2022 Better Buildings SUMMER WEBINARS

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Grid Outages from Natural Disasters

U.S. 2021 Billion-Dollar Weather and Climate Disasters

- Drought/Heat Wave
- Flooding
- Hail
- Hurricane
- Tornado Outbreak
- Severe Weather
- Wildfire
- Winter Storm/Cold Wave

Western Wildfires 2021
Central Severe Weather July 8–11
Midwest Derecho and Tornado Outbreak December 15
North Central Severe Weather August 10–13
Central Severe Weather June 24–26
Ohio Valley Hail Storms June 17–18
Southeast, Central Tornado Outbreak December 10
Eastern Severe Weather March 27–28
Southeast Tornadoes and Severe Weather March 24–25
Tropical Storm Fred August 16–18
Tropical Storm Elsa July 7–9

California Flooding and Severe Weather January 24–29
Western Drought and Heat Wave 2021
Texas and Oklahoma Severe Weather April 27–28
Texas Hail Storms April 12–15
Louisiana Flooding May 17–18
Hurricane Ida August 29–September 1

Northwest, Central, Eastern Winter Storm and Cold Wave February 10–19
Hurricane Nicholas September 14–18

This map denotes the approximate location for each of the 20 separate billion-dollar weather and climate disasters that impacted the United States in 2021.
What are Critical Facilities?

- Buildings that provide critical public services during grid-disabling emergency events
- Examples:
  - Designated emergency shelters, such as schools or community centers
  - Food preparation and storage facilities
  - Hospitals, nursing homes, and other health care facilities
  - Water and wastewater treatment facilities
  - And other services, as determined by the community
How Energy Efficiency Contributes to Resilience

- Resilience benefits of energy efficiency:
  - Energy conserved for critical functions
  - Longer-lasting backup power from distributed generation
  - Lower risk of grid overload
  - Increased passive survivability

- Examples of efficiency projects:
  - HVAC upgrades
  - LED lighting retrofits
  - Upgrading insulation
  - Reducing plug loads
DOE State and Local Resources

- **Energy Resilience in the Public Sector** – webpage with funding and planning resources

- **State and Local Solution Center** – central DOE website with more than 400 tools, resources, and best practices for the public sector

- **State and Local Spotlight** - Monthly newsletter with ~33,500 subscribers

Subscribe to State and Local Spotlight newsletter: http://energy.gov/eere/slsc

Contact us: stateandlocal@ee.doe.gov
Please go to www.slido.com using your mobile device, or by opening a new window

Enter Event Code

#DOE
We want to hear from you!

Welcome Polls

Please go to www.slido.com and enter code #DOE to respond
Today’s Presenters

Ian LaHiff
City of Orlando

Tony Sparks
Albuquerque Public Schools

Indu Priya Manogaran
National Renewable Energy Laboratory
Ian LaHiff
Energy Project Manager, City of Orlando
Resilience Hubs in the City of Orlando
Resilience Hubs

Agenda

- Green Works Orlando
- Climate Vulnerability & Risk Assessment
- Resilience Hubs 101
- CDBG-MIT grant – Resilience Hubs
- AARP grant – Resilience 'Tables of Connection'
- Q&A
Green Works Orlando
Office of Sustainability & Resilience

• Award-winning sustainability program called “Green Works Orlando” launched by Mayor Buddy Dyer in 2007

• Develops internal and citywide policies + programs to:
  • Protect natural resources and the environment (air, water, land)
  • Improve public health and social equity
  • Create green economic dev. and green jobs opportunities
  • Decrease air pollution and carbon emissions
  • Enhance city resilience and adapt to climate change impacts
  • Reduce operational expenses and enhance efficiency
  • Educate the residents and businesses on sustainable practices

• Focuses on 7 key areas:
  • Clean Energy
  • Green Buildings
  • Local Food Systems
  • Zero Waste
  • Livability
  • Clean Water
  • Electric & Alternative Transportation
Pathway towards Sustainability & Resilience


Climate Vulnerability Assessment (2017)

Greenhouse Gas Inventory (2018)

