Techno-Economic Performance of Microgrid with Large-Scale Battery

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25 YEARS OF ESTCP
2019 | Enhancing DoD's Mission Effectiveness

Purpose of this ESTCP R&D Topic: <u>Isolate</u> Security Contribution & Cost of Batteries in Microgrids

Improve reliability during outages

- Probability of critical load being served
- Extent of redundancy
- Power quality

Lower capital, O&M, & electricity costs

- Reduce # of diesel generators and/or UPS
- Reduce utility charges (e.g., peak demand & time-of-use energy)

Capture power market revenues

Introduce performance risks

- Technology uncertainty
- Other risks

Add costs (for batteries & integration)

- Capital
- O&M
- Re-powering/replacement

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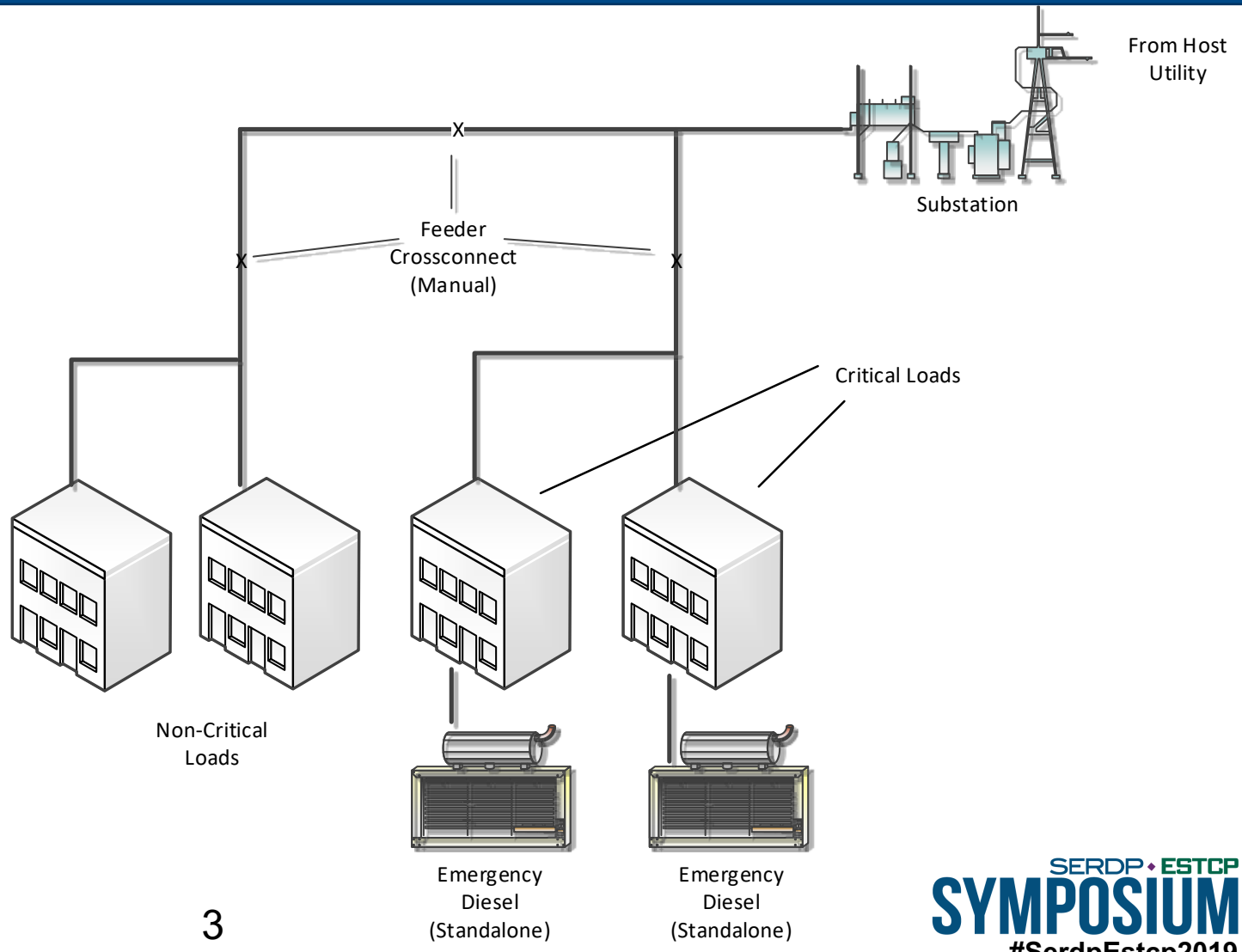
Existing Paradigm: Largely Unchanged for Decades

- Electricity security at DoD installations
  - Overwhelming dependence on commercial utility grid +
  - Building-tied, back-up diesel generators for critical loads



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Microgrids as Alternative, with Potential for Security & Economic Gains

