# National Capabilities to Support Decision Making Around Energy Storage

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# Direct Technical Assistance & External Engagement

Regulators, policymakers, and market designers often lack independent, objective, and robust information upon which to make decisions around energy storage and other forms of distributed energy resources (DERs).

LBNL researchers directly support State (Governors Office, Regulators, Energy Office) and Regional (ISO/RTO) entities.

## Technical Assistance Activities

- Work shops
- Webinars
- Technical Analysis
- White Papers
- Consul-tation
- Lit. Review
- Review Memos
- Training
- Facilitated Dialogue w/ Stake-holders

## Recent Engagements

**Purpose**: Better understand economic valuation and assessment of energy storage in integrated resource plans (IRPs)
**Support Provided**: Technical review of over a dozen IRPs to catalogue assumptions and compare methodologies
**Outcome**: Improve representation of energy storage into state's IRP process

**Purpose**: Develop a first-of-its-kind DER aggregation electric utility tariff
**Support Provided:** Direct advisor to Commission staff, review filed materials, facilitate stakeholder engagement
**Outcome**: TBD (In process)

**Purpose**: Provide robust analytical support to ISO/RTOs on high-priority market challenges
**Support Provided:** Identify and prioritize technical challenges due to rapid changes in the power system (e.g., storage deployment). Conduct analytical studies to address top 3 challenges.
**Outcome**: TBD (In process)

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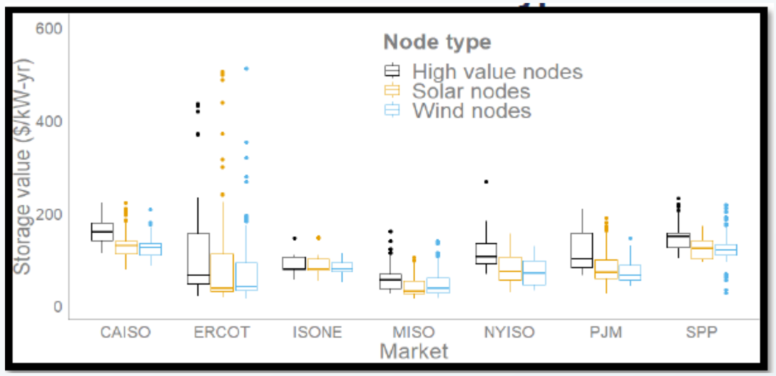
# Analysis & Tools to Inform Markets, Policy & Regulation

Utility-scale and customer-scale hybrid technologies (PV+ES) have dramatically increased in popularity over the last 3 years but little is known about cost, performance, valuation, and integration experience.

LBNL researchers have focused on informing future market, policy, and regulation development.

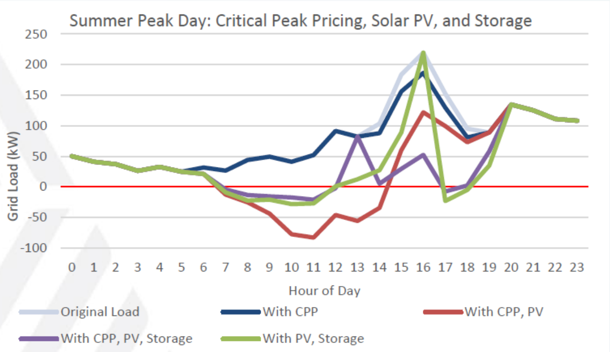
## Utility-Scale Hybrid Valuation Analysis




Hybrid systems can significantly boost standalone VRE value across all markets in the U.S.; but there is still a penalty in restricting the location to a wind or solar node.

Source: Gorman et al. (2021). "Are coupled renewable-battery power plants more valuable than independently sited installations?"

## Distributed Hybrid Valuation Analysis




Combining DERs provides utilities with menu of options that allow them to generate, shift, and shed net load. Rates can be a powerful tool in directing distributed hybrid owners to manage their grid imports and exports.

Source: Miller and Leach. "Impacts of DERs on Net Loads And Approaches for Actively Managing Load Shapes." *Integrated Distribution System Planning Training for Midwest/MISO Region*. Presented October 13-15, 2020.

## Retail Electric Utility DER Rate Analysis

| Rate Design Trend | PV | EE | EV & Electrification | Storage & DR |
|---|---|---|---|---|
| Time-Based Rates | Highly constrained; Slightly constrained; No impact; Slightly accelerated | Slightly constrained; No impact; Slightly accelerated | Slightly accelerated | Slightly accelerated |
| Load Building Rates | Highly constrained; Slightly constrained; No impact | Slightly constrained; No impact | No impact; Slightly accelerated; Highly accelerated | Slightly accelerated; Highly accelerated |
| 3-Part Rates | Highly constrained; Slightly constrained | Slightly constrained | Highly constrained; Slightly constrained; No impact; Slightly accelerated | Slightly accelerated; Highly accelerated |
| NEM Alternatives | Highly constrained; Slightly constrained; No impact | Slightly constrained; No impact | No impact; Slightly accelerated; Highly accelerated | No impact; Slightly accelerated; Highly accelerated |
| EV-Specific Rates | No impact | No impact | Slightly accelerated; Highly accelerated | No impact |

Key: ● =Highly constrained; ● =Slightly constrained; ● =No impact; ● =Slightly accelerated; ● =Highly accelerated

Growth in DERs and changes in net load profiles are motivating substantial changes in retail rates, which have feedback effects on deployment.

Source: Satchwell, Cappers, & Barbose. "Retail Rate Designs: Current Developments in the Industry" *IEEE Power and Energy Magazine, 18(3): 81-84.*

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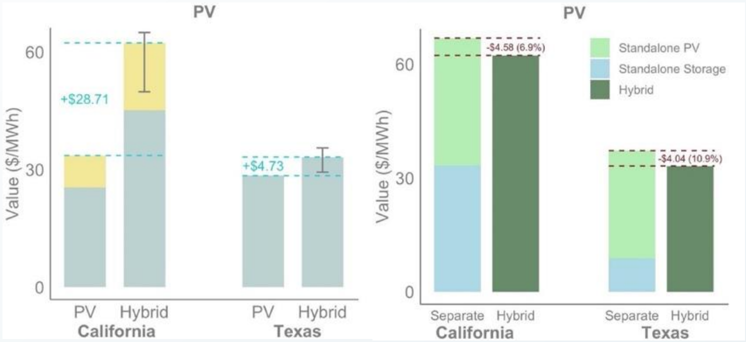
# Analysis & Tools to Inform Planning & Operations

Energy storage technologies have tremendous opportunities to support the grid as it evolves away from carbon-intensive resources.

