DOE OE PEER REVIEW

Virtual Conference | September 29-October 1, 2020

MUSTANG PRAIRIE ENERGY

Richard Baxter
President
Mustang Prairie Energy

Energy Storage Pricing Survey
&
Energy Storage Financing Study Series

Thursday, October 1st, 4:45pm

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

Acknowledgements

The author would like to acknowledge the support and guidance from:

Dr. Imre Gyuk, DOE – Office of Electricity

- Program Manager for the OE's Energy Storage Program

Dr. Ray Byrne – Sandia National Laboratories

- Manager, Electric Power System Research Department

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Author Contact Information

- Richard Baxter
- Mustang Prairie Energy
- rbaxter@mustangprairie.com
- M: 617-320-0598

Lead Researcher

MUSTANG PRAIRIE ENERGY

Richard Baxter - President
Mustang Prairie Energy

Bridging the financial and technical sides of the energy storage industry for capital providers, developers, and manufacturers

Energy Storage Financing

- 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, SAND2019-2973
- Energy Storage Financing: Project and Portfolio Valuation, SAND2020-xxxx
- Energy Storage Financing: Operations & Strategy, SAND2021-xxxx (underway)

Energy Storage System Pricing

- Lazard Levelized Cost of Storage, LCOS1.0, 2.0, 3.0 (pricing survey & cost modeling)
- Energy Storage Pricing Survey: 2018, SAND2019-14896
- Energy Storage Pricing Survey: 2019, SAND2019-xxxx
- Energy Storage Pricing Survey: 2020, SAND2020-xxxx (underway)

Author

- PennWell - *Energy Storage: A Nontechnical Guide*

Executive Director

- Advancing Contracting in Energy Storage (ACES) Working Group

Former Board Member

- NovoCarbon Corporation (TSX-V: GLK) - Chairman
- Energy Storage Association (ESA)
- Charitable Foundation of the Energy Bar Association

Today

MUSTANG PRAIRIE ENERGY

Energy Storage Financing

Outreach to Financial Industry

- Reduce Barriers to Entry
- Promote Greater Transparency
- Promote Wider Access to Low Cost Capital
- Reduce Project & Transaction Costs

Study Components

- Workshop: System Modeling Advances
- Summit: Current Market Insights
- Report: Document Lessons Learned

Work Product in Series

- 4 Completed Reports
- 9 Completed Summits

Energy Storage Pricing Survey

System Pricing Benchmark

- Standardized Methodology
- All Relevant Technologies
- Provides Expected System Price for Customers
- Input to SNL analysis / reports

Internally Consistent Cost Structure

- Component Based
- Market Price, not Component Cost
- Incorporates Profit Margin

Work Product in Series

- 2018 Energy Storage Financing Survey
- 2019 Energy Storage Financing Survey
- 2020 Energy Storage Financing Survey (underway)

Energy Storage Financing Study Series

MUSTANG PRAIRIE ENERGY

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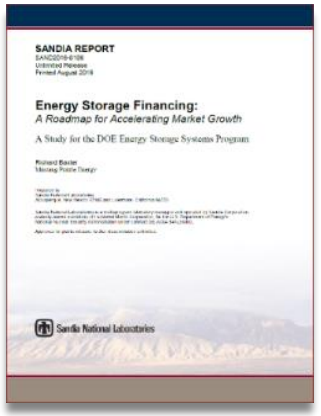

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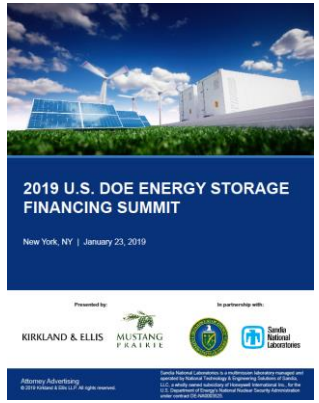
- Workshop: System Modeling Advances
- Summit: Current Market Insights
- Report: Synthesize & Document Lessons Learned



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- Energy Storage Financing: Project & Portfolio Valuation — SAND2020-xxxx
- Energy Storage Financing: Operations & Strategy *(Underway)* — SAND2021-xxxx

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Energy Storage Financing: Operations & Strategy (Current Study)

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Operations

Market Roles / Applications
- Design Requirements
- Performance Requirements
- Market Rules

Operating Expenses
- O&M Costs
- Warranties
- Round Trip Efficiency
- Thermal Management

