REopt: Energy Decision Analysis

NREL REopt Team

reopt.nrel.gov
The Nation’s Energy Supply Is in the Midst of a Transformation

• As costs decrease, renewable energy deployment is growing worldwide
• Generation is increasingly distributed, with 31% of new capacity behind-the-meter
• With increasingly integrated and complex systems, back-of-the-envelope calculations are no longer sufficient to determine distributed energy project potential
REopt Optimizes Integrated Energy Systems

- NREL’s REopt™ platform optimizes planning of generation, storage, and controllable loads to maximize the value of integrated systems.
- It transforms complex decisions into actionable results for building owners, utilities, developers, and industry.
- REopt analysis guides investment in economic, resilient, sustainable energy technologies.
REopt Energy Planning Platform

Formulated as a mixed integer linear program, REopt provides an integrated, cost-optimal energy solution.

Resources
- Renewable Generation
  - Solar PV
  - Wind
  - Biomass, etc.
- Conventional Supply
  - Electric Grid
  - Fuel Supply
  - Conventional Generators
- Energy Storage
  - Batteries
  - Thermal storage
  - Water tanks
- Dispatchable Loads
  - Heating and Cooling
  - Water Treatment

Drivers
- Energy Costs & Revenue
  - Energy & Demand Charges
  - Market Participation
  - Escalation Rate
- Economics
  - Technology Costs
  - Incentives
  - Financial Parameters
- Goals
  - Minimize Cost
  - Net Zero
  - Resilience

Optimized Minimum Cost Solution
- Technologies
  - Technology Mix
  - Technology Size
- Operations
  - Optimal Dispatch
- Project Economics
  - Capital Costs
  - Operating Costs
  - Net Present Value

Energy Planning Platform
Techno-Economic Optimization

- Thermal Loads
- Water Demand
- Electric Loads
What is the optimal size of distributed energy resources (DERs) to minimize my cost of energy?

How do I optimize system control across multiple value streams to maximize project value?

Where do market opportunities for DERs exist? Now and in the future?

What will it cost to meet my sustainability or resilience goal?

What is the most cost-effective way for me to survive a grid outage?
REopt considers the trade-off between ownership costs and savings across multiple value streams to recommend optimal size and dispatch.

Example of optimal dispatch of PV and BESS
How Does REopt Evaluate Resilience?

REopt finds the system size and dispatch that minimizes life cycle energy costs for grid-connected operations and survives a specified grid outage. It evaluates thousands of random grid outage occurrences and durations to identify the probability of survival.

Existing generator with fixed fuel supply sustains the critical load for 5 days with 90% probability.

Adding solar and storage to the existing generator increases survivability from 5 to 9 days by extending fixed diesel fuel supplies and provides utility cost savings while grid-connected.
Optimal Sizing and Dispatch at Single Site

- REopt helps partners make well-informed energy investment decisions backed by credible, objective data analysis.
- Typical questions from clients include:
  - How should RE and storage be sized and dispatched to minimize site energy costs?
  - What is the value (or net present value) of a project?
  - How should I dispatch my battery to maximize the value across multiple value streams? During an outage?
  - What technologies will sustain my critical load during an outage at lowest cost?
  - What is the optimal mix and size of technologies to meet a renewable energy goal? How much will it cost?
  - How can dispatchable loads, such as smart domestic water heaters, air conditioners, water purification and treatment, electric vehicles, and storage, be used to maximize the value of RE and provide grid services?

Alcatraz PV-battery-diesel hybrid system completed in 2012. NREL provided technical assistance to optimize the dispatch.

Ft. Carson 4.25 MW/8.5 MWh peak-shaving Li-ion BESS completed in 2019. NREL provided technical assistance to validate the $0.5 million/year savings.
Project Economics at National Scale

- REopt enables national-scale analysis of renewable energy (RE) and storage economics and impacts on deployment
- Analysis questions include:
  - Where in the country is storage and photovoltaics (PV) currently cost-effective?
  - At what capital cost is storage adopted across the United States?
  - Under what conditions (utility rate, load profile, location) can RE and storage provide cost savings and resilience benefits for commercial buildings?
  - How do varying utility rates, projected costs, and incentive structures impact storage profitability?
  - How do I prioritize projects across a portfolio of sites with varying energy costs and use, renewable energy resources, and land availability?