LBNL researchers are trying to better understand how different forms of storage could affect electric system planning and operations in the near and not-to-distant future.

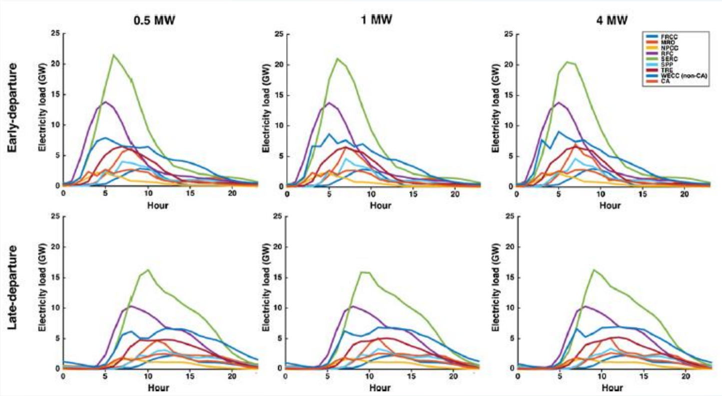
## Utility-Scale Hybrid Valuation Analysis




Additional revenues from adding a 4-hr battery to solar can exceed additional costs. However, realizing hybrid projects' full value depends on nascent strategies for integrating them in current/future wholesale market design paradigms

Source: Gorman et al. "Motivations and Options for Deploying Hybrid Generator-Plus-Battery Projects Within the Bulk Power System?" *The Electricity Journal*, 33(5), June 2020, 106739.

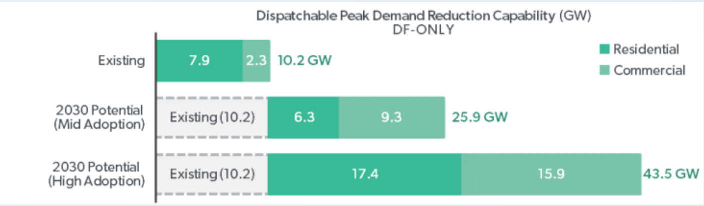
## Electric Vehicle Integration Analysis




Load curve from fully-electrified fleet of long-haul freight trucks is distinctly different from privately-owned EVs. Peak charging loads may occur midday when the curtailment of renewable energy is most likely and could act as an integration resource.

Source: Tong et al. "Energy Consumption and Charging Load Profiles from Long-Haul Truck Electrification in the United States." *Environmental Research Infrastructure and Sustainability*. In Press.

## Demand-Side Valuation Analysis




Identified 14.6 GW of new, dispatchable peak reduction capability from demand-flexibility-only programs coming online by 2030, with 6.3 GWs provided by residential and 9.3 GW from commercial GEBs.

Source: Satchwell et al. (2021). "A National Roadmap for Grid-Interactive Efficient Buildings." Available at: GEBRoadmap.lbl.gov

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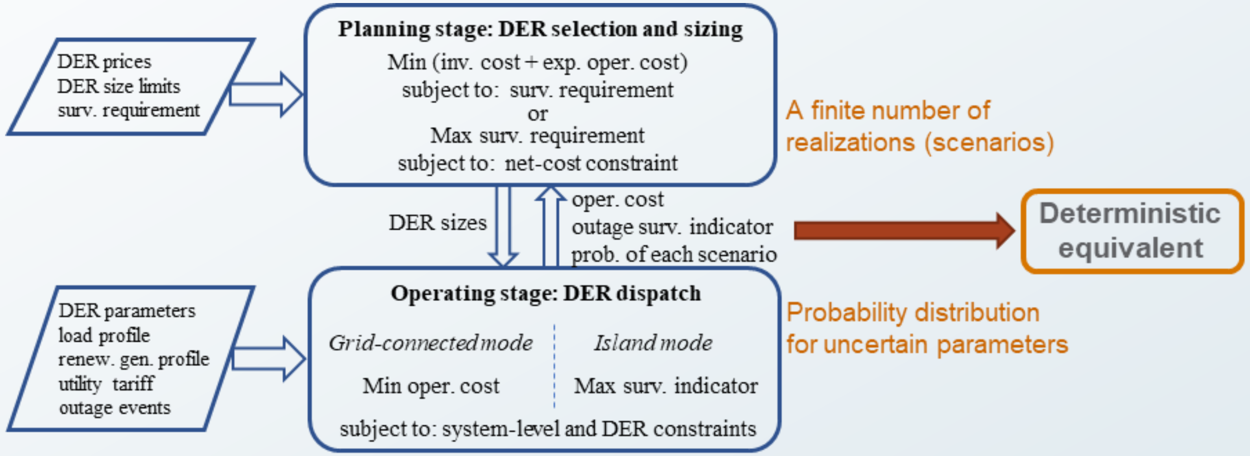
# Energy Storage Valuation

## Description

- Through more than 30 real-world project evaluations, PNNL has developed and refined the Energy Storage Evaluation Tool (ESET™)
- ESET contains five distinct modules for evaluating batteries, hydrogen, pumped storage, buildings (virtual batteries) and microgrids
- The tool is publicly available online (registration required)




**Two-stage stochastic sizing for cost-effective and resilient microgrids**

## Impact

- ESET allows utilities, regulators, policymakers, and others to independently study the technical capabilities and economic values of commercial storage technologies
- Cost and Performance report provides a key reference and baseline for ESGC activities

## Projects/Applications

- Battery Energy Storage: nine sites (WA, OR, MA, NC)
- Hydrogen Energy Storage: Three sites (NY, MA, and ID)
- Microgrid Design: Ten sites (civilian and military)
- Pumped hydro storage: Four sites (CA, NY, HI and WA)
- Virtual batteries (buildings): Four sites (Southern Company territory, OK, CA, MT)

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# Energy Storage Safety Codes and Standards

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## Description

- PNNL staff actively participate in the development and dissemination of codes and standards for the safe interconnection and operation of energy storage assets
- Active development and testing of new technologies to improve energy storage safety
- Program staff frequently participate in trainings for state code officials, policymakers, and regulators

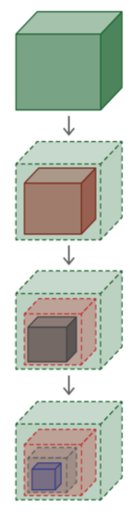
## Impact

- IntelliVent, a recently patented PNNL invention, improves battery safety by preventing flammable gas buildup
- Energy Storage Safety Collaborative (with Sandia and industry) disseminates best practices in safe operations

