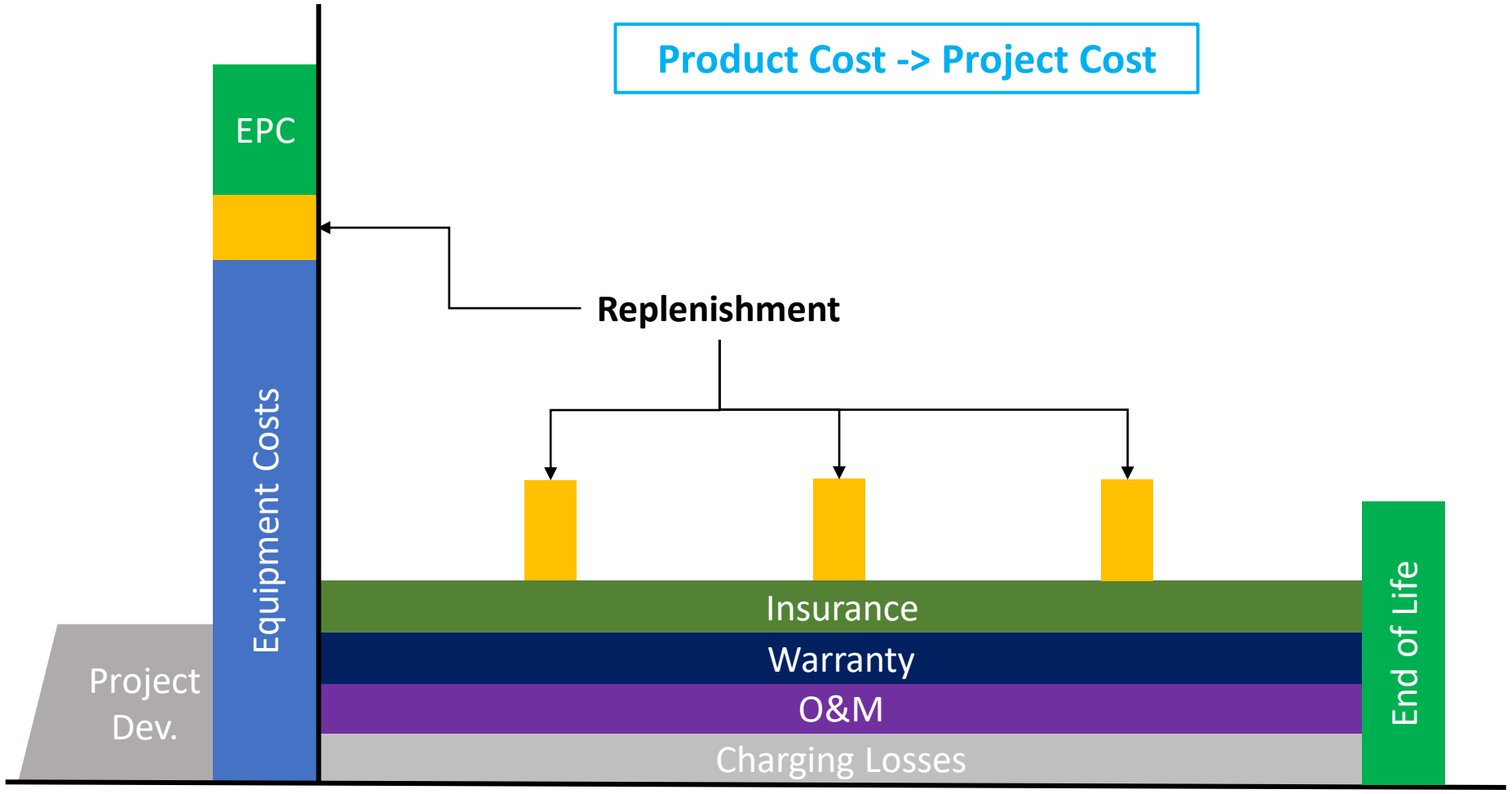
Project Development Cost Structure

Project Development
- Legal / Insurance
- PPA / Revenue Contract
- Permitting
- Interconnection
- Site Control