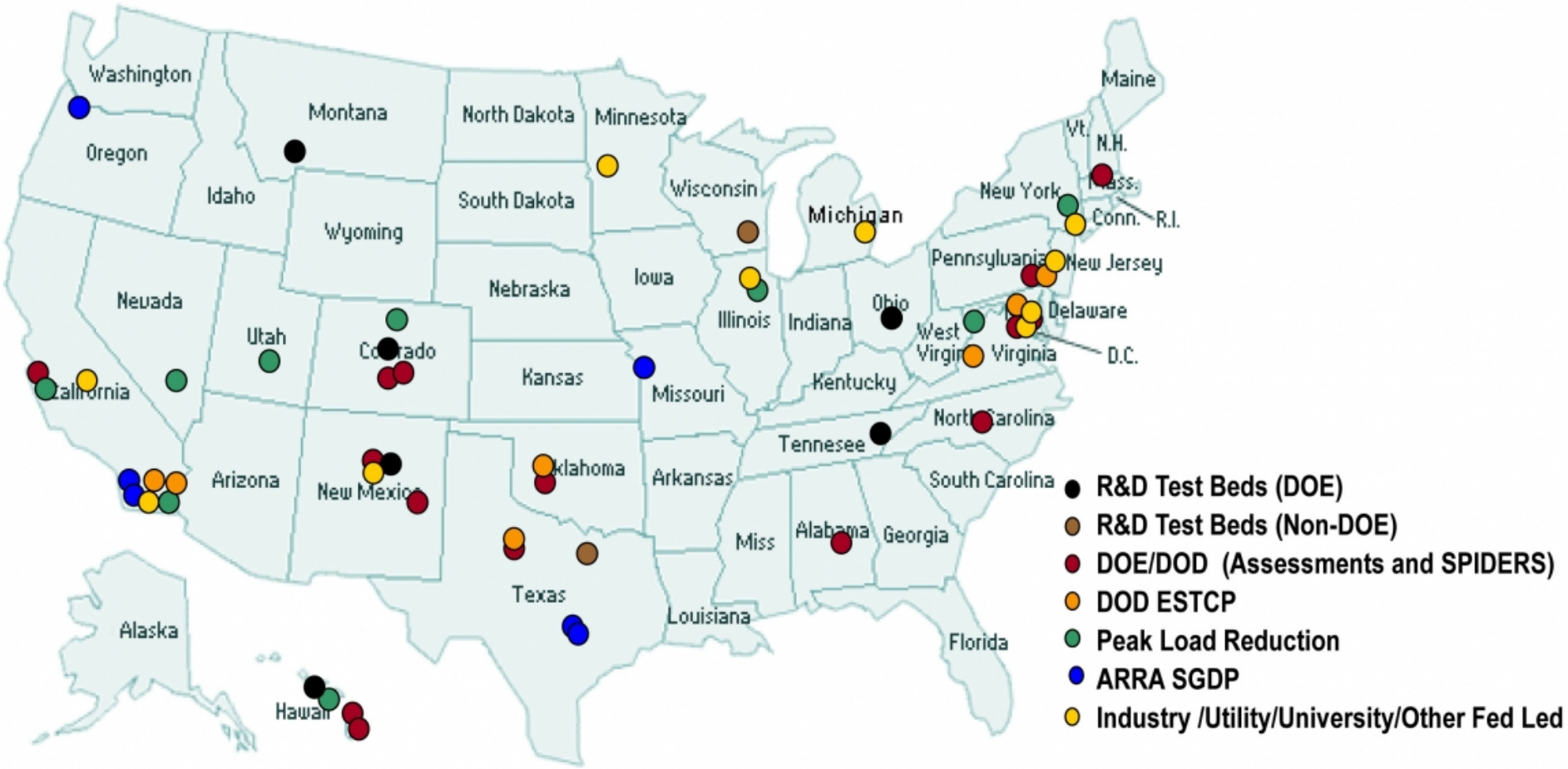
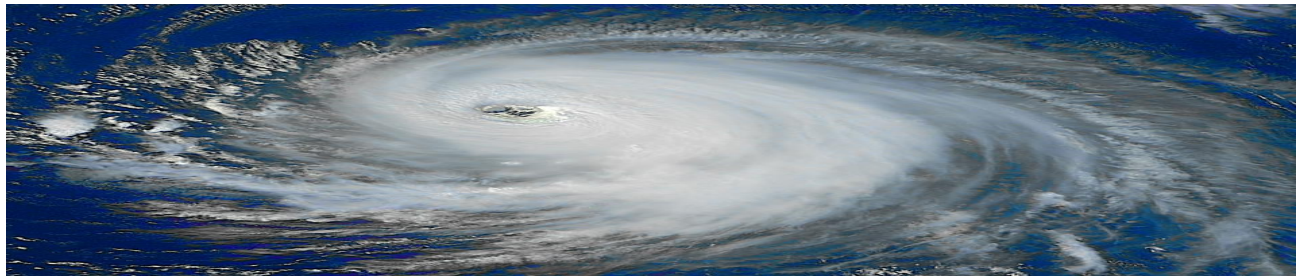