Community Sustainability Action Plan (2013, updated in 2018)

Vision Zero Plan (2019)

Future-Ready Master Plan (2020)
Global Covenant of Mayors CVA Structure

- Current Probability
- Current Consequence
- Frequency
- Intensity
- Timescale
- Impact
- Services and Assets impacted
- Adaptive Capacity
Threat assessment:

<table>
<thead>
<tr>
<th>Current Probability</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Consequence</td>
<td>Med High/High</td>
</tr>
<tr>
<td>Future Frequency</td>
<td>Increasing</td>
</tr>
<tr>
<td>Future Intensity</td>
<td>Increasing</td>
</tr>
<tr>
<td>Timescale</td>
<td>Current to Long term</td>
</tr>
<tr>
<td>Magnitude</td>
<td>Extremely Serious</td>
</tr>
</tbody>
</table>

Description
- Orlando area is vulnerable to many storms regardless of their orientation and track (<50 mi. E. coast <70mi W. coast)
- Increased surface water temps, air temps and moisture, provide precipitation and increased storm strength

Assets or Services Impact:
- Safety + Security: Injuries and fatalities: debris, flooding, CO poisoning, power outages (extreme heat), food and waterborne illness
- Infrastructure: Residential, commercial and public structures, roads, communication, electric grid T&D
- Poverty and Equality: Ability to prepare home and/or evacuate –LMI HH
- Economic health: residential, local business, tourism

Factors that influence adaptive capacity:
- Hurricane preparedness: Residential and Local Business
- SWM: SWM capacity + Green infrastructure
- Electricity provision: mobile solar + storage stations, 100+ workhorse vehicles (vehicle to grid capabilities)

Tropical Storms and Hurricanes

Climate Vulnerability & Risk
Hurricanes & Tropical Cyclones

- Orlando area is vulnerable to tropical storms and hurricanes regardless of their orientation and track (<50 mi. E. coast <70mi W. coast)

- Following hurricanes, some residents witness:
  - Power outages
  - Food shortages
  - Poor/No internet
  - Ice shortage
  - Access to clean water
Grid Resiliency - Lessons Learned

Texas
5 million lost power, 30+ died
February 2021

Florida
Lack of power leads to indirect Hurricane deaths 2017 season

Hundreds of Florida nursing home residents likely died indirectly from Hurricane Irma, study finds

Researchers at the University of South Florida and Brown University found that there were 262 nursing home deaths at 30 days and 433 more at 90 days, compared to the same time frame in 2015.

Source: https://tinyurl.com/pma36wtb
Resilience Hubs

Agenda

- Green Works Orlando
- Climate Vulnerability & Risk Assessment
- Resilience Hubs 101
- CDBG-MIT grant – Resilience Hubs
- AARP grant – Resilience 'Tables of Connection'
- Q&A
What are Resilience Hubs?

Established, community-serving facilities augmented to:

- Support residents and coordinate resource distribution and services before, during, or after a natural hazard event.
- Provide equitable resilience
Purpose:
Restoring Lifelines

Charge phones, laptops, oxygen machines, portable wheelchairs

FEMA LIFELINES

Energy (Power & Fuel)

Contact family members;
  Contact employers;
  Apply for assistance;
  Pay bills;
  Apply for jobs;
  Learn remotely

Communications

Pick up food and water;
Stay cool or warm

Food, Water, Shelter

Find out about emergency orders such as curfews, evacuations

Safety and Security

Get vaccinated or tested;
Continue exercise / fitness routines

Health and Medical
WHAT IS A RESILIENCE HUB?

OFF GRID SOLAR POWER
Designed to provide power during an emergency and reconnect to the grid once power is restored.

COMMUNICATION HUB
A single point for access to news and information before, during, and after an emergency.

RISK REDUCTION AND DISASTER TRAINING
Access to risk mitigation and response best practices to better prepare for future emergencies.

POTABLE WATER
Reinforces existing water systems so communities have access to safe drinking water in case of emergency.