Equipment & Installation
- Capital Equipment
- Energy Management System
- Grid Integration
- EPC / Commissioning

Operating Costs
- O&M (Fixed & Variable)
- Charging Losses
- Replenishment Costs
- Extended Warranty
- Insurance

End of Life
- Removal / Transportation
- Site Remediation
- Recycle / Disposal



Mustang Prairie Energy

2020 Energy Storage Pricing Survey Results (LiNMC)

2020 Energy Storage Pricing					
	Size (MW)				
	100	10	1	0.1	0.01
$/kW					
PHS	2634.0				
CAES	1369.1				
ACAES	1727.8				
FWSD		1081.5	1196.6	1470.0	
$/kW (4 Hr)					
GES	358.8				
FWLD		666.8	735.8	814.6	937.5
LiNMC	315.6	382.3	444.9	667.8	947.5
LiLFP	296.6	366.8	427.7	653.2	929.7
Zn	275.3	300.4	343.0	402.4	
Pb			370.1	518.4	687.1
$/kW (6 Hr)					
Na	367.5	393.7	425.6		
FBZnBr	348.8	370.3	384.4	425.5	
$/kW (8 Hr)					
FBV	322.6	374.3	427.6	605.8	
FBFe	344.6	370.5	393.0	435.4	
LAES	267.4				

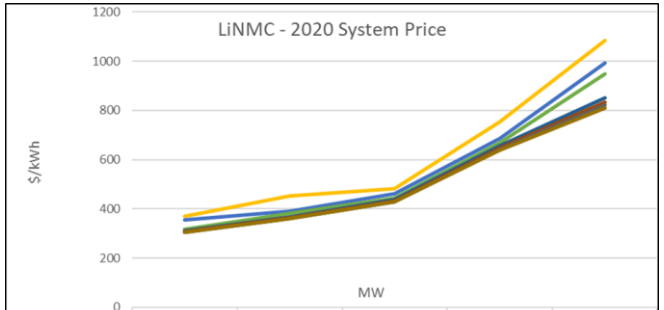
Reporting Metric Based on Available Products

- Ratings: Power & Energy
- Differing Duration

Proprietary Data

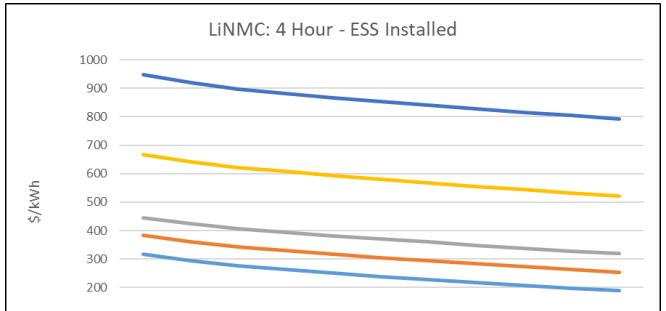
- Averaged Component Prices
- Standardized Components (BOS/PCS/EPC)
- Synthetic Total Price