Image Source: Office of Electricity, U.S. Department of Energy, https://www.energy.gov/oe/services/technology-development/smart-grid/role-microgrids-helping-advance-nation-s-energy-syst-0

Energy Security Threats: Likely Growing



- Cyber Attacks
- Weather
- Aging Infrastructure
- Physical Terrorism

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Battery Use Cases: No Shortage

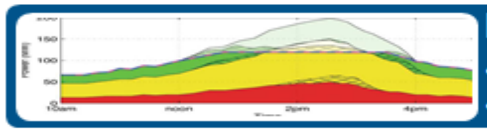
Deferral of Grid Investments
- Transmission
- Distribution

Integration of Renewable Generation
- Locally/Project Level
- System/Grid Level

Energy Resilience
- Standalone Uses
- Integration with other Electricity Security Assets

Capacity Markets
- Front-of-the-meter and bulk power system
- Reducing capacity charges for end-use customers (e.g., peak load contribution in deregulated markets)

Other Wholesale and Distribution System Markets
- Ancillary Services
- Demand Response



Peak Demand Charge Reduction
- Existing customers
- Lowering requirements for new customers

Time-of-Use (TOU) Energy Charge Reduction
- Existing market opportunities
- Markets where TOU rates are being introduced

Battery Storage System Costs: Quickly Improving, Room to Continue

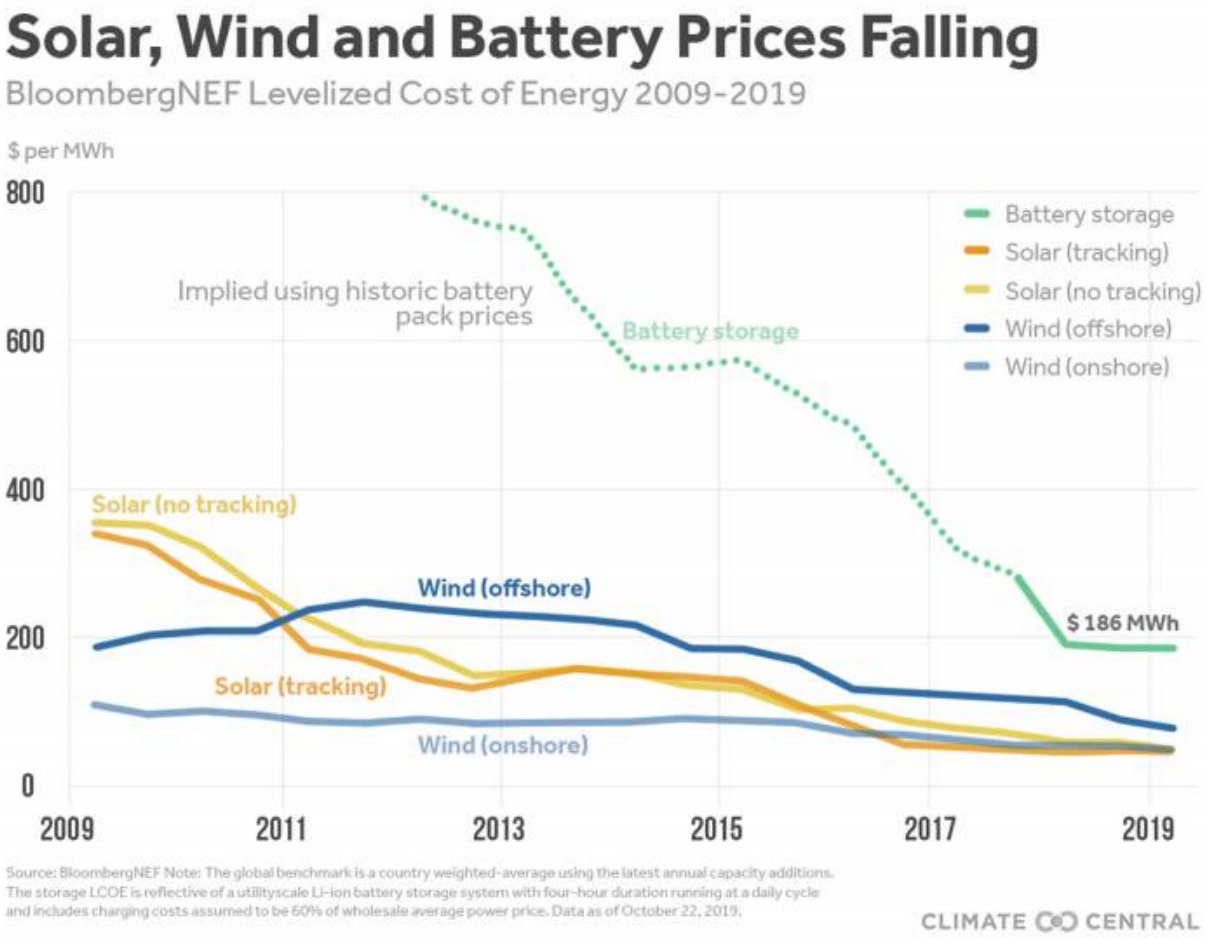


Image Source: KQED (Public Media/NPR) using Bloomberg New Energy Finance data, https://www.kqed.org/science/1951005/the-cost-of-battery-storage-plummets-at-the-right-moment-for-california