Strategy

Cost Impacts
- Performance Requirements
- Operating Cost Impacts

Revenue Impacts
- Application Stacking
- Dispatch Value

Performance Implications
- O&M Costs
- Warranties

Role for US DOE
- Data & Analysis
- Application Performance Metrics

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Energy Storage Financing Study Series: Summits & Workshops

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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

Workshops

- Valuation Models: GUI & Open Source
- Compare Modeling Approaches
- Revenue Recognition / Value Stacking
- Results from Project Analysis

2020 U.S. DOE Energy Storage Financing Summit (SF)
- Sept 22nd & 23rd, 2020, Virtual
- 140 Attendees

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2020 US DOE Energy Storage Financing Summit (SF) – Sept 22nd & 23rd

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Day 1: Valuation Workshop

Welcome	Rohit Chaudhry, Kirkland & Ellis LLP
Chairman	Richard Baxter, Mustang Prairie Energy
US DOE - OE	Imre Gyuk, U.S. Department of Energy
Break	
	• Moderator: Ray Byrne, SNL • Tu Nguyen, SNL • Di Wu, PNNL • Jan Alam, PNNL • Giovanni Damato, EPRI

Day 2: Industry Panels

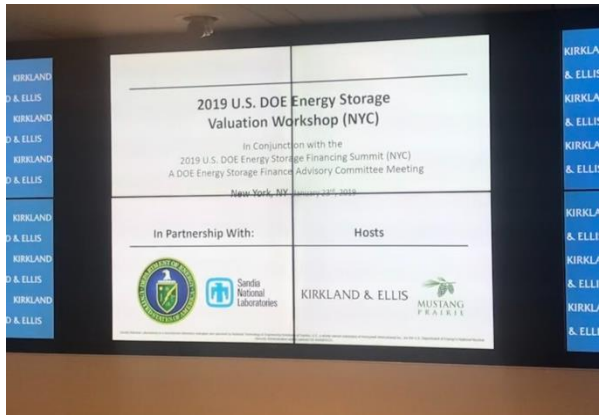
Welcome	Rohit Chaudhry, Kirkland & Ellis LLP
Chairman	Richard Baxter, Mustang Prairie Energy
Keynote	Vice Chair Janea Scott, California Energy Commission
Keynote	Eric Hsieh, U.S. Department of Energy
Break	
Panel 1: Market Overview	• Moderator: Robert Fleishman, Kirkland & Ellis • Jay Goldin, Munich RE • Nick Warner, Energy Storage Response Group • Mark Stout, Viridity Energy Solutions: an Ormat Company • Moe Hajabed, Aypa
Panel 2: Capital Providers	• Moderator: Brian Green, Kirkland & Ellis • Patrick Norton, Javelin Capital • Caleb Waugh, Macquarie Group • Tim Larrison, Primergy Solar • Benoit Allehaut, Capital Dynamics

Next Summit & Workshop

2021 U.S. DOE Energy Storage Financing Summit (NYC)

- Late January 2021
- Virtual Event
- Hosted by Kirkland & Ellis, LLP
- Free Event / Invitation to Register
- Day 1: Energy Storage Valuation Workshop
- Day 2: Industry Panels

➢ Invitations will be sent to Peer Review Presenters



<u>Possible Expansion</u>

Energy Storage Financing: Webinar Series

- Periodic through the year
- Topic Specific Webinars
- Posted to Sandia Website

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2019 Energy Storage Pricing Survey

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Pricing Survey

System Pricing Benchmark

- Standardized Methodology
- All Relevant Technologies
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Internally Consistent Cost Structure

- Component Based
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- Market Price, not Component Cost
- Incorporates Profit Margin

Results

- Power: 10kW, 100kW, 1MW, 10MW, 100MW
- Energy: 1-8 Hour & Long Duration
- 10 Year Forecast

Synthetic Price Quote

What Is it?

- An Average System Price
- Specified Power / Energy Rating

Difference

- Calculate Average Component Costs
- Specific to System Scale (kW & kWh)

Construction

- Build System Cost from Components
- Components cost are Standardized per Technology
- Calculate Component Costs

Benefits

- Utilize Component or System price Quotes
- Specific OEM Price Quote remains Confidential
- Maintains anonymity

Energy Storage Pricing Survey: Methodology – Data Gathering

Data
- System Component
- System - DC or AC Level
- EPC Costs
- Performance

Weighting
- Direct / Indirect
- Commercial Success

Primary - Interviews
- Direct (Component)
- Indirect (System)