NREL explored solutions for increasing affordability of DC fast charging (DCFC) nationwide through pairing with solar, storage, and building loads.
The **REopt team** provides a suite of trusted techno-economic **decision support services** and **software** to optimize energy systems for buildings, campuses, communities, microgrids, and more.

The team also develops the publicly available REopt Lite tool, which contains a subset of REopt’s features. Capabilities developed in REopt are transferred to REopt Lite based on broad use and validation, customer needs, and funding available.

**REopt Decision Support Services**

Allows organizations to work closely with NREL’s team of experts on customized analysis, answering complex energy questions using an expanded set of internal modeling capabilities.

**REopt Lite™ Software**

Developed by the REopt team, the tool guides users to the most cost-effective or resilient PV, wind, and battery storage options at no cost to users. Available via web tool, application programming interface (API), and open source.

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REopt Projects and Successes
Value of Behind-the-Meter Storage at Fort Carson

**Description:** NREL used REopt to independently verify the predicted utility savings estimated by the project developer from battery peak shaving.

**Technology:** Li-ion battery storage

**Impact:** 4.2 M; 8.5-MWh battery installed at Ft. Carson under an ESPC. Largest battery in the Army at time of installation, saving Ft. Carson $500,000 per year in utility costs.

**Partner:** Army, AECOM
Description: NREL validated the technical and economic feasibility of an emerging vanadium flow battery technology through loss modeling, characterization, and field test

Technology: High fidelity vanadium flow battery

Impact: Identified value streams through the application of utility-scale vanadium redox flow battery for local grid support use cases

Partners: Sumitomo and SDG&E

**Description:** NREL used REopt to evaluate how long existing and proposed backup energy systems could sustain the critical load during an outage at an Army National Guard base. REopt evaluated thousands of random grid outage occurrences and durations and compared hours survived with diesel gensets vs. gensets augmented with PV and battery.

**Technology:** Solar, storage, diesel generation

**Impact:** PV and battery can provide savings and resilience. Site can achieve 4 extra days of resilience with no added cost.

**Partner:** Army National Guard

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<table>
<thead>
<tr>
<th></th>
<th>Generator</th>
<th>Solar PV</th>
<th>Storage</th>
<th>Lifecycle Cost</th>
<th>Outage</th>
</tr>
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<tbody>
<tr>
<td>1. Base case</td>
<td>2.5 MW</td>
<td>-</td>
<td>-</td>
<td>$20 million</td>
<td>5 days</td>
</tr>
<tr>
<td>2. Lowest cost</td>
<td>2.5 MW</td>
<td>625 kW</td>
<td>175 kWh</td>
<td>$19.5 million</td>
<td>6 days</td>
</tr>
<tr>
<td>3. Proposed system</td>
<td>2.5 MW</td>
<td>2 MW</td>
<td>500 kWh</td>
<td>$20 million</td>
<td>9 days</td>
</tr>
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</table>
Aligning Generation and Load With Storage and Demand Flexibility

**Description:** NREL evaluated controllable load and storage options to improve customer economics of solar under post-net metering utility tariffs.

**Technology:** Solar, storage, buildings

**Impact:** Flexible loads increase the value of solar by aligning generation to load to maximize value.

**Partner:** DOE Solar

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Description: NREL evaluated opportunities for synergistic integration and control of electrified transportation fleets with flexible buildings loads, RE, and stationary storage.

Technologies: Mobility, storage, buildings, solar, advanced system integration controls

Impact: Demonstrated optimal control of integrated RE, building loads, storage, and EV system in laboratory testing. Integrated system provided increased value to the site owner.