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Regulatory and Policy Backdrop for Batteries: Becoming Much More Favorable

- Federal Energy Regulatory Commission (FERC) 841
  - Unanimously-approved 2018 order expanding opportunities for energy storage to participate in wholesale electricity markets
    - Energy
    - Capacity
    - Ancillary services (e.g., frequency regulation, spinning & non-spinning reserve)
  - Being implemented in regional transmission markets

- State-level incentives and capacity targets for storage
  - E.g., California, Maryland, Massachusetts, New Jersey, New York

Sequential Approach to Battery/Microgrid R&D: Create Broadly Applicable Outcomes & De-Risk Field Demos

I. Detailed Simulation/ Modeling with Installation & Market Data

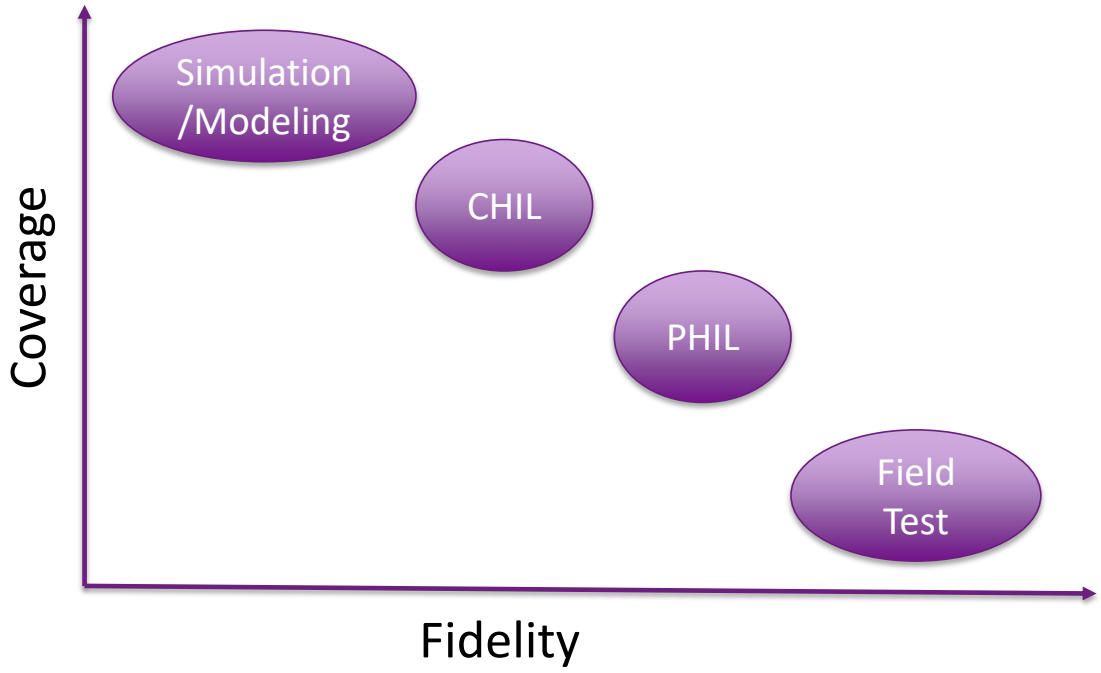
(FY19)

II. Hardware-in-the-Loop (HIL) Testing

(FY20)

III. Possible Field Demonstration Tests

(FY21)



CHIL - Controller Hardware-in-the-Loop
PHIL - Power Hardware-in-the-Loop

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Beginning of R&D Effort (FY19): Techno-Economic Modeling

1. Establish modeling framework & tools
2. Review starting conditions among 7 military installations & their markets
   - Load profiles, PV, utility tariffs, market prices
3. Determine batteries to include in microgrid
   - Chemistry, cost, size (power & duration), performance, use cases, placement, etc.
4. Determine if/how existing diesel gensets & UPS can be replaced
5. Conduct probability-based modeling of reliability & economic outcomes vs. ESTCP-provided microgrid baselines
6. Publish results & implications