## Projects/Applications

- Technical advisement to the Energy Storage Association's Corporate Responsibility Initiative
- Program staff have assisted in the development of IEEE 1547, NFPA 855, UL 9540, UL 1974, and IEC TC120
- Annual Safety and Reliability Forum (with Sandia)

Standards and Model Codes Hierarchy



**BUILT ENVIRONMENT**
- ICC IFC, ICC IRC, ICC IBC
- NFPA 5000
- NFPA 1

**INSTALLATION / APPLICATION**
- NFPA 855
- NFPA 70
- UL 9540 A
- IEEE C2
- IEEE 1635/ASHRAE 21
- IEEE P1578
- DNVGL GRIDSTOR
- FM GLOBAL 5-33
- NECA 416 & 416

**ENERGY STORAGE SYSTEMS**
- UL 9540
- ASME TES-1
- NFPA 791

**SYSTEM COMPONENTS**
- UL 1973
- UL 1974
- UL 810A
- UL1741
- CSA 22.2 No. 340-201
- IEEE 1547
- IEEE 1679 Series

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# Regulatory Support and Policy Analysis

## Description

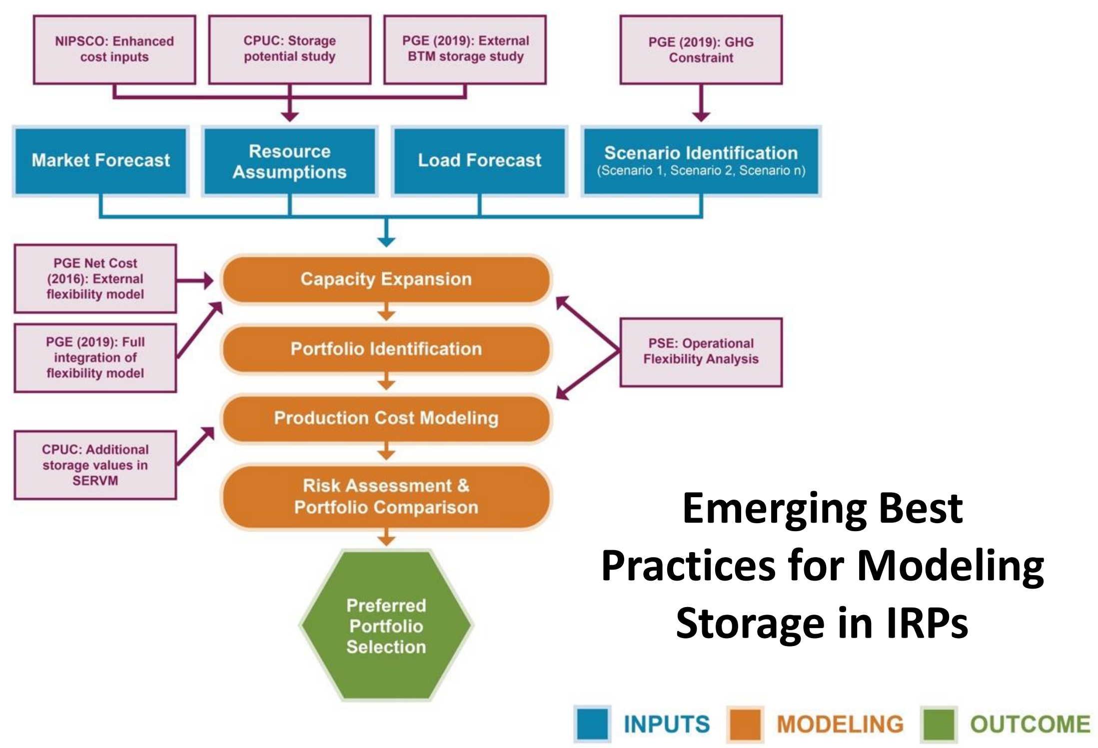
- Identification of barriers to energy storage deployment and best practices for removing/reducing them
- Study of emerging applications for energy storage and the necessary policy/regulatory adaptations necessary to enable them
- Objective, technical assistance to regulators, state energy offices, legislative staff, and municipalities

## Impact

- 26 workshop and conference presentations in FY2021
- Co-development of an energy storage primer with the National Conference of State Legislators for its membership

## Projects/Applications

- Energy Storage in IRPs
- Energy Storage as a Transmission and Dual-Use Asset
- Energy Storage for Social Equity
- GMLC support




Emerging Best Practices for Modeling Storage in IRPs

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# Impact Analysis

## Description

- Providing a holistic analysis of the impact of energy storage within the entire electricity or energy system

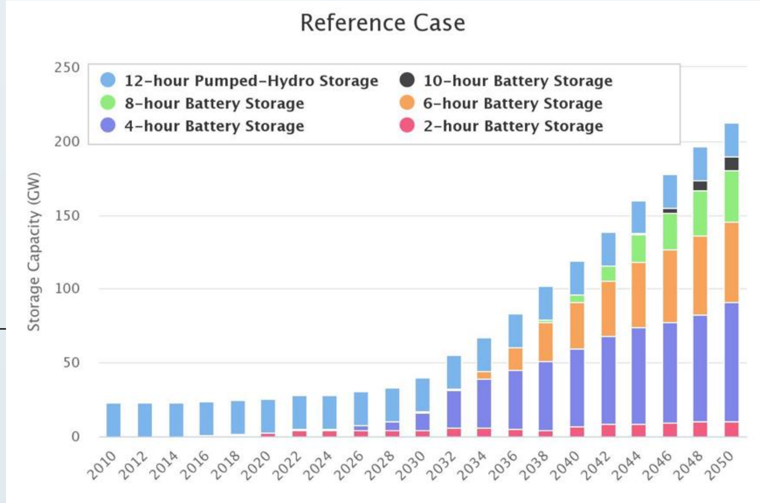
- Key questions
  - How to reach 100% renewable power without massive storage?
  - How much storage is likely to be needed with other flexibility options being deployed and available?
  - For cities, how to get to high levels of RE penetration?
  - When should the system owner buy storage?
  - How does storage fit with DER, etc?
- Existing capabilities being applied
  - Grid Investment models – ReEDS, RPM, dGen, dsGrid
  - Grid Operation models – PLEXOS, SIIP (scalable integrated infrastructure planning), FESTIV, MAFRIT, IGMS