Partners: Eaton (funding partner), Holy Cross Energy, SDG&E, Duke Energy, UPS, EPRI
Additional Information

REopt Technical Description
REopt Development Team
Mixed Integer Linear Program

- Mathematical model written in the MOSEL programming language solved using commercial FICO Xpress solver
- Analysis typically requires significant site-specific and client-requested customizations

Solves energy balance at every time step for entire year (typically 15-minute or hourly interval)

- Load must be met from some combination of grid purchases, on-site generation, or discharge from storage
- Typically does not consider power flow or transient effects
- Has perfect prediction of upcoming weather and load
- Assumes all years in analysis horizon are the same (typically 25 years)

Technology modules based on empirical operating data

Finds optimal technology sizes (possibly 0) and optimal dispatch strategy subject to resource, operating, and goal constraints

- Objective function is to minimize life-cycle cost of energy
- Resulting life cycle cost is guaranteed optimal to within a known gap (typically 0.01%) subject to modeling assumptions
REopt Team

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More REopt Projects

Storage Sizing and Operation
Resilience and Microgrids
Integration of Flexible Loads
Electric Vehicles
Portfolio Optimization
Market Participation Strategy for SDG&E Utility Storage

**Description:** NREL optimized the dispatch of a battery on a San Diego Gas & Electric (SDG&E) feeder with high-PV penetration across multiple value streams (locational marginal price [LMP] arbitrage, frequency regulation, grid support functions).

**Technology:** Li-ion battery

**Impact:** Informed battery market participation strategy to maximize value for SDG&E

**Partners:** SDG&E

NREL assessed the value the battery provided by enabling deferral of a transformer upgrade through peak shaving on the feeder.

Battery market participation strategy: Incorporating degradation into the model changes optimal wholesale market dispatch.

PV+Battery Dispatch for Municipal Utility in PJM

**Description:** NREL used REopt to determine the optimal dispatch to mitigate coincident peak demand charges.

**Technology:** Natural gas reciprocating engines and battery storage

**Impact:** Identified potential for $171 million in savings, including:

- **92.8-GWh** reduction in annual market purchases ($79.6 MM)
- **53.6-MW** reduction in 1 CP demand charges ($39.1 MM)
- **61.2-MW** reduction in 5 CP demand charges ($51.8 MM)

**Partner:** Utility in PJM
Health-Conscious Battery Economics

**Description:** NREL evaluated the economic impact of health-conscious battery controls that consider the trade-off between operational value and degradation cost.

**Technology:** Storage

**Impact:** Evaluated battery sizing and operational decisions considering degradation impacts. Findings are being validated through battery pack testing at NREL and will then be integrated into Eaton controls approaches.

**Partner:** Eaton

Degradation increases with maximum depth of discharge and high mean state of charge.
Evaluating Centralized vs. De-centralized Microgrid Options for Military Installations

**Description:** NREL performed an integrated microgrid feasibility analysis for three U.S. military installations to support U.S. Army energy resilience requirements.

**Technologies:** Solar PV, battery storage, combined heat and power (CHP), chillers (adsorption and centrifugal), hot- and cold-water thermal storage, microgrid components

**Impact:** Developed conceptual design and cost estimate for integrated microgrids to provide energy cost savings and resilience across the three international U.S. military installations.

- Addressed electric vs. heat and resiliency vs. cost prioritization for CHP operation
- Resulted in successful RFP for optimized microgrid design.

**Partners:** United States Army Garrison Italy

Microgrids for Rural Energy Access In Africa

Description: NREL used REopt to optimize microgrid designs for systems across sub-Saharan Africa, analyzing the impact of cost trends, technology choices, business models, and regulatory structures to identify least-cost pathways to rural electrification

Technology: PV, li-ion and lead-acid batteries, diesel generation

Impact: Informed rural microgrid design decisions and government policies around energy access goals

Partners: USAID, AMDA, individual microgrid developers, national governments in sub-Saharan Africa


Market Revenues for Backup Generators

Description: NREL evaluated the value backup generators can provide when used for grid-connected economic dispatch. NREL considered potential revenues from tariff switching, peak shaving, energy self-generation, coincident peak reduction, wholesale real-time pricing, spinning reserve markets, and emergency standby programs.