Phase
energy
microgrid
storage
installations
installation
military
security
electricity
provided
generation
power
diesel
cost
renewable
modeling
DoD
solar
can
provide
following
proposed
markets
calculated
demonstration
microgrids
systems
generators
backup
costs
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portion
value
without
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configuration
capability
operational
market
physical
United
Power
within
hours
Energy
conditions
outages
critical
baseline
information
MICROGRIDS
STORAGE
ESTCP
SCACE
technologies
develop
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requested
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associated
improved
maintenance
including
function
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renewables
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Year
Risks
Plan
Found
Fully
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Longer
Scale
Cases
Solution
Parallel
Typical
Technical
Loads
Mode
Key
UPS
Requirements

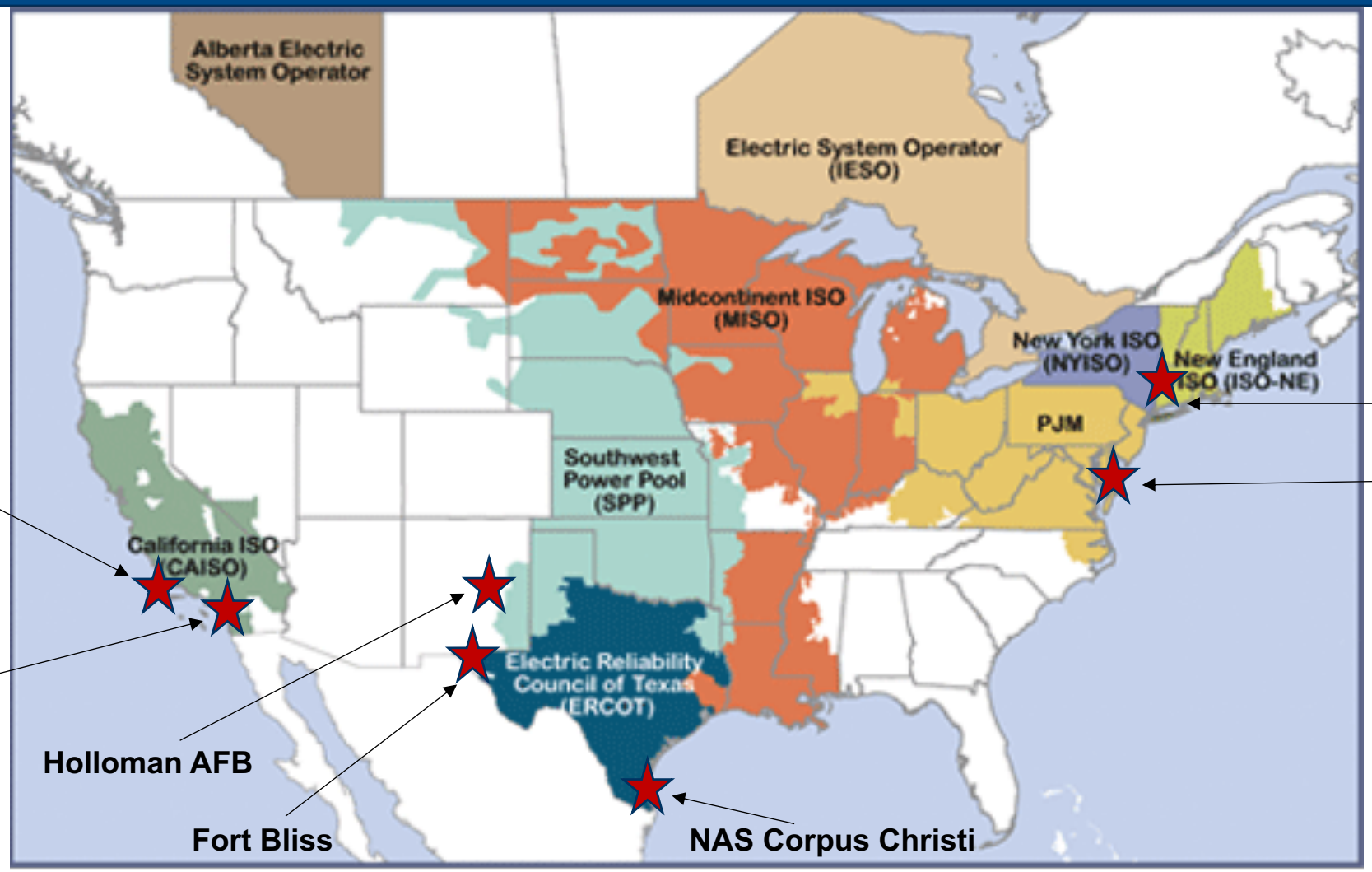
Seven Installations for Techno-Economic Modeling: Range of Sizes, Military Services, and Mission Types

Military Installation	Representative Values of Peak Critical Load (kilowatts) for Techno-Economic Modeling
Fort Bliss	12,500
Naval Air Station (NAS) Patuxent River	8,000
Holloman Air Force Base (AFB)	6,000
Naval Air Station (NAS) Corpus Christi	4,500
Naval Base Ventura County	4,000
Westover Air Reserve Base (ARB)	1,500
March Air Reserve Base (ARB)	500