## Impact

- Planners both of energy systems and R&D can benefit from this analysis.
- Assists to determine research areas, potential markets, impacts of policy, and allows for exploration of results

## Projects/Applications

- *Renewable Energy Futures Study (2012)*
  - Chapter 12. Energy Storage Technologies
- *Electrification Futures Study Vol 1 &2*
- *ReEDS Storage Improvement Project added additional value streams and storage options in ReEDS 100% Scenarios for the US (underway)*
- *LA 100 Project examines a variety of scenarios across the energy sector to support the LA 100% renewables goal*
- *Storage Futures Study (underway) seeks to look at a variety of scenarios for the electric grid and examine the feasibility of those models in PLEXOS*

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# Transmission Grid Analysis

## Description

- Providing a holistic analysis of the impact of energy storage within the electric grid

- Key questions
    - How to value storage?
    - How to model seasonal storage?
    - How to model varying levels of storage?
    - How to model emerging (low TRL) storage options?
    - How to model value of hybrid plants?
- Existing capabilities being applied
    - Grid Investment models – ReEDS, RPM
    - Grid Operation models – PLEXOS, SIIP (scalable integrated infrastructure planning), PowerSimulations.jl

## Impact

- System operators can explore and understand issues related to high storage systems.
- Assists to determine research areas, potential markets, impacts of policy, and allows for exploration of results

## Projects/Applications

- **Analysis of Energy Arbitrage in Restructured Markets** (Sioshansi, R., P. Denholm, T. Jenkin, and J. Weiss. (2009) "Estimating the Value of Electricity Storage in PJM: Arbitrage and Some Welfare Effects" Energy Economics. 31, 269-277)
- **Analysis of Storage Capacity Value within the Grid** (Sioshansi, R., S.H. Madaeni, and P. Denholm. "A Dynamic Programming Approach to Estimate the Capacity Value of Energy Storage" IEEE Transactions on Power Systems.)
- **Analysis of Wind and Solar Impact on Energy Storage Value** (Denholm, P., J. Jorgenson, M. Hummon, D. Palchak, B. Kirby, O. Ma, and M. O'Malley (2013) Impact of Wind and Solar on the Value of Energy Storage. NREL Report No. TP-6A20-60568.)
- **Analysis of Energy Storage as an Alternative to Transmission** (Denholm, P., and R. Sioshansi (2009). "The Value of Compressed Air Energy Storage with Wind in Transmission-Constrained Electric Power Systems" Energy Policy 37, 3149-3158. )
- **Analysis of Hybrid Electric Vehicles as Grid Storage** (Denholm, P., M. Kuss, and R.M. Margolis. (2013) "Co-Benefits of Large Scale Plug-In Hybrid Electric Vehicle and Solar PV Deployment" Journal of Power Sources 236, 350-356.)
- In SIIP, NREL represents EV charging preferences and the impacts on the bulk power system and extending to include buildings and thermal energy systems.
- SIIP also working to understand the opportunities to leverage flexibility (energy storage) of water systems.
- PowerSimulations.jl is setup to enable custom representations of different scheduling horizons, including long term/seasonal energy storage within the context of other power system decision horizons

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# Storage System Design & Optimization

## Description

- Analysis and valuation of individual storage systems via techno-economics

- Key questions
  - What is the optimal size of storage (and optimal PV size) for least cost capabilities?
  - What is the value (or net present value) of a storage project?
  - If you want resiliency (backup), what system will do that for you?
  - What are the impacts of various dispatch methods / use cases?
  - How long will a battery last under different usage scenarios?
  - What do costs need to come down to for emerging technologies to have similar financial options to existing storage options?
- Existing capabilities being applied
  - Expertise in system-level techno-economic analysis (SAM, REOpt, etc.)
  - Expertise in building software tools for use by industry and academia.
  - Testing at the system scale resulting in validation of models and results.

## Impact

- Project developers have tools they can use (100k+ for SAM)
- Enables bankability analysis from independent modeling product.
- Improves design and optimization across all tools/capabilities.

## Projects/Applications

-System Advisor Model (SAM) includes PV + battery and CSP + thermal storage

-REOpt tool suite optimizes BTM energy systems for financial or resiliency goals.

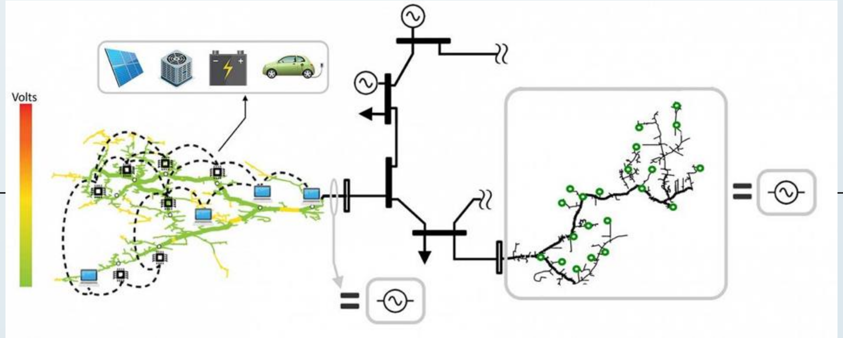
-Emerging BTMS (Behind the Meter Storage) tool (EnStor) analyzes combination of building thermal storage, PV, EV charging and batteries

*-Development of home energy management system algorithms*

System Advisor Model (SAM)

REopt Lite

Behind the Meter Storage (BTMS)

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# Tools to design and optimize integrated energy systems (IES)

INL IES expertise includes combinations of electricity and heat generation, hydrogen production and utilization, and energy storage (electro-chemical, thermal, controllable loads, etc.).

- **Optimize IES designs:** Aspen HYSYS, FORCE, Modelica (HYBRID).
- **Perform technoeconomic assessment and set optimal dispatch:** HERON
- **Design and evaluate distribution grids with storage to handle high EV futures:** Caldera

## Example Projects

- **Exelon** – Design and optimize nuclear + hydrogen technoeconomic performance.
- **Xcel Energy** – Assess value of (a) hydrogen production using nuclear power and (b) smart charging management strategies for EV charging.
- **Arizona Public Service** – Analyze design and dispatch of multiple technologies, including batteries, hydrogen production, and desalination in coordination with a nuclear power plant operating in context of variable generation resources.
- **Internally funded** – Improve design and dispatch of renewable, storage, and small modular reactor IES.