COMMUNITY GARDEN AND FARMING RESOURCES
Rehabilitate and/or develop farming projects as well as help small farmers to recover lost supplies, seed, and crops.

EXISTING COMMUNITY CENTER RESILIENCE HUB

Source: Mercy Corps  *Note that Mercy Corps is an international aid organization, there may be slight differences in our models.
Resilience Hubs

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CDBG Resilience Hubs Project summary

The City of Orlando sought $2.85 million to develop Six (6) Resilience Hubs that will provide community lifelines in the recovery phase of a disaster.

This project aims to support residents and coordinate resource distribution and services before, during, or after a natural hazard event.

- Prepare our residents and neighborhoods for weather emergencies and potential disasters
- Assist residents, neighborhood organizations and businesses in coping with and recovering from the effects of natural and manmade disasters
- Enhance resilience efforts among those who are likely to be disproportionately impacted by a disaster
Community Value – (Post disaster)

Value to community

- Support residents and coordinate resource distribution and services before, during, or after a natural hazard event
- Place to charge devices during a power outage
- Each center includes computer labs & free Wi-Fi
  - Residents can use high-speed internet to apply for FEMA assistance, unemployment, SNAP benefits, etc.

- Emergency Meal Services
- Emergency Pantry
- Food and water for distribution
- Community Sharing in a safe, fully operational facility
LMI / Diverse Areas of Benefit

Value to LMI communities

- Facilities are located strategically in areas of most need
  - Many low to moderate-income City residents have a center within walking distance of their home.

- All sites provide before/afterschool care to students attending nearby schools

- Sites are served by multiple utility substations - this greatly reduces the risk of simultaneous power outages.
Income Characteristics

<table>
<thead>
<tr>
<th>Median Household Income</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 28,000</td>
<td>Dark Red</td>
</tr>
<tr>
<td>28,000 - 35,000</td>
<td>Red</td>
</tr>
<tr>
<td>35,000 - 40,000</td>
<td>Medium Red</td>
</tr>
<tr>
<td>40,000 - 45,000</td>
<td>Light Red</td>
</tr>
<tr>
<td>45,000 - 51,000</td>
<td>Very Light Red</td>
</tr>
<tr>
<td>51,000 - 56,000</td>
<td>Light Blue</td>
</tr>
<tr>
<td>56,000 - 64,000</td>
<td>Medium Blue</td>
</tr>
<tr>
<td>64,000 - 75,000</td>
<td>Dark Blue</td>
</tr>
<tr>
<td>75,000 - 93,000</td>
<td>Very Dark Blue</td>
</tr>
<tr>
<td>93,000 - and more</td>
<td>Black</td>
</tr>
</tbody>
</table>

© JusticeMap.org
Racial Characteristics

<table>
<thead>
<tr>
<th>Blacks</th>
<th>0 - 1%</th>
<th>1 - 2.5%</th>
<th>2.5 - 5%</th>
<th>5 - 9%</th>
<th>9 - 16%</th>
<th>16 - 26%</th>
<th>26 - 47%</th>
<th>47 - 79%</th>
<th>79 - 100%</th>
</tr>
</thead>
</table>

© JusticeMap.org
Ethnic Characteristics

© JusticeMap.org
Using the USDN Guide as a model, we’ve distilled our plan into 3 parts

- **Improve Ventilation and Indoor Air Quality**
  - Reducing spread of airborne contaminants

- **Improve Electrical Infrastructure**
  - Upgrading electrical systems to allow for remote power generation

- **Onsite Generation**
  - Rooftop solar (2)
  - CNG generators (2)
Tables of Connection (Small Resilience Hubs)

- Small parks without a neighborhood center
- Integrated mapping (park locations, internet access, internet speed, energy burden, solar access, etc.)
- Year-round amenity with local public art
- Two pilots via internal funding and AARP grant (Prince Hall and Willows parks)
- Leveraging CDBG-MIT and / or ARPA for future tables
Example Maps – Internet access and speed