Installations Modeled are a Cross-Section of:

- *Sizes*
- *Military Services*
- *Mission Activities*
- *Geographies*
- *Energy Market Areas*

Seven Installations for Techno-Economic Modeling: Geographic and Energy Market Diversity



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Baselines to Beat when Adding Batteries to a Microgrid: Technical (Reliability) and Economic

Technical Reliability Performance

(during power outages of 1 to 168 hours)

Net Lifecycle Cost

(per kW of peak critical load over 20 years)

Compared to Modeled Baseline Microgrid at each Installation with no Storage, N+1 Back-Up Diesel Generators, solar PV, and UPS

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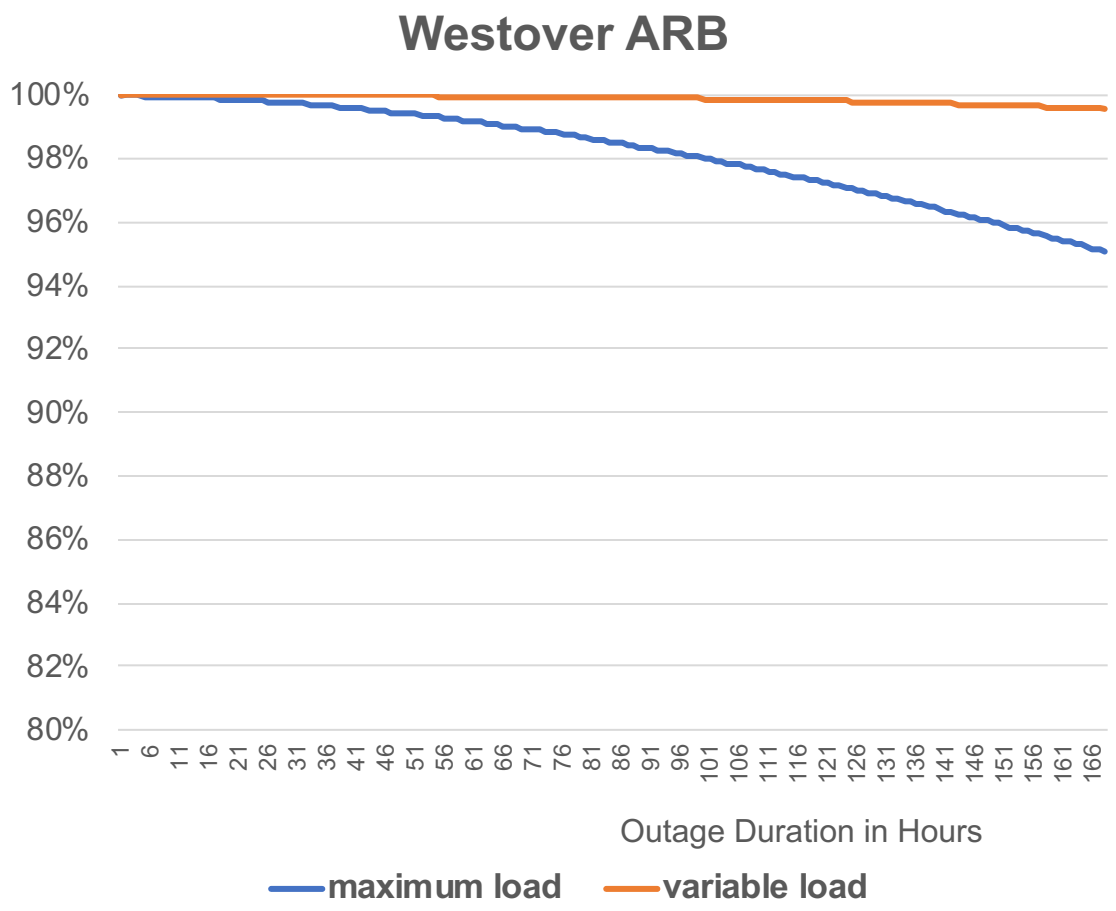
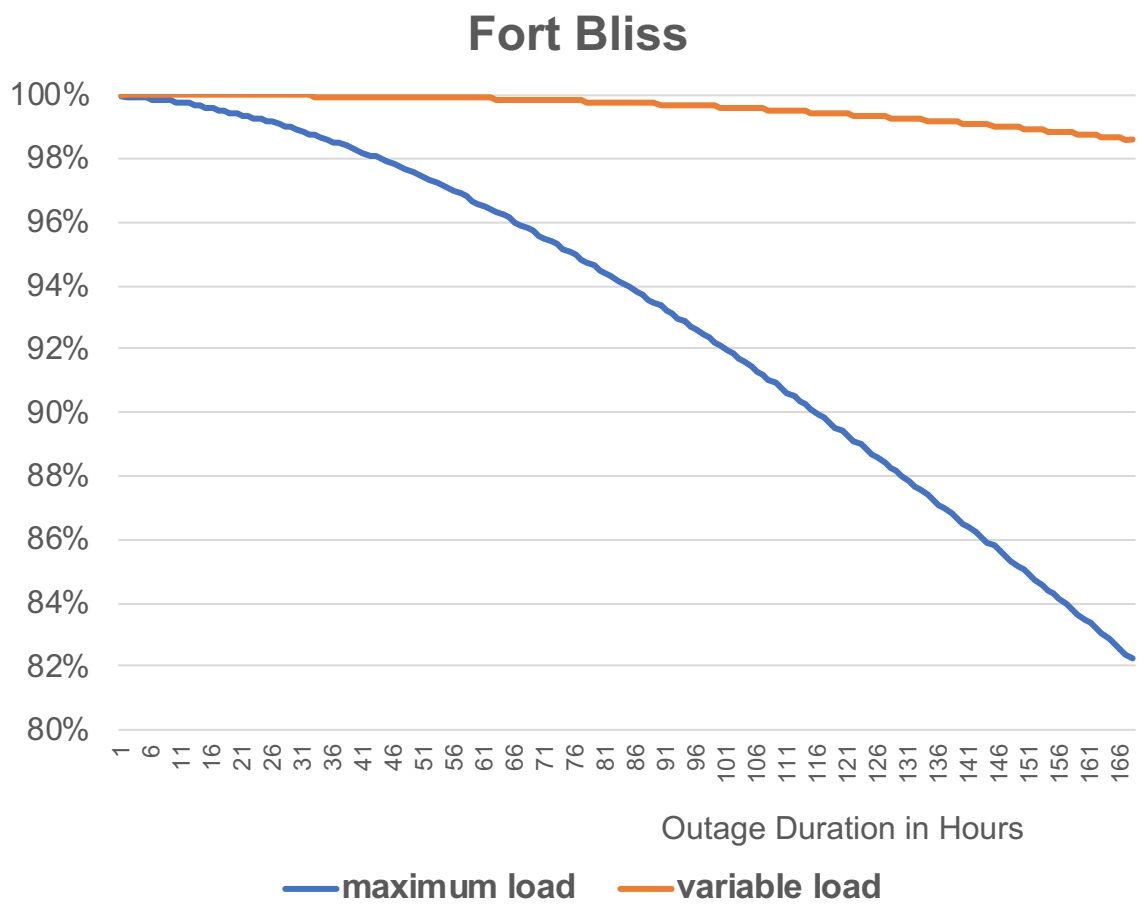
Examples of Reliability Baselines to Beat: For Power Outages of 1 to 168 Hours