INL has developed ecosystem of tools to design IES design and optimize their technoeconomic performance.

| *Hydrogen Market Price* | *Discount Rate [%]* | *HTSE size [kg/s]* | *Hydrogen Market Size [kg/s]* | *Storage Size [kg]* | *ΔNPV (2019$)* |
|---|---|---|---|---|---|
| *Low* | 12 | 2 | 1.8 | 28800 | 9.83E+07 |
| *Low* | 10 | 2 | 1.8 | 28800 | 1.41E+08 |
| *Low* | 8 | 3.8 | 3.6 | 28800 | 2.13E+08 |
| *Med* | 12 | 3.8 | 3.6 | 28800 | 2.09E+08 |
| *Med* | 10 | 5.6 | 5.4 | 57600 | 3.07E+08 |
| *Med* | 8 | 7.4 | 7.2 | 115200 | 4.39E+08 |
| *High* | 12 | 7.4 | 7.2 | 115200 | 7.42E+08 |
| *High* | 10 | 7.4 | 7.2 | 115200 | 9.45E+08 |
| *High* | 8 | 7.4 | 7.2 | 115200 | 1.19E+09 |

*Example impacts of market and design choices on project net present value*



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# Facilities to perform hardware-based design valuation

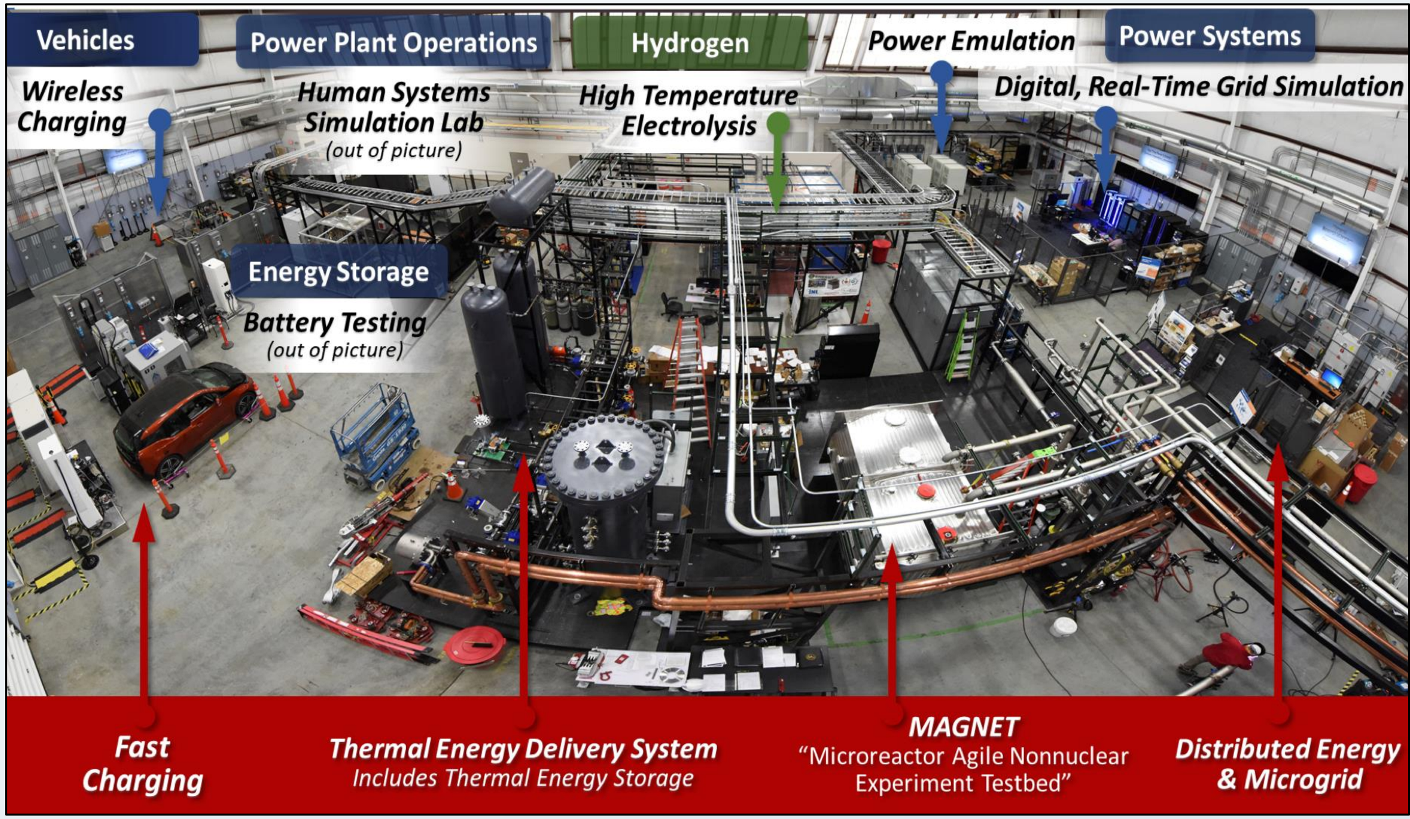
Test energy storage and grid hardware to improve operability and de-risk grid integration

- Conduct experiments with Li-ion batteries, flow batteries, ultracapacitors, and thermal energy storage hardware.
- Identify valuation impacts of design tradeoffs.
- Verify value of technologies using real hardware.

## Example Projects

- **Idaho Falls Power:** Assess storage impacts for small municipal utility in context of regional grid.
- **Hydrogen:** Demonstrate H2 as controllable load to provide grid value and support stability.
- **Electrified transportation:** Assess how stationary storage and microgrids can facilitate EV fast charging.
- **Military:** Design and validate base microgrid architectures and components.