Lack of Internet Access above 25% by Census Tract

Legend
- Census Tracts No Internet Access over 25%
- Commissioner District

Audubon Park
Download: 170 Mbps
Upload: 67 Mbps
Technical Details

- Table with benches and shade
- ADA accessible
- 175 MPH wind rating
- Off grid with 1,800W solar and 4,800 Wh battery
- Four wireless charging stations
- Four 120V outlets
- 4G Wi-Fi hotspot (will likely upgrade to 5G)
- LED lighting
Prince Hall Park
Prince Hall Park
Willows Park
Willows Park
Resilience Hubs

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- Questions!
Thank you!
Tony Sparks
Staff Project Manager / Albuquerque Public Schools
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

APS' largest campus, largest utility bills.

Summertime electricity bills over $50K; demand charges more than 50%.
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Center of the Community

Large disadvantaged population.
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Demographics

- Serves 2200 students (impacting thousands of families)
  - 14% from disadvantaged households (below Federal poverty line)
    - 99% eligible for Federal free or reduced lunch (APS average is 65%)
      - 20% English language learners
      - 28% Special education
    - On-site community health clinic

An ideal location.
Nick Fury’s Helicopter Arrives at Avenger’s Headquarters.
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Project objectives

• Charge from grid ‘off-peak.’

• Deploy strategically during ‘on-peak.’

• Reduce daily peak demand to below 500 kW.

• Test case for replication elsewhere in District.

• Potential for resiliency during power emergency.

Is it cost-effective?
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Added PV to improve the payback

- 850 kW to optimize payback
- 2200 PV panels . . . one per student!
- Without PV – 17 years*
- PV plus battery– 13 years

* Entirely dependent on utility rate structure.

Doubled project cost, but provides net savings of $3.5 M over life of battery.
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Tesla Mega Pack 2

Dimensions:
- 8' - 3" Tall
- 5' - 6" Deep
- 25' - 6 " Long
- 56,000 lbs
- 28 Tons

Largest Tesla installation in New Mexico – 721 kW / 2884 kWh
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Available for on-site ‘Learning Lab.’
Lots of roof available; triggered significant roof repairs.
Atrisco Heritage Academy HS – Battery Storage for Peak Shaving

Resiliency

• Adding PV to battery storage allowed opportunity for ‘islanding’
  • Conduct feasibility study to identify grid disconnect requirements, critical loads, etc.
  • Create islanding implementation plan & design
  • Pursue funding for implementation project

Many new opportunities opened up.
Resiliency

**CHALLENGES**

- OBSOLESCENCE – Technology is still new
- COST – Early adopter; schools are publicly funded
- EQUITY – Placement at one site excludes others
- LEADERSHIP – Needs a champion and buy-in from District

Can We Lead the Way? Will You?
The importance of partners

- Expertise, experience
- Detailed, reliable analysis
- Many eyes, many viewpoints
- Shared financial burden

A win for everybody!
Indu Priya Manogaran
Research Engineer, National Renewable Energy Laboratory
REopt for Resilient Buildings: Leveraging Energy Efficiency and Distributed Energy Resources for Resilience Solutions

Indu Manogaran
reopt.nrel.gov
Introduction to REopt
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
- Distributed energy technologies and demand-response strategies can provide cost savings, resilience, and emissions reduction
- 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
- REopt considers electrical, heating, and cooling loads and technologies simultaneously to identify the optimal technology or mix of technologies
- 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.

**Energy Planning Platform**

**Techno-Economic Optimization**

**Goals**
- Minimize Cost
- Clean Energy
- Resilience

**Drivers**
- Economics
  - Technology Costs
  - Incentives
  - Financial Parameters
- Energy Costs & Revenue
  - Energy & Demand Charges
  - Market Participation
  - Escalation Rates

**Resources**
- Renewable Generation
  - Solar PV
  - Wind
- Conventional Supply
  - Electric Grid & Fuel Supply
  - Conventional Generators
  - Combined Heat and Power
- Energy Storage
  - Batteries
  - Thermal storage
- Ground Source Heat Pumps

**Energy Planning Platform**

**Optimized Minimum Cost Solution**

- Technologies
  - Technology Mix
  - Technology Size
- Operations
  - Optimal Dispatch
- Project Economics
  - Capital Costs
  - Operating Costs
  - Net Present Value
- Progress towards Goals
  - Emissions Reduction
  - Length of Outage
  - Sustained

Note some capabilities were developed for specific projects only
Will DERs Work for Your Site?