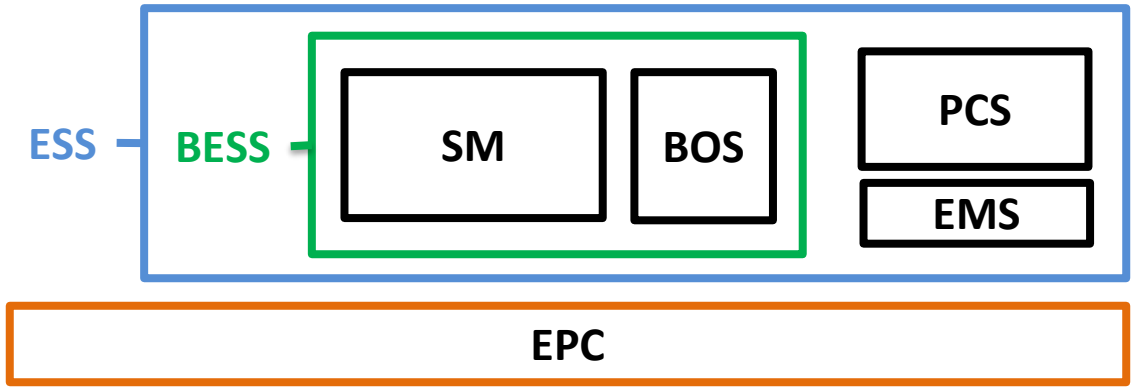
Secondary - Published
- Published Price Quotes
- Reports
- Media

All Price Quotes Tracked to Specific Power / Volume Cost

Participating Groups	19 ESPS
Energy Storage OEM	29
Gov. / NGO / Academia	4
System Integrator	9
Power Electronics	2
Project Developer	7
Financial Industry	11
Consultants	6
Balance of System	1
EPC	1
Electrical Construction Industry	1
Utility	1
Total Interviews	**72**
Published Data Sources	7
Total All Data Sources	**77**

Energy Storage Price Survey	
Unique Component Price Quotes	234
Final Synthetic Price Quotes	114

Energy Storage Pricing Survey: Methodology – System 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

Storage Module (SM)
- Module Level
- Rack System

Battery Storage System (BESS)
- DC Level
- Containerized (BOS)

Energy Storage System (ESS)
- AC Level
- PCS & Software

Installed
- AC Level
- Included EPC Costs

Energy Storage Pricing Survey: Methodology – Coverage / Filter

			Power (MW)				
			100	10	1	0.1	0.01
1	**Pumped Hydro Storage**	PHS	■				
2	**Compressed Air Energy Storage**	CAES	■				
3	**Liquid Air Energy Storage**	LAES	■	■			
4	**Gravity Energy Storage**	GES	■	■			
5	**Sodium**	Na	■	■	■		
6	**Flywheel - Long Duration**	FW LD		■	■		
7	**Flywheel - Short Duration**	FW SD		■	■		
8	**Flow Battery - Vanadium**	FB V	■	■	■	■	
9	**Flow Battery - Zinc Bromide**	FB Zn	■	■	■	■	
10	**Flow Battery - Iron**	FB Fe	■	■	■	■	
11	**Lithium-Ion (Energy)**	Li	■	■	■	■	■
12	**Lithium-Ion (Power)**	Li	■	■	■		
13	**Zinc**	Zn	■	■	■	■	
14	**Lead**	Pb			■	■	■
15	**Lead Carbon**	PbC			■	■	■

			Energy (Hours)								
			<1	1	2	3	4	5	6	7	8
1	**Pumped Hydro Storage**	PHS									■
2	**Compressed Air Energy Storage**	CAES									■
3	**Liquid Air Energy Storage**	LAES					■				■
4	**Gravity Energy Storage**	GES					■				
5	**Sodium**	Na							■		
6	**Flywheel - Long Duration**	FW LD					■				
7	**Flywheel - Short Duration**	FW SD	■								
8	**Flow Battery - Vanadium**	FB V					■		■		■
9	**Flow Battery - Zinc Bromide**	FB Zn				■	■	■	■		
10	**Flow Battery - Iron**	FB Fe					■				■
11	**Lithium-Ion (Energy)**	Li	■	■	■	■	■	■	■	■	■
12	**Lithium-Ion (Power)**	Li	■								
13	**Zinc**	Zn					■				■
14	**Lead**	Pb			■	■	■				
15	**Lead Carbon**	PbC			■	■	■				