2020 Installed System Costs



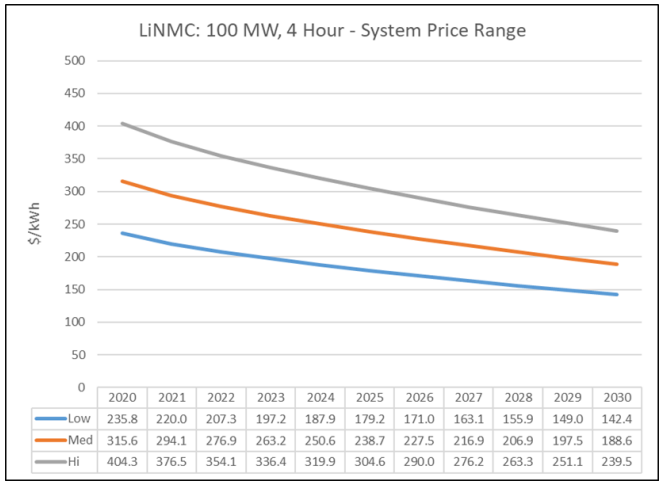
	100	10	1	0.1	0.01
LiNMC: 2-Hr	370.6	452.9	482.1	753.7	1083.4
LiNMC: 3-Hr	355.5	390.4	460.9	687.3	992.8
LiNMC: 4-Hr	315.6	382.3	444.9	667.8	947.5
LiNMC: 5-Hr	311.1	368.1	437.1	656.1	851.6
LiNMC: 6-Hr	308.1	364.9	432.9	648.3	833.4
LiNMC: 7-Hr	305.9	362.6	429.9	642.7	820.5
LiNMC: 8-Hr	304.3	360.8	427.6	638.6	810.8

System Price Forecast



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
100 MW	315.6	294.1	276.9	263.2	250.6	238.7	227.5	216.9	206.9	197.5	188.6
10 MW	382.3	360.3	343.1	329.9	317.2	305.3	293.8	282.8	272.5	262.6	253.1
1 MW	444.9	423.4	406.9	394.2	381.9	370.4	359.1	348.3	338.0	328.1	318.5
.1 MW	667.8	641.8	622.2	607.8	593.8	580.6	567.7	555.0	543.2	531.5	520.2
.01 MW	947.5	918.8	897.2	882.1	867.3	854.0	840.8	827.9	816.3	804.8	793.4

Hi / Low Forecast Price Range



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low	235.8	220.0	207.3	197.2	187.9	179.2	171.0	163.1	155.9	149.0	142.4
Med	315.6	294.1	276.9	263.2	250.6	238.7	227.5	216.9	206.9	197.5	188.6
Hi	404.3	376.5	354.1	336.4	319.9	304.6	290.0	276.2	263.3	251.1	239.5

Lithium-Ion NMC	
Lifespan:	10-20 Yrs.
Round-Trip Efficiency (AC):	80-85%
Operating Range (Depth of Discharge %):	80%-100%
Capacity at End of Life (% of Original):	70%
Operation & Maintenance (O&M):	2-3%