Many factors affect whether distributed energy technologies can provide cost savings and resilience to your site, and they must be evaluated concurrently.
What is the optimal size of 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 renewable energy goal?

What is the most cost-effective way to sustain a grid outage spanning 1 day? What about 9 days?

REopt Provides Solutions for a Range of Users

Including researchers, developers, building owners, utilities, and industry
**How Does REopt Work?**

REopt considers the trade-off between ownership costs and savings across multiple value streams to recommend optimal size and dispatch.

**Demand Reduction**
- Setting peak for the month

**Energy Arbitrage**
- Buy cheap, use high

Example of optimal dispatch of PV and BESS:
- Grid Serving Load
- PV Serving Load
- Storage Discharging
- PV Charging Storage
- Electric Load

**Graph Details:**
- **X-axis:** Monday to Sunday
- **Y-axis:** MW (MegaWatt)
- **Legend:**
  - Light gray: Grid Serving Load
  - Blue: PV Serving Load
  - Orange: Storage Discharging
  - Gray: PV Charging Storage
  - Black: Electric Load
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.
**REopt Capability Development**

Capabilities developed by the team are transferred to REopt based on broad use and validation, customer needs, and funding available.

| REopt Custom Analysis & Development | • New feature development  
|                                  | • Support specific entities |
| REopt API and O/S                 | • Additional features with longer run-time  
|                                  | • Customizable  
|                                  | • Tool integration |
| REopt Web                         | • Easy to use web access  
|                                  | • Key standardized capabilities |
REopt Web Tool

User Interface and Key Results
REopt Web Tool User Interface

- **REopt Web Tool** offers a free, publicly available, user-friendly web tool that offers a subset of NREL's more comprehensive REopt™ model.

- Optimizes **PV, wind, CHP, GHP, and battery energy storage system (BESS)** sizes and dispatch strategies to **minimize life cycle cost of energy** while meeting the site loads.

- **Resilience mode** optimizes PV, wind, and storage systems, along with backup generators, to sustain critical load during grid outages.

- **Clean energy goals** allow users to consider renewable energy targets, emissions reductions targets, and emissions costs in optimization.

REopt Web Tool Key Outputs - Economic

**System Size and NPV**

- Recommended solar installation size: 3,885 kW
- Recommended battery power and capacity: 276 kW battery power, 598 kWh battery capacity
- Potential life cycle savings (20 years): $1,972,493

**Hourly Dispatch**

**Detailed Financial Outputs**
REopt Web Tool Key Outputs – Resilience

**System Size and NPV**

- **Your recommended solar installation size**
  - 13,137 kW (PV size)
- **Your recommended battery power and capacity**
  - 1,171 kW (battery power)
  - 3,419 kWh (battery capacity)
- **Your recommended generator size**
  - 7,200 kW (generator size)

**Potential life cycle savings (25 years)**

- $2,078,711

**Resilience Probability of Survival Curves**

- Probability of survival (%) vs. Outage duration (days)

**Hourly Dispatch (Outage Duration Highlighted)**

- Hourly dispatch showing system performance during an outage duration.
Case Study: Community Resilience in Manatee County
Analysis Overview

- This case study leverages REopt to evaluate the resilience and economic benefits of energy efficiency (EE), PV, BESS, and backup diesel generators at two municipal facilities in Manatee County, Florida.

- The facilities’ resilience goal was to optimize backup generator, PV and BESS sizes in order to sustain their critical loads during a three-day (72-hr) grid outage.