Survey Results: Snapshot

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Reporting Metric

- Some Power
- Some Energy
- Differing Duration

Data Based on Company Reporting

- Only Model Supported System Sizes

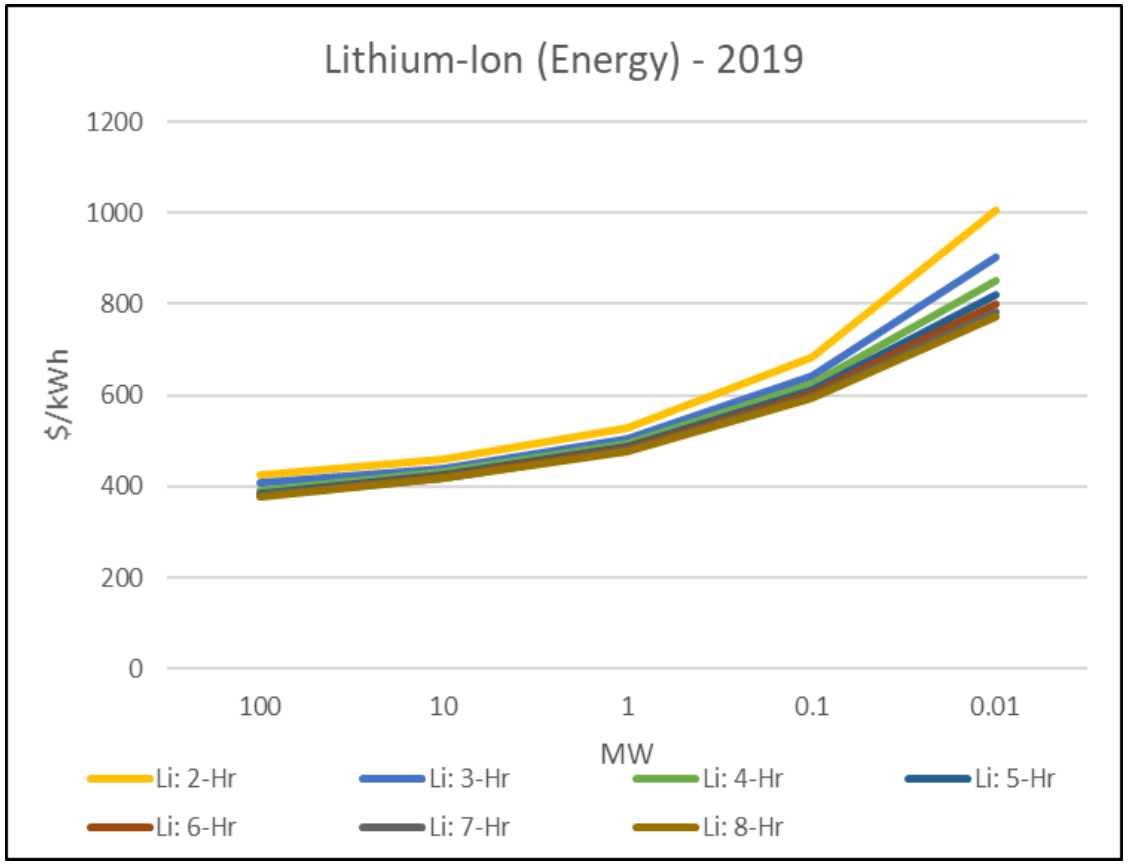
Proprietary Data

- Component Averages from Multiple OEM/Customers
- Standardized Components (BOS/PCS)
- Standardized EPC Costs