Techno-Economic Modeling: Forming a Realistic Backdrop & Allowing Flexibility/Innovation

Fixed Factors		Modeling Choices	
Military Installation Conditions - Critical Load Size & Shape - Solar PV Assets - Electric Rate Structure - Other Conditions	Energy Markets - Rules - Prices (multiple scenarios)	Energy Storage Technologies - Lithium-Ion - Flow - Other	Technology Configuration and Operational/ Simulation Approaches

Six Contractors Selected for Techno-Economic Modeling: Diversity of Approaches

Lead Organization Name	Phase I Project Name (Simulation/Modeling Approach)
Accord EI	*Modeling of a High-Efficiency, Resilient, Dual-Battery Microgrid combined with Diesel GenSet and Solar PV*
Ameresco	*Demonstrating the Benefits of Long-Duration, Low-Cost Flow Battery Storage in a Renewable Microgrid*
Electric Power Research Institute (EPRI)	*Energy Security for Military Installations through Optimized Integration of Large-Scale Energy Storage into Microgrids*
Raytheon Integrated Defense Systems	*Advanced Phasor-based Control of Energy Storage Microgrids*
Siemens Corporation	*CMES: Comprehensive Microgrid Energy Storage Designs with Guaranteed Optimality*
Southern Research Institute/Arizona State University	*Design, Modeling, and Control of Hybrid Energy Storage System for Defense Installation Microgrids*

Contractor Modeling Approaches: Types of Batteries Reviewed

- Lithium-ion with high-speed, phasor-based control
- Redox flow vs. Lithium-ion
  - Head-to-head review from two different contractors
- Comparison of five battery types, paired with ultracapacitors:
  - Sodium sulfur, vanadium redox flow, aqueous zinc, & two variations of lithium-ion
- Alkaline rechargeable