INL's Systems Integration Lab enables testing diverse systems in controlled environment prior to field demonstration and deployment





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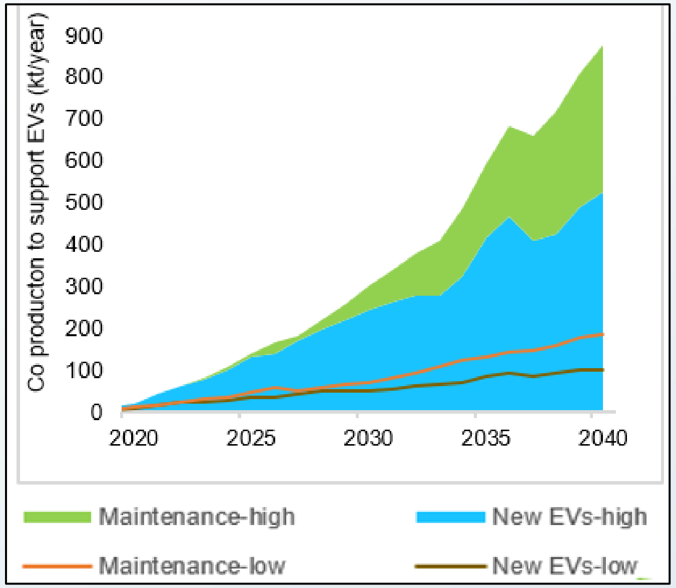
# Models to assess supply chain resilience

Supply chain models to assess impacts of energy storage technology choices on scalability, prices, reliability, and geopolitics

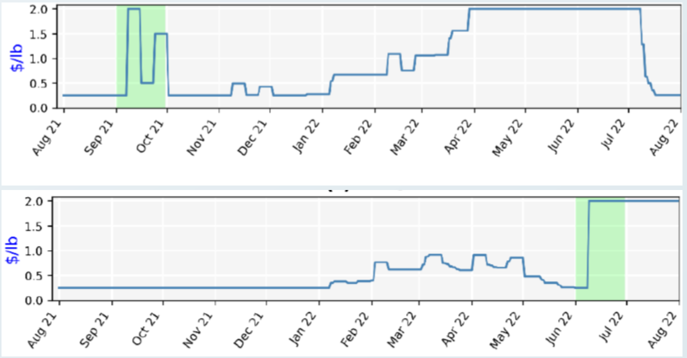
- **Quantify impacts of energy storage critical materials and decarbonization scenarios on global supply chains:** Cobalt-Copper-Nickel supply chains (CoCuNi) and Lithium Supply Analysis model (LISA)
- **Estimate market dynamics and viability of meeting specific targets involving rare earth minerals:** Dynamic Rare Earth Element Model (DREEM)
- **Assess linkages and impacts of disruptions on complex societal systems:** All Hazards Analysis (AHA)

## Example projects

- **Cobalt impacts:** Assess Cobalt supply to EV sector and associated demand under different EV scenarios.
- **Supply chain dynamics:** Assess impacts of demand surges on prices and product availability.




Simulate impacts of Cobalt use and policy on EV prices and deployment.




Supply chain resilience framework shows the impacts of demand surge on prices.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# Development of Models and Software Tools

## Description

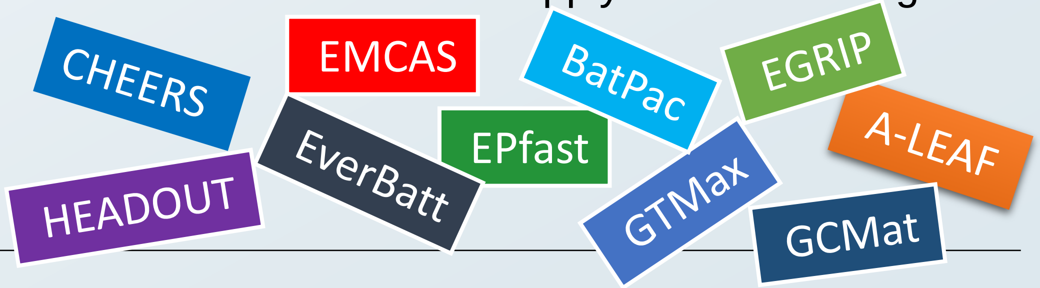
- Argonne has developed many software tools that can model and simulate energy storage technologies
- Most of the tools are publicly available, some can be licensed

## Impact

- Software tools represent ES in planning and operational models, reliability and resilience assessments, electricity market analyses, valuation of projects and their services, etc.
- Key beneficiaries include utilities and system operators, regional planners and reliability coordinators, regulators, and independent project developers.


## Software Tools and their Applications

- **BatPac** – ES cost and performance
- **EverBatt** – Battery life cycle analysis
- **A-LEAF** – Low-carbon energy analysis framework
- **CHEERS** – Power plant and system optimization
- **GTMax** – Optimization of generation and transmission
- **EMCAS** – Agent-based modeling of electricity markets
- **EPfast, NGfast, POLfast** – Resiliency modeling
- **HEADOUT** – Hurricane outage assessment
- **EGRIP** – Power system restoration
- **GCMat** – Critical materials supply chain modeling





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# Energy Storage Valuation

## Description

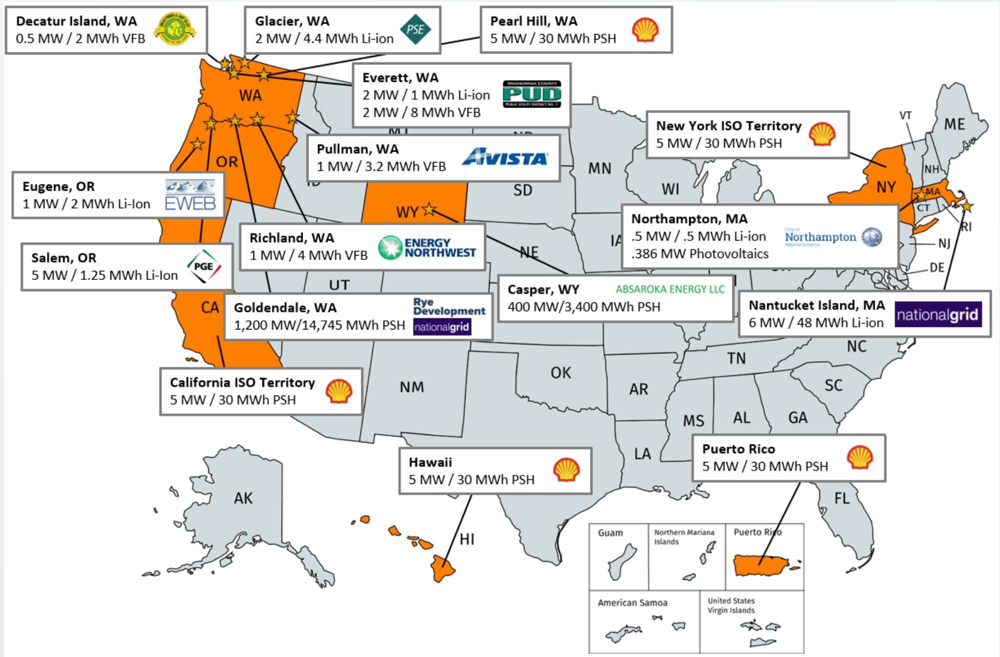
- Development of a taxonomy of energy storage values, including bulk energy, transmission, ancillary service, distribution, and customer energy management services.
- Broad application of valuation taxonomy to numerous technologies (e.g., hydrogen power-to-gas, pumped storage hydro, multiple battery chemistries) to evaluate both market and non-market benefits of storage.
- Argonne has developed both market- and systems-based models (e.g., A-LEAF) to evaluate the benefits of storage.