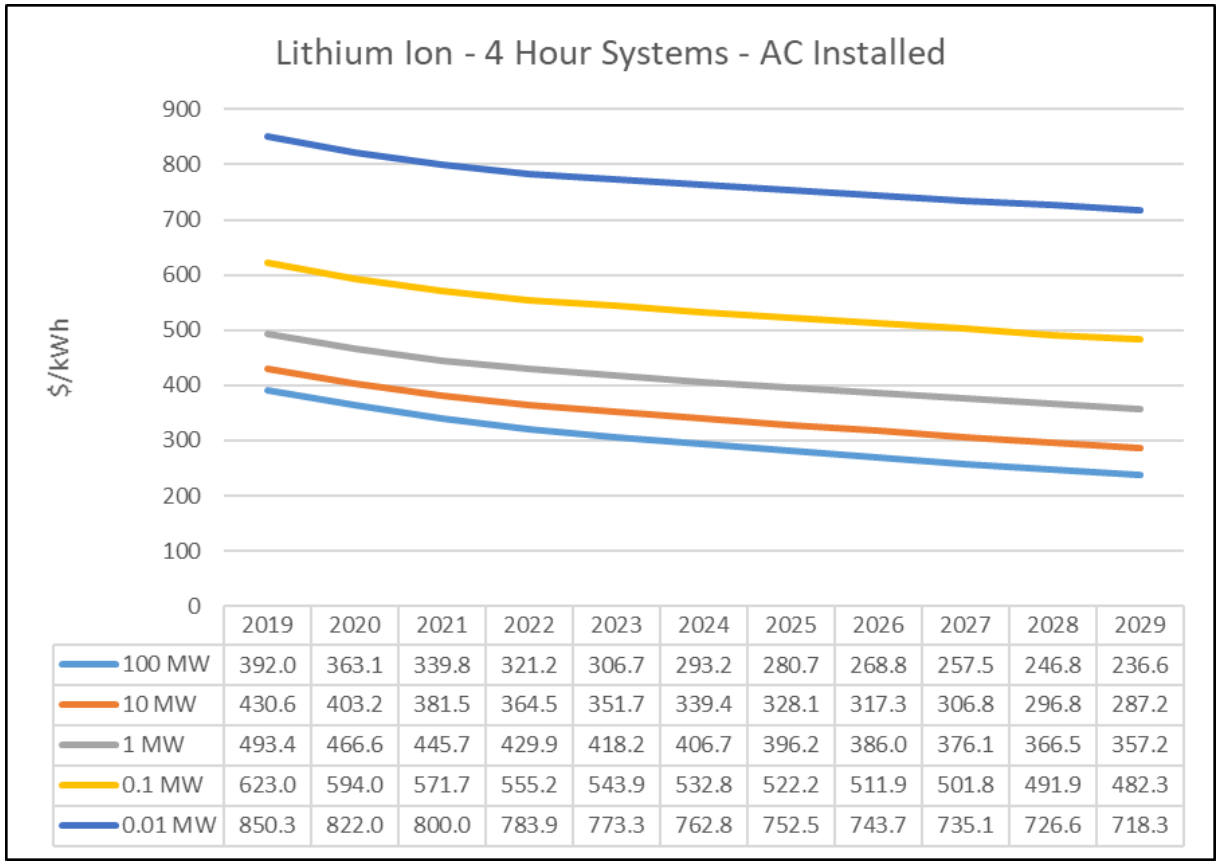
2019 Energy Storage Pricing					
	Size (MW)				
	100	10	1	0.1	0.01
$/kW					
PHS	1676.9				
CAES	1506.2				
FW SD		984.0	1190.0	1500.0	
$/kW (1 Hr)					
Li (Power)	504.2	545.6	629.1		
$/kW (4 Hr)					
LAES	451.0	511.5			
GES	903.0				
FW LD		677.8	766.0	855.3	975.0
Li (Energy)	392.0	430.6	493.4	623.0	850.3
Zn	271.4	289.7	336.8	398.7	
Pb			352.0	425.5	588.4
PbC			557.2	620.0	768.2
$/kW (6 Hr)					
Na	376.3	389.6	428.7		
FB ZnBr	450.9	464.9	478.8	510.6	
$/kW (8 Hr)					
FB V	309.7	372.2	439.0	620.2	
FB Fe	362.7	381.7	404.7	438.4	

Survey Results: Lithium Ion

2019 Installed System Costs



System Price Forecast (Installed)



	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
100 MW	392.0	363.1	339.8	321.2	306.7	293.2	280.7	268.8	257.5	246.8	236.6
10 MW	430.6	403.2	381.5	364.5	351.7	339.4	328.1	317.3	306.8	296.8	287.2
1 MW	493.4	466.6	445.7	429.9	418.2	406.7	396.2	386.0	376.1	366.5	357.2
0.1 MW	623.0	594.0	571.7	555.2	543.9	532.8	522.2	511.9	501.8	491.9	482.3
0.01 MW	850.3	822.0	800.0	783.9	773.3	762.8	752.5	743.7	735.1	726.6	718.3

Current Project: 2020 Energy Storage Pricing Survey

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Changes

Technology
- CAES: Split CAES & LAES
- Lead Acid: Combine
- Lithium Ion: Split NMC & LFP
- Long-Duration: PHS, CAES, LAES

Balance of System
- Refine BOM
- Pricing: Technology / Scale
- Safety

Energy Rating
- Steps: 1 – 8 hours of Storage
- Specific by Technology

Coverage
- 10 Year Forecast
- Incorporate History to Common Pricing Structure
- Expand Technologies Covered

Expansion

Operations & Maintenance
- Fixed/Variable
- Application Specific

Round Trip Efficiency
- Efficiency Curves
- Thermal Management

Project Development Costs
- Warranty
- Insurance
- Development Fees
- EPC

End of Life
- Site Deconstruction
- Transportation
- Disposal

MUSTANG PRAIRIE ENERGY

Richard Baxter
President
Mustang Prairie Energy

Appendix 1:

U.S. DOE Resources Supporting Energy Storage Financing

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

Energy Storage Financing Study Series

MUSTANG PRAIRIE ENERGY

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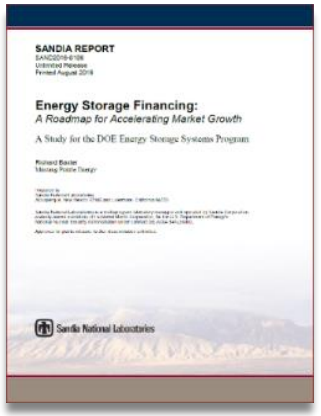
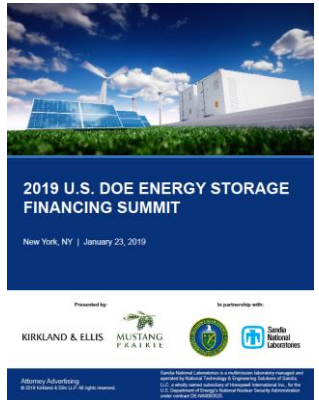


Study Components

- Workshops: System Modeling Advances
- Summits: Current Market Insights
- Reports: Synthesize & Document Lessons Learned



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Hosts:

KIRKLAND & ELLIS LLP

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Energy Storage Financing: A Roadmap for Accelerating Market Growth SAND2016-8109

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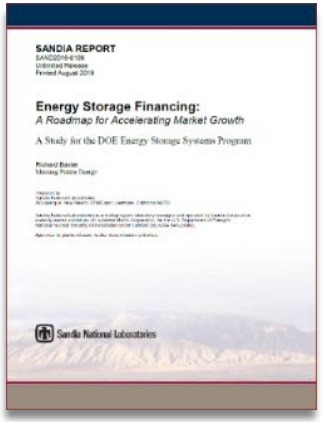
Study #1



Challenges

Technology
- Commercialization
- Capabilities & Performance

Codes, Standards & Regulations
- Development & Adoption
- Application Based, Not Technology

Public Policy
- Market Rules→ Revenue Roles
- Sustainable Support

Finance
- Interested Capital
- Risk Management (Insurance)

Accelerate Growth

Data & Analysis
- FTM – Market Signals
- BTM – Customer Load Data/Usage
- Standardized Models

Codes, Standards & Regulations
- Safety / Performance
- Installation – Ordinances

Financing / Contracts
- Performance Metrics
- Reliable Revenue
- Warranties
- Insurance

Energy Storage Financing: Performance Impacts on Project Financing SAND2018-10110

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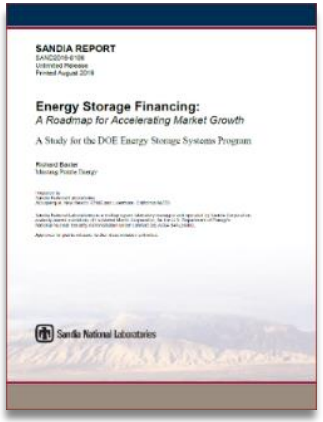
Study #2



Challenges

Performance
- System Rating
- Technical Performance
- System Performance

Technology Design Review
- Equipment / Integration
- EPC / Commissioning
- Operation

Economic
- Cost
- Revenue

Project Development
- Revenue Contracts
- Supporting Technical Documents

Next Steps

Data
- Engineering & Technical Services
- Performance Testing & Verification
- Data Formatting

Project Modeling
- Market / Economic Data
- Project Economic Models
- Simulation Models

Financial Performance Metrics
- Grid Services
- Utility
- Consumer

Energy Storage Financing: Advancing Contracting in Energy Storage SAND2019-14896 1/2

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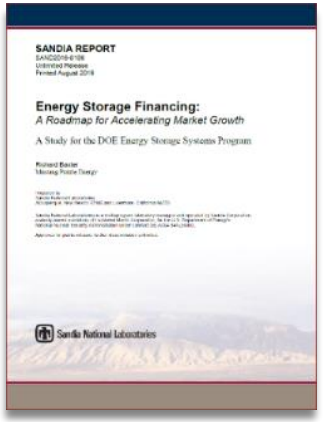
Study #3


SANDIA REPORT

Energy Storage Financing:
A Roadmap for Accelerating Market Growth

A Study for the DOE Energy Storage Systems Program

Sandia National Laboratories

Why Contracts Matter

Revenue Certainty
- Power Purchase Agreements
- Energy Savings Performance Contracts