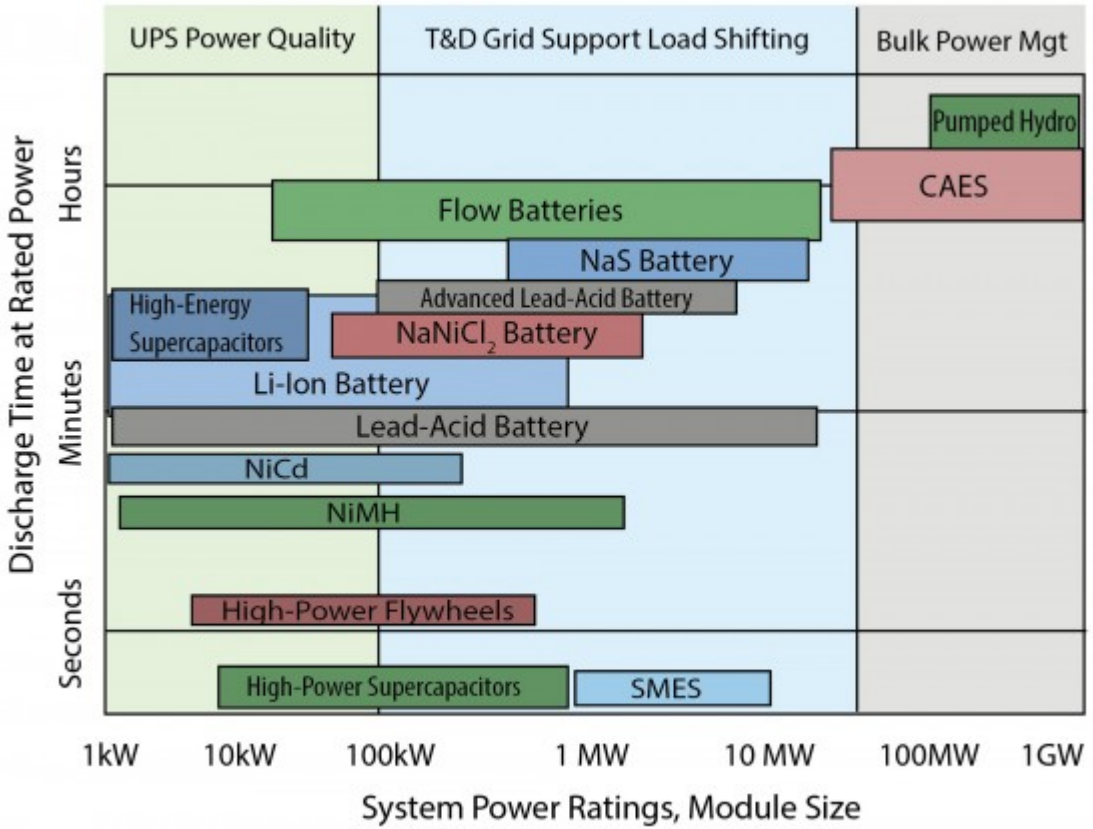


Image Source: Center for Sustainable Systems, University of Michigan, http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

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Contractor Modeling Approaches: Battery Cost & Performance Data Collected & Utilized

- Battery capital cost
- Balance of system capital cost
- O&M cost
- Roundtrip efficiency
- C-rate (discharge rate)
- Minimum state of charge
- Response time
- Mean time between failure
- Auxiliary load requirements
- Degradation rate
- Useful life

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Contractor Modeling Approaches: Partial Substitution of Batteries for Diesel Gensets & UPS

- Diesel Gensets
  - Difficult to eliminate more than 1-2 large gensets from baseline microgrid while meeting reliability requirements
- Uninterruptable Power Supplies (UPS)
  - Various approaches taken
  - Some contractor teams were able to reduce the # of UPS or O&M burden on UPS
    - E.g., via lithium-ion batteries with high-speed control or via batteries paired with ultracapacitors

Contractor Modeling: Sample of Initial Reliability & Economic Results

- Reliability (during power outages)
  - Storage-enabled microgrid typically met or exceeded islanded performance of baseline microgrid (without storage)
    - Covering 100% of peak critical load
  - Promising, though uneven, results on other reliability performance metrics
    - Covering 130% of peak critical load
    - Covering 10% & 30% of peak critical load after fuel supply is exhausted
- Economics (net lifecycle costs)
  - Storage-enabled microgrids typically, but not always, improved on economics of baseline microgrid
    - Often 5% to 50%+
  - Primary sources of savings vary widely from installation to installation and depend on battery technology & operations choices of contractors
    - Market participation (demand response, physical energy markets, ancillary service markets)
    - Retail electric bill impacts (peak shaving & time-of-use energy shifting)
    - Reduction in number of diesel generators and UPS required

Next Steps

- Phase I: Techno-Economic Modeling
  - Six contractor teams publish results on ESTCP website by early 2020
  - ESTCP produces synthesis report and briefing
    - Key outcomes and suggested actions drawn from work of contractors, National Renewable Energy Laboratory (NREL), ICF, and industry on the reliability value and cost of including battery storage in DoD microgrids
    - Expected in late Spring 2020
- Phase II: Hardware-in-the-Loop (HIL) Testing
  - Three contractor teams expected to complete at government HIL facility in 2020
  - Publish results through ESTCP
- Phase III: Field Demonstrations at DoD Installations
  - Planned activity beginning in FY21 cycle