Technology: Natural gas and diesel generators

Impact: The overall cost of back-up generation can be lowered, but opportunities vary across the United States, depending on markets.

Partner: Enchanted Rock

<table>
<thead>
<tr>
<th>Generator Type</th>
<th>Diesel</th>
<th>Natural Gas</th>
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<tbody>
<tr>
<td>Region</td>
<td>TX</td>
<td>FL</td>
</tr>
<tr>
<td>CAPEX + O&amp;M ($/kW)</td>
<td>-$1,205</td>
<td>-$1,405</td>
</tr>
<tr>
<td>Revenues/savings ($/kW)</td>
<td>$968</td>
<td>$1,380</td>
</tr>
<tr>
<td>Fuel cost ($/kW)</td>
<td>-$187</td>
<td>$0</td>
</tr>
<tr>
<td>NPV ($/kW)</td>
<td>-$425</td>
<td>$175</td>
</tr>
</tbody>
</table>

Life cycle costs and revenues ($/kW) for diesel generator providing grid services in Camden, NJ

Net present values by region and by fuel type

Optimizing Off-Grid Water Treatment and Storage

**Description:** NREL optimized an off-grid water treatment and storage system on Navajo lands.

**Technologies:** PV, diesel generator, storage, water treatment and storage

**Impact:** Identified opportunities to reduce battery size and fuel use by flexing pumping loads and using storage inherent in water tank.

**Partner:** U.S. Bureau of Reclamation

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DC Fast Charging Station Design

Description: NREL explored solutions that can help make DC fast charging (DCFC) more affordable for EV drivers in the United States:

- Solar PV and/or energy storage (batteries)
- Co-locating DCFC with a commercial building

Technologies: DCFC, solar, battery storage

Impact: Found 11%–40% of sites can reduce lifetime electricity cost by installing technologies. Co-location often economically preferable but relative savings diminish as load increases.

Partners: DOE Vehicle Technologies Office

Impact of EV Workplace Charging in Minnesota

**Description:** NREL used REopt to evaluate the economics of workplace EV charging. NREL’s EVI-Pro database used to generate static and flexible EV load profiles.

**Technology:** EVs, PV, storage

**Impact:** Found savings from adding PV and storage to EV charging infrastructure and/or flexibility in EV charging times.

**Partner:** City of Minneapolis

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**Description:** Analyzed behind-the-meter solar and storage economics across 16 climate zones, 16 building types, 80 utility rate tariffs, and varying technology price points

**Technology:** PV, storage

**Impact:** Identified critical factors in the cost-effectiveness of solar+storage in commercial buildings

**Partner:** DOE Solar Energy Technologies Office

Deploying Cost-Effective Efficiency, Renewable Energy, and Storage

**Description:** NREL is working with the Army Office of Energy Initiatives to evaluate RE and storage projects across 100 Army bases. NREL is prioritizing technically and economically feasible projects and assisting in project development.

**Technology:** PV, wind, CHP, biomass, natural gas, storage, microgrids

**Impact:** Identifying cost-effective RE, storage, and microgrid projects to reduce Army energy cost and increase installation resilience

**Partners:** U.S. Army Office of Energy Initiatives

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Identifying and Prioritizing Projects Across a Portfolio

**Description:** NREL evaluated 700 sites for Time Warner Cable to identify and prioritize technically and economically feasible RE and storage projects and estimate the cost of meeting renewable energy goals.

**Technology:** PV, wind, ground-source heat pump, storage

**Impact:** Identified cost-effective RE and microgrid projects to meet Time Warner Cable energy goals for reduced energy use, reduced energy cost, and increased resilience.

**Partners:** Time Warner Cable, Inc.

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**Economically viable PV projects across TWC portfolio**

<table>
<thead>
<tr>
<th>Sites Evaluated</th>
<th>696</th>
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<tbody>
<tr>
<td>Sites with Cost-Effective PV</td>
<td>306</td>
</tr>
<tr>
<td>Size</td>
<td>38.79 MW</td>
</tr>
<tr>
<td>NPV</td>
<td>$37 million</td>
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