Risk Reduction
- Project Documentation
- Technical Material
- Market Segments Roles

Non-Lithium Technologies
- Level Playing Field
- Quantify Differentiation

Contract Standardization

Best Practices
- Documenting Expertise
- Disseminate Technical Advancements

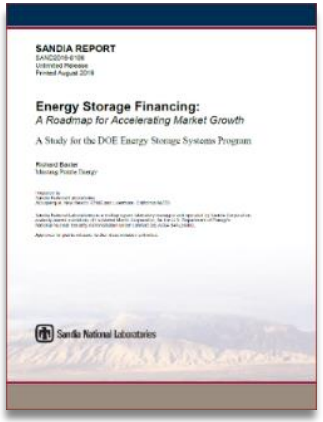
Model Contracts
- Trade Associations
- Reduce Costs / Expand Market

Industry Standards
- Safety
- Reliability & Performance
- Business Practice

Energy Storage Financing: Advancing Contracting in Energy Storage SAND2019-14896 2/2

MUSTANG PRAIRIE ENERGY

Study #3


SANDIA REPORT

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Sandia National Laboratories

Project Developers

Reduce Time
- Technical Documents
  - Engineering
  - Warranties
- Project Documentation
  - Technical Documents
  - Permitting / Real Estate
  - Off-Take Agreements
- Compliance with Codes & Standards

Reduce Cost
- Standardize Project Documentation
- Regional Market Rules / Qualification Verification

Investors (Equity / Debt)

Reduce Review Time
- Reduce Time Needed to Review Package
- Standardization of Economic Analysis
- Clearly Defined Assumptions

Risk Reduction
- Project Documentation
- Technical Material
- Uncover areas where technology can not support usage pattern

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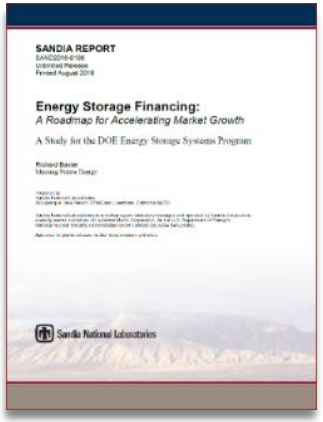
Study #4



Project Valuation

Project Economic Model
- Revenue
- Costs
  - Capital
  - Operating
  - Project

Market Simulation
- Models
- Revenue Streams
- Value Stacking

Bankability
- IE Reports
- Non-Lithium

Portfolio Valuation

Portfolio Risks
- Technology / Vintages
- Changing Revenues / Costs

Capital
- Risk Tolerance
- Investment Mandates

Market Issues
- Regional Market Rules
- Requirements to Layer Services

Supply Chain
- Equipment / Services
- Construction: EPC / ECI

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Richard Baxter
President
Mustang Prairie Energy

Appendix 2:

U.S. DOE Resources Supporting Energy Storage Financing

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

U.S. DOE Resources Supporting Energy Storage Financing

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U.S. Department of Energy

Database

- Global U.S. DOE Energy Storage Database: https://www.energystorageexchange.org/

Funding and Financing for Energy Projects

- Funding & Financing for Energy Projects: https://energy.gov/funding-financing-energy-projects

Areas of Support:

- Loan Programs Office: https://energy.gov/funding-financing-energy-projects
- State Energy Program: https://energy.gov/eere/wipo/state-energy-program
- Federal Financing Facilities Available for Energy Efficiency Upgrades and Clean Energy Deployment: Link to Report
- Federal Financing Programs for Clean Energy: https://energy.gov/sites/prod/files/2016/05/f32/Federal%20Financing%20Programs%20for%20Clean%20Energy.pdf

U.S. DOE Resources Supporting Energy Storage Financing (cont.)

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Sandia National Laboratory (SNL)

Energy Storage Program

- U.S. Department of Energy, Energy Storage Systems https://www.sandia.gov/ess-ssl/
- U.S. Department of Energy, Energy Storage Systems: Publications: http://www.sandia.gov/ess/sandia-national-laboratories-publications/