- The analysis considers two separate impacts that EE and PV+BESS may have:
  1. Improving building resilience
  2. Providing economic savings

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Public Safety Complex</th>
<th>R. Dan Nolan Middle School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Type</td>
<td>Large Office and Hospital</td>
<td>Secondary School</td>
</tr>
<tr>
<td>Annual Consumption (kWh)</td>
<td>3,892,560</td>
<td>1,926,144</td>
</tr>
<tr>
<td>Peak Load (kW)</td>
<td>928</td>
<td>787</td>
</tr>
<tr>
<td>Electric Utility Provider</td>
<td>Florida Power &amp; Light (FPL)</td>
<td>Peace River Electric Cooperative (PRECO)</td>
</tr>
<tr>
<td>Critical load (%)</td>
<td>60%</td>
<td>60%</td>
</tr>
<tr>
<td>Existing backup generation</td>
<td>Two 1MW generators and two 800 gallons diesel tanks</td>
<td>None (currently renting generator and diesel tank for storm season)</td>
</tr>
</tbody>
</table>

Facility information and resilience goals were provided by Manatee County.

Technologies & Strategies Analyzed

- Business-as-usual: Electricity from grid; vulnerable to outages without backup systems
- Load reduction through energy efficiency measures
- Diesel generator to provide building resilience
- Solar photovoltaics (either rooftop or ground-mount)
- Battery electric storage system to provide demand reduction and resilience
Resilience Benefits of Energy Efficiency and PV+Battery

The Public Safety Complex already has 2MW of existing diesel generator. Can EE and PV+BESS improve the system resilience and save the site some costs? Yes!

Resilience Benefits

- With the existing generator, the system will not be able to sustain 27% of all potential grid outages in a year.
- Adding PV+BESS decreases the unmet outages to less than 3%. Adopting 10% EE further decreases those unmet outages to 0%.

Economic Benefits

- Each 10% load reduction through EE results in 10% savings (~$700,000) in lifetime costs compared to business-as-usual (i.e., not adopting EE and PV+BESS).
- Savings result mostly from reduction in utility costs.

1Costs for adopting EE measures are not included in this case study.
The R. Dan Nolan Middle School serves as an emergency shelter, and should therefore be resilient to outages from extreme weather. The facility currently has no backup generator, so we need to design an optimal system that includes on-site diesel generator. Can EE and PV+BESS provide economic benefits compared to installing just a backup generator? Can they provide additional benefits from resource diversification? Yes!

**Economic Benefits**

- Installing cost-optimal PV+BESS results in 10% savings (~$570,000) in lifetime costs compared to business-as-usual (not adopting EE and PV+BESS).
- Each 10% load reduction through EE results in an additional 10% savings (~$480,000) in lifetime costs compared to business-as-usual.
- Savings result from reduction in utility costs and utility (PRECO) a rate structure which incentivizes renewable energy generation (unique to this case).

---

1 Costs for adopting EE measures are not included in this case study.
Thank you

REopt website (analysis services and case studies): reopt.nrel.gov
Tool feedback and questions: reopt@nrel.gov

www.nrel.gov

Publication Number: NREL/PR-7A40-83498
Appendix: Additional Information
REopt Model Technical Description

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
Accessing REopt

The REopt team works with stakeholders to provide a suite of trusted techno-economic decision support services to optimize energy systems for buildings, campuses, communities, microgrids, and more. The team also develops publicly available REopt software; capabilities developed by the team are transferred to REopt 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 Software

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

• What is an API?
  – Application Programming Interface
  – Programmatic way of accessing REopt Lite (sending and receiving data from a server)
  – File format used for sending and receiving the data: JSON.

• Advantages:
  – Multiple simulations for different sites can be run programmatically;
  – Scenario analysis can be automated; and
  – Application can be integrated with other programs.

https://github.com/nrel/reopt-api-analysis/wiki
Analysis Enabled by API

• The REopt API enables national-scale analysis of storage economics and impacts on adoption/deployment.