## Impact

- Methods/models can benefits utilities, regulatory agencies, financial organizations, manufacturers, and markets, with values assessed from a societal, private, or system perspective
- Key benefits include enhanced planning/design, asset management, and real-time control of storage systems

## Projects/Applications

- Argonne PIs have led techno-economic assessments of storage systems at 16 sites across the U.S. with combined power and energy capacities of 1.6 GW, 18.2 GWh, respectively.

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# Methodology and Tool for Valuation of PSH

## Description

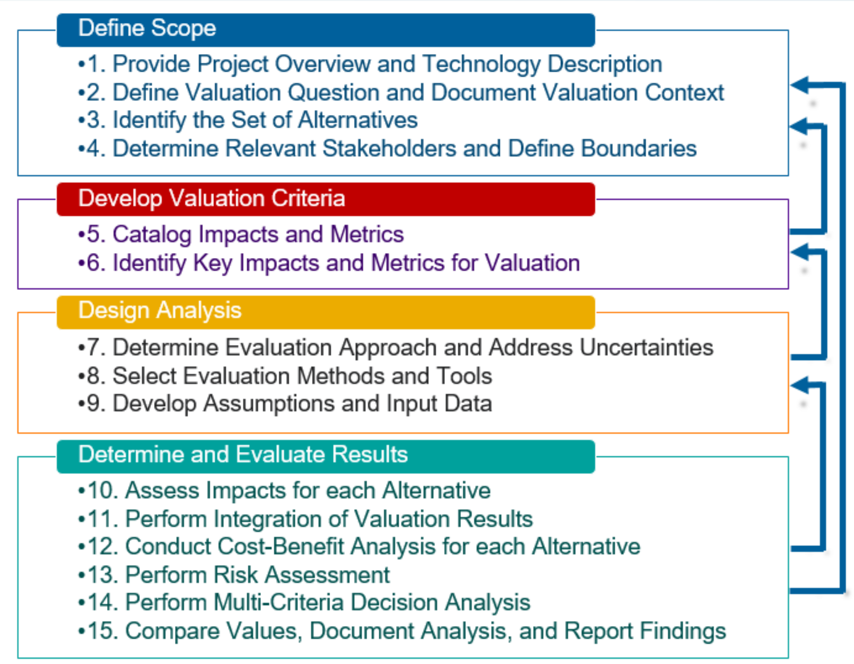
- A cost-benefit and decision analysis framework to assess the value of existing and new PSH projects.
- PSH Valuation Guidebook describes a 15-step valuation process developed by a 5-lab project team funded by DOE/WPTO HydroWIRES initiative
- A publicly available online PSH Valuation Tool is currently being tested by industry reviewers.

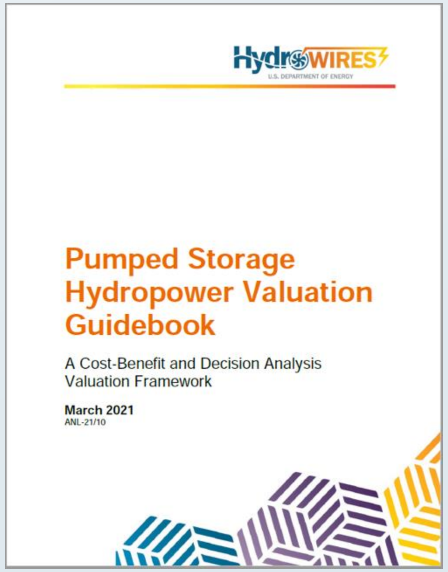
## Impact

- PSH valuation methodology and tool will benefit developers of new PSH projects, but also owners/operators of existing PSH plants, regulatory agencies, lending and financial organizations, industry research organizations, and academia.
- Key benefits include more accurate valuation of the full range of services that PSH provide to the grid and better understanding of value of PSH plants and their role in the power system.

## Projects/Applications

- Two test case studies were conducted for proposed PSH projects:
  - Goldendale (1,200MW) proposed by Rye Development and Copenhagen Infrastructure Partners (CIP)
  - Banner Mountain (400MW) proposed by Absaroka Energy.

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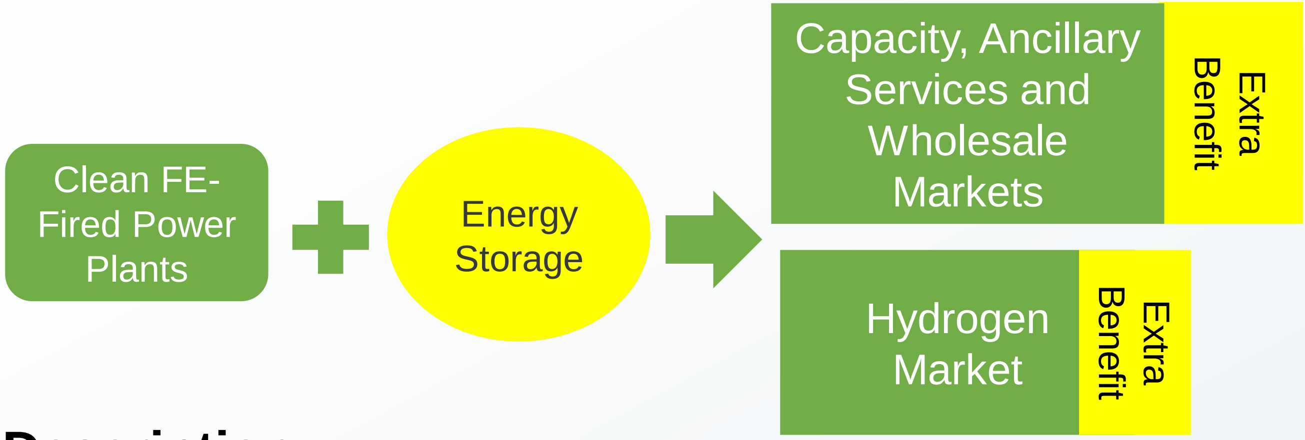
# Valuation of Energy Storage (ES) in Fossil Energy (FE) Power Sector




## Description

- This capability evaluates potential enhanced revenues from Ancillary Services, Wholesale Electricity, and Capacity Markets by pairing energy storage (ES) with fossil power-plants (FE).
- ES coupled with FE is important as it can provide operational benefits to the power plant generator and can be valuable to the whole system.
- This capability is an ES valuation methodology and is used in conjunction with PNNL's ES Cost and Performance Database*.