2021 Energy Storage Pricing Survey *(Current Study)*

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Changes

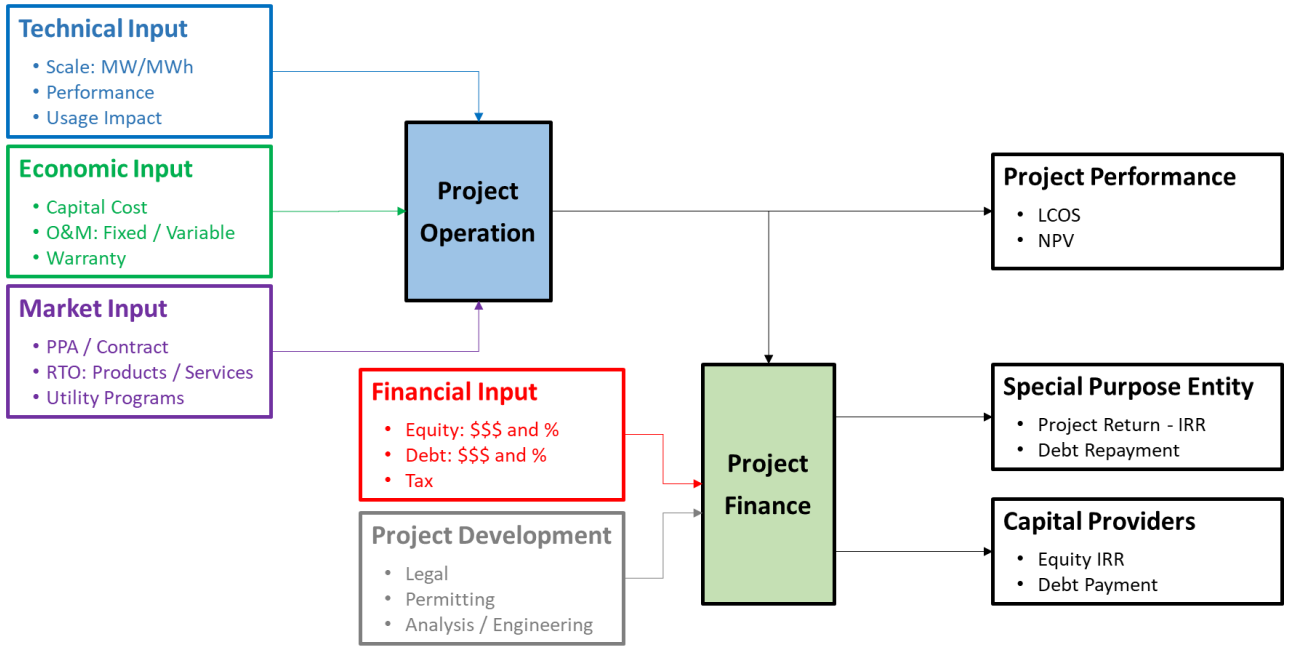
Technology
- Evaluate Adding Thermal: Cold
- Evaluate Adding Thermal: Hot

Long Duration Energy Storage
- Expand Duration to 10 Hr

System Components
- Grid Integration (Substation)
- EPC (Deployment Differentiation)
- End of Life

Project Costs
- Standardized Usage Profiles
- Performance Characteristics
- Project Economic Model
- Total Cost of Ownership (TCO)