• Analysis questions include:
  – Where in the country is storage (and PV) currently cost-effective?
  – At what capital costs is storage adopted across the United States?
  – How does varying utility rate, escalation rates, and incentive structures impact storage profitability?
  – How (and where) can stationary storage support DC-fast-charging electric vehicle economics and deployment?
REopt Development Team

- Kathleen Krah, Program Lead
- Dan Olis, Technical Lead
- Nick Laws, API Development Lead
- Bill Becker, Development & Analysis
- Sakshi Mishra, Development & Analysis
- Sean Ericson, Analysis
- Linda Parkhill, Validation and User Support
- Hallie Dunham, Development and Analysis
- Amanda Farthing, Analysis
- Indu Manogaran, Analysis
- Doug Gagne, Analysis
- Rob Eger, UI Development
- Nick Muerdter, UI Development
- Heidi Blakely, Communications
- Andy Walker, Team Advisor

Contact: Kathleen Krah, Kathleen.Krah@nrel.gov
REopt@nrel.gov

https://reopt.nrel.gov/about/team.html
More REopt Capabilities
Thermal Technologies in REopt

- In addition to solar PV, wind power, and battery energy storage systems (BESS), REopt includes combined heat and power (CHP), geothermal heat pumps (GHP), absorption chiller, and thermal energy storage (TES).
- These enable analyses of electric and thermal loads together:
  - Simultaneously serving heating and electricity loads with CHP
  - Switching from heating with fuels to electricity with GHP
  - Switching from generating cooling with electricity to heat with an absorption chiller
  - Value of decoupling thermal loads from when the thermal energy is produced with TES
Emissions in REopt

Using REopt, users can:

- Quantify emissions changes and the monetary impact of emissions reductions on climate (CO₂) and health (NOₓ, SO₂, PM2.5) outcomes
- Set a climate emissions reduction target and allow REopt to determine the cost-optimal DER investment to meet the target
- Include climate and/or health costs within the optimization objective, allowing these costs to impact system sizing and dispatch
- Use locational default emissions rates and costs or input custom values
- Evaluate lifecycle emissions, considering future “greening of the grid”

Currently, REopt uses the following defaults:

Grid emissions rates: marginal rates calculated from EPA's AVERT
Grid emission rate change projections: calculated from NREL's Cambium

REopt determines the emissions and emissions cost impacts of a DER investment, accounting for the hourly emissions intensity of grid electricity as well as on-site fuel consumption.

Climate costs: U.S. Interagency Working Group 2021 social cost of carbon
Health emissions costs: location-specific, obtained from EASIUR model

Grid emissions [tons] = Electric grid purchases [kWh] × Marginal emissions intensity [ton/kWh] of the grid (location-specific) in each hour

Case-Study: REopt
Terminology and Definitions
**Evaluation Metrics**

**Optimal System Sizes:** The least cost system sizes (backup generator size (kW), solar PV capacity (kW) and battery storage capacity (kW/kWh)) required to sustain a 3-day outage starting at facility peak load.

**Life Cycle Costs (LCC, $)**: All costs (capital costs, O&M costs, fuel costs, utility costs) incurred by the facility, discounted over a 25-year period.

**Business-As-Usual (BAU) Case:** Baseline costs calculated using current loads (0% EE, no PV/BESS), existing generators, and utility rates.

**Net Present Value (NPV, $):** Calculated as the difference between the LCC of the scenario being considered and the LCC of BAU case. A negative NPV indicates a net investment into the system or additional costs compared to the BAU case. A positive NPV indicates net savings compared to the BAU case.

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**Outage Survivability Duration (days):** Average outage survivability duration is a measure of resilience corresponding to a 50% probability of survival. Minimum and maximum outage survivability durations indicate durations which have a 100% and 0% probability of survival respectively.

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In the sample plot of outages simulated at each hour of the year, the system can survive 100% of outages with duration 2.4 days or less, 50% of all 4-day outages, and 0% of outages with duration 5.8 days or more.