## Impact

- Informs stakeholders of benefits of storage-enhanced flexible FE power plants.
- Enables operators to understand market opportunities.
- Prepares groundwork for better market rules for hybrid assets in the power system.

## Projects/Applications

- Valuation of ES integrated in fossil energy power plants in major Independent System Operators (ISOs), such as Mid-Continent (MISO), Electric Reliability Council of Texas (ERCOT), California (CAISO), and Pennsylvania, Jersey, Maryland Power Pool (PJM)
- Future valuation of hybrid Carbon Capture and Storage (CCS) systems and blue hydrogen

*Energy Storage Cost and Performance Database | PNNL

**For more information:**

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# Assessing the Value of Energy Storage Within the Electrical Grid System

## Description

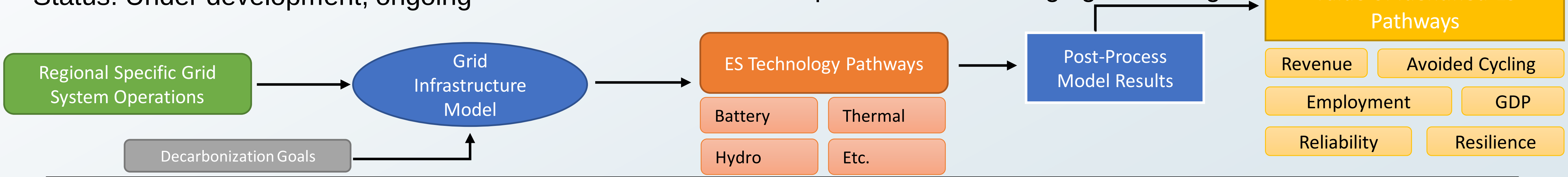
- Leverage grid infrastructure models to identify technically optimal energy storage (ES) pathways.
  - Considers regional difference in electrical grid system operations, generation, transmission, and distribution constraints, resource availability, variable and firm capacity, decarbonization goals.
- Post-process grid infrastructure model results to assess the potential value of identified ES pathways.
  - Value can be measured as additional revenue from participation in capacity markets, avoided cycling costs, avoided customer outages, jobs created or supported, impacts to GDP, reliability, or resilience.
- Topic Areas: Power Systems Operations, Energy System Planning, Policy Analysis, & Market Design
- Status: Under development, ongoing

## Impact

- Potential Users: policy and program analysts, grid infrastructure planners, utility commissions, and power-plant operators
- Key Benefit: provides information on potential for ES across regions, as well as identified the value of ES opportunities

## Projects/Applications

- Reports: (1) quantify the impact of adding grid-scale battery storage on greenhouse gas emissions and 2) examining revenue at the ISO level for ES.
- Ongoing Projects: refinement of grid infrastructure models (PROMOD, IDAES, and MARKAL) to include new ES practices and emerging technologies.

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# Disclaimer

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# A Flexible Storage Model for Power Network Optimization

## Description

- A flexible storage model for use in multi-period optimal power flow problems:
  - can represent the dynamics of an energy buffer at a wide range of scales;
  - compatible with both balanced and unbalanced power flow equations;
  - convex relaxations and linear approximations allow seamless integration of the model into applications where convexity or linearity is required;
- Topic areas: Power Systems Operations, Resilience
- Stable, **high-TRL** implementations in open-source software
  - PowerModels (github.com/lanl-ansi/PowerModels.jl)
  - PowerModelsDistribution (github.com/lanl-ansi/PowerModelsDistribution.jl)

## Impact

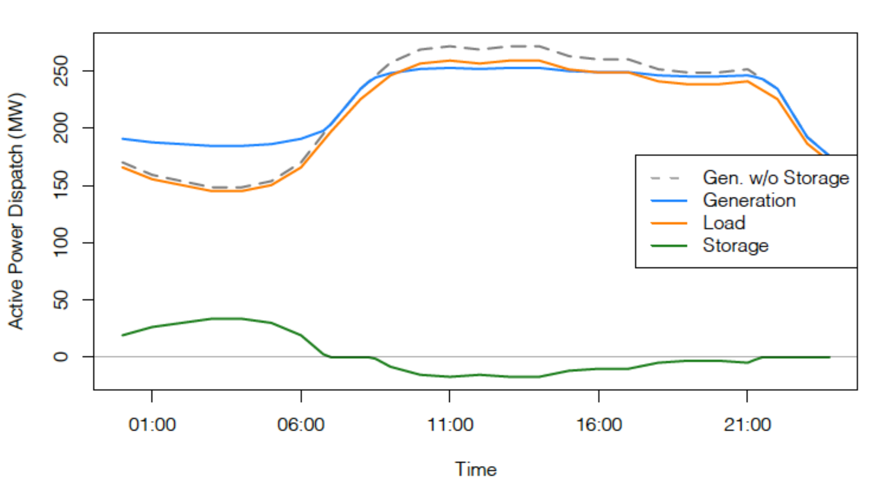
- Formulated initially to enable a single flexible model for research for many types of transmission or distribution energy storage systems, which are numerous in their types and complexity, but now has applications for power systems operations, particularly in analysis and advisement.
- Key Benefit: it can represent generic storage types with only a minimal set of parameters derived from technical specs

## Projects/Applications

- DOE/GMLC: CleanStart DERMS
  - Restoration of distribution feeders with existing DER, e.g., batteries, fuel cells, etc.
- DOE/OE/Microgrids: Resilient Operations of Networked Microgrids (RONM)
  - Recovery and resilient operations from contingencies by networking microgrids
- DOE/OE/AGM: Optimized Resilience for Distribution and Transmission Systems
  - Co-optimization of transmission networks with distribution feeders with DER

*Figure*: A comparison of storage impacts to generator dispatch in single-phase AC optimal power flow. In particular, we observe a peak shaving behavior that is discovered by the storage optimization approach.

Publication DOI: 10.1145/3396851.3402121

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# Any Questions?

# Thank you!

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