Energy Storage Valuation Modeling

- QuESt Model, https://energy.sandia.gov/tag/quest/

Key Reports

- DOE/EPRI Electricity Storage Handbook with NRECA: http://www.sandia.gov/ess/publications/SAND2015-1002.pdf
- DOE OE Energy Storage Systems Safety Roadmap Focus on Codes and Standards— SAND2017-9147R: http://www.sandia.gov/energystoragesafety/wp-content/uploads/2017/08/Roadmap-CS-report-August-2017-final.pdf
- Energy Storage Financing: *A Roadmap for Accelerating Market Growth* http://www.sandia.gov/ess/publications/SAND2016-8109.pdf
- Energy Storage Financing: *Performance Impacts on Project Financing*, https://www.sandia.gov/ess-ssl/wp-content/uploads/2018/12/ESF2-MustangPrairie_SAND2018-10110_final.pdf
- DOE OE Energy Storage Systems Safety Roadmap, http://www.sandia.gov/ess/publications/EnergyStorage_safetyroadmap_2017.pdf
- Energy Storage Procurement - Guidance Documents for Municipalities, http://www.sandia.gov/ess/publications/SAND2016-8544O.pdf
- Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, http://www.sandia.gov/ess/publications/SAND2016-3078R.pdf
- Methodology to Determine the Technical Performance and Value Proposition for Grid-Scale Energy Storage Systems: A Study for the DOE Energy Storage Systems Program, http://www.sandia.gov/ess/publications/SAND2012-10639.pdf

U.S. DOE Resources Supporting Energy Storage Financing (cont.)

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Pacific Northwest National Laboratory (PNNL)

Energy Storage Program

- PNNL Stationary Energy Storage Reports- DOE OE Energy Storage Program, https://energymaterials.pnnl.gov/esp/reports.stm

Energy Storage Valuation Modeling

- Energy Storage Optimization Tools https://availabletechnologies.pnnl.gov/technology.asp?id=413

Key Reports

- Energy Storage System Safety: Plan Review and Inspection Checklist, https://energymaterials.pnnl.gov/pdf/PNNL-SA-124486.pdf
- Measuring and Expressing the Performance of Energy Storage Systems (Presentation) https://energymaterials.pnnl.gov/pdf/PNNL-SA-118995.pdf
- Energy Storage System Guide for Compliance with Safety Codes and Standards; http://www.sandia.gov/ess/publications/SAND2016-5977R.pdf
- Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, https://energymaterials.pnnl.gov/pdf/PNNL-22010Rev2.pdf
- Overview of Development and Deployment of Codes, Standards and Regulations Affecting Energy Storage System Safety in the United States; http://www.sandia.gov/ess/docs/safety/Codes_101_PNNL_23578.pdf
- Inventory of Safety-related Codes and Standards for Energy Storage Systems with some Experiences related to Approval and Acceptance; https://energymaterials.pnnl.gov/pdf/PNNL-23618.pdf

U.S. DOE Resources Supporting Energy Storage Financing (cont.)

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National Renewable Energy Laboratory (NREL)

Renewable Energy Finance

- Renewable Energy Project Finance, https://financere.nrel.gov/finance/

Energy Storage Valuation Modeling

- REopt: Renewable Energy Integration & Optimization, https://reopt.nrel.gov/tool

Key Reports

- Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016, https://www.nrel.gov/docs/fy17osti/67474.pdf
- Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges, https://www.nrel.gov/docs/fy17osti/68963.pdf
- Battery Energy Storage Market: Commercial Scale, Lithium-ion Projects in the U.S., https://www.nrel.gov/docs/fy17osti/67235.pdf

Argonne National Laboratory (ANL)

Energy Storage Program

- https://www.anl.gov/pse/energy-storage

Joint Center for Energy Storage Research (JCESR)

Energy Storage Program

- http://www.jcesr.org/

U.S. DOE Resources Supporting Energy Storage Financing (cont.)

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Idaho National Laboratory (INL)

Energy Storage Program

- Clean Energy & Transportation, https://at.inl.gov/SitePages/Energy%20Storage.aspx

Energy Storage Publications

- https://avt.inl.gov/project-type/advanced-energy-storage-publications

Energy Storage Technology Advancement Partnership (ESTAP)

Energy Storage Technology Advancement Partnership (ESTAP)

- The Energy Storage Technology Advancement Partnership (ESTAP) is a federal-state funding and information sharing project, managed by the Clean Energy States Alliance (CESA), which aims to accelerate the deployment of electrical energy storage technologies in the U.S. https://www.cesa.org/projects/energy-storage-technology-advancement-partnership/

Key Reports

- Energy Storage Procurement Guidance Documents for Municipalities: http://www.cesa.org/assets/2016-Files/Energy-Storage-Procurement-Guidance-Document.pdf
- Commissioning Energy Storage: http://www.cesa.org/assets/Uploads/ESTAP-Webinar-Slides-5.20.14.pdf