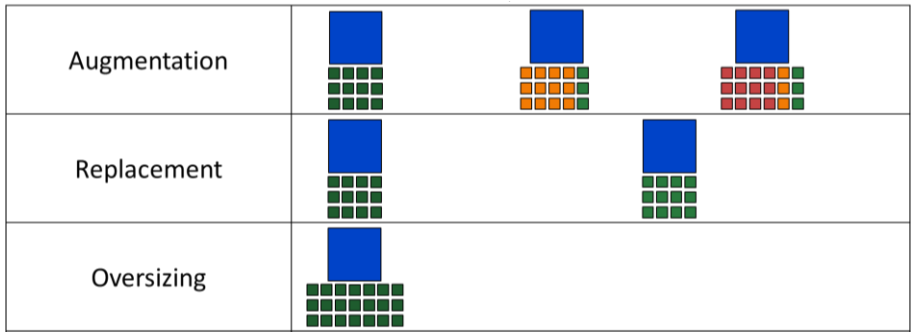
Project Finance Model



Reference Cost
- Installed Capital Cost
- Total Cost of Ownership

Model Sensitivity
- Input Cost Impacts
- Cost of Capital

2021 Energy Storage Pricing Survey: Replenishment *(Current Study)*



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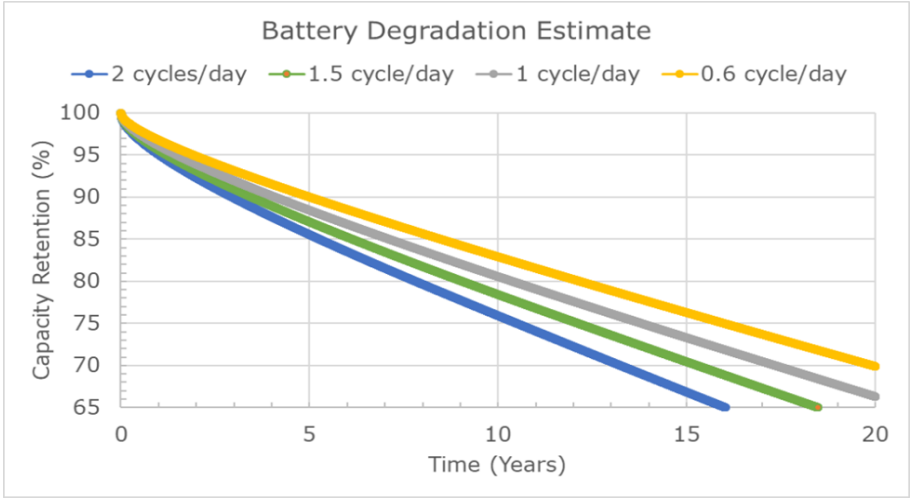
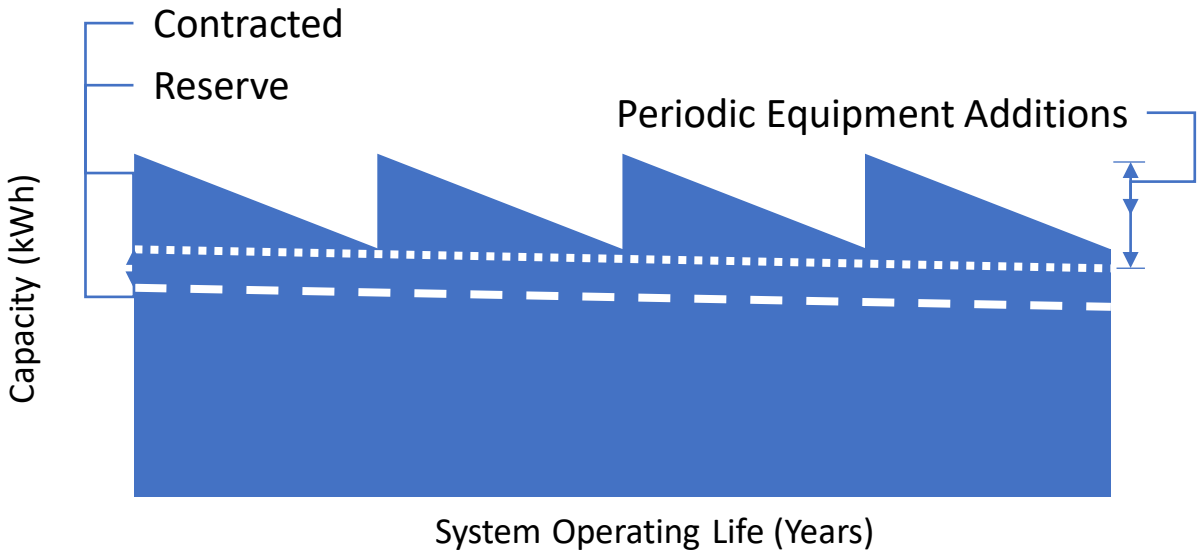
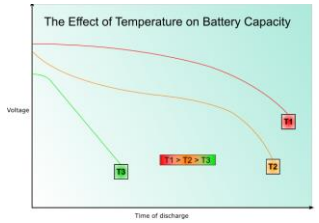


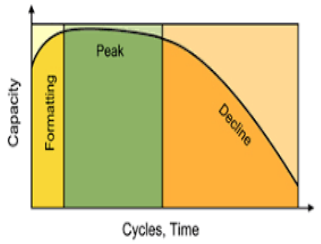
Source: DNV

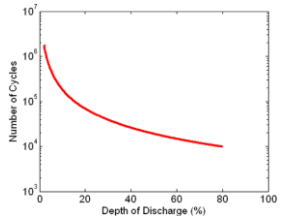


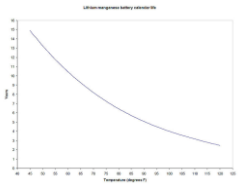
System Degradation Drivers

Environment	Cycle Life	Depth of Discharge	Calendar Life









Thank You / Questions

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