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1LCCs do not include costs to implement EE measures. Therefore, LCCs and NPV (costs)/savings identified maybe higher/lower respectively.
More REopt Projects

Storage Sizing and Operation
Resilience and Microgrids
Integration of Flexible Loads
Electric Vehicles
Portfolio Optimization
**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

### Table: Generator, Solar PV, Storage, Lifecycle Cost, Outage

<table>
<thead>
<tr>
<th></th>
<th>Generator</th>
<th>Solar PV</th>
<th>Storage</th>
<th>Lifecycle Cost</th>
<th>Outage</th>
</tr>
</thead>
<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>
</tbody>
</table>

### Graph: Probability of Surviving Outage [%] vs. Length of Outage [Days]
Where Does Solar and Storage Make Sense?

**Description:** NREL evaluated thousands of combinations of utility territories, solar resources, climate zones, and capital costs to identify scenarios where battery storage is cost-effective across the US.

**Technology:** Solar PV and Li-Ion battery 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:** Federal Energy Management Program

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This map shows where in the United States there is potential for cost savings from implementing a behind-the-meter storage system with solar PV, compared to purchasing all electricity from the utility. Areas in green indicate percent life cycle cost savings (including utility costs as well as capital and operations and maintenance costs) of the deployed systems. Areas in yellow indicate that the area was evaluated, but a system would not provide life cycle cost savings. Image from NREL.
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

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

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**Tools for developers**

**Assumptions**
- Length of analysis: 20 years
- Average solar resource (kWh/m²/day): 5.3 kWh/m²/day
- Installed PV system (kW): $3,000
- Battery storage cost (kW): $100
- Inverter replacement cost (kW): $100
- Diesel generator cost (kW): $1,000
- Annual load factor (kWh): 80%
- Fuel cost (a): $4.00
- Annual fuel cost (kWh): $320
- Annual total system cost (kWh): $3,080
- Annual load factor (kWh): 80%

**LCOE Breakdown by Scenario**

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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
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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Looking Beyond Bill Savings to Equity in Microgrid Deployment

- **Description:** The value of microgrids is often measured by the economic savings and resilience; here we quantify broader costs and benefits including utility bill savings, value of resilience, social cost of carbon, public health costs, and jobs associated with the construction and operation of microgrids.

- **Technology:** Solar PV, battery storage, diesel generators

- **Impact:** When climate, health, resilience, and job creation are considered, cost-optimal microgrids include more renewable generation, leading to a 52-82% reduction in emissions and diesel fuel use. The net present values of the grow by $10-16 million, indicating potential for greater microgrid deployment if energy justice values are incorporated in decision making. These findings may be useful to communities as they seek to strengthen resilience to natural disasters while also improving public health, meeting climate goals, and providing economic opportunity for residents.

- **Partners:** Federal Energy Management Program

Cost-optimal system sizes across locations and optimization scenarios. Smaller diesel generators and larger PV and storage systems become cost-optimal as health and climate costs are incrementally included within the lifecycle cost calculation.
Balancing Cost and Resilience with Combined Heat and Power (CHP) at Wastewater Treatment Facility

Description: NREL evaluated opportunities for CHP and other DERs to provide cost savings and resilience benefits to the Northside wastewater treatment plant, a critical infrastructure susceptible to power outages.

Technology: CHP fueled by free on-site biogas and natural gas, diesel generator, solar PV, battery storage

Impact: Building a hybrid CHP-PV-storage system reduces lifecycle cost of energy for the site by 3% ($301,000 over 25 years). If load can be reduced during the outage by storing and deferring wastewater treatment, required system sizes and costs decrease. 60% of the load can be met in the No-Diesel scenario, and 80-85% in the CHP-Only or All-Technologies scenario, at no additional lifecycle cost compared to the business-as-usual no-outage case.

Partners: DOE Advanced Manufacturing Office
Q & A

Submit Questions
www.slido.com event code #DOE
DOE's new 50001 Ready decarbonization management guidance helps organizations align internal systems, processes, and stakeholders to reduce energy-related GHG emissions effectively and efficiently. Embedded tools enable teams to improve the quality of emission data and information shared internally and with key stakeholders. Learn how to use continuous improvement practices to decarbonize and reduce energy intensity.
Congratulations Better Buildings partners for achieving **2.5 quadrillion Btus of energy savings** — equaling more than **$15 billion** and **155 million metric tons of CO₂** avoided — to date!

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