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Sandia National Laboratories

Quest Equity

A New Open Source Powerplant Replacement Tool

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OUTLINE

- Introductions
- QuESt overview / applications
- A short primer on peaker plants
- Powerplant Replacement Tool
  - Powerplant Dispatch and Pollution Data
  - Analysis Parameters and Assumptions
  - Optimization Algorithm
- Results
  - Locational Impacts of Power Generation
  - Distributional Impacts and social Net Present Value (sNPV)
  - Capital Cost / Social Benefit plot
- Conclusions and Next Steps

Introductions

David Rosewater

BIO - My research focuses on improving how batteries can be integrated into engineering and human systems of every scale.

I have spent the past decade on carefully designing the interfaces between batteries, other technologies, and the people who depend on both. Battery control systems are how batteries interact with energy markets and the grid. Battery safety is the discipline of engineering the interaction of batteries and humans. My work has advanced the state of the art in battery energy storage control and has made grid-scale battery systems safer to build and operate. His resent work has focused on the intersection of battery energy storage and energy equity and environmental justice (EEEJ) initiatives. I am Senior Member in the IEEE and I currently chair the IEEE P2686 working group developing a recommended practice for design and configuration of battery management systems in energy storage applications. I hold a professional engineering license in the state of New Mexico.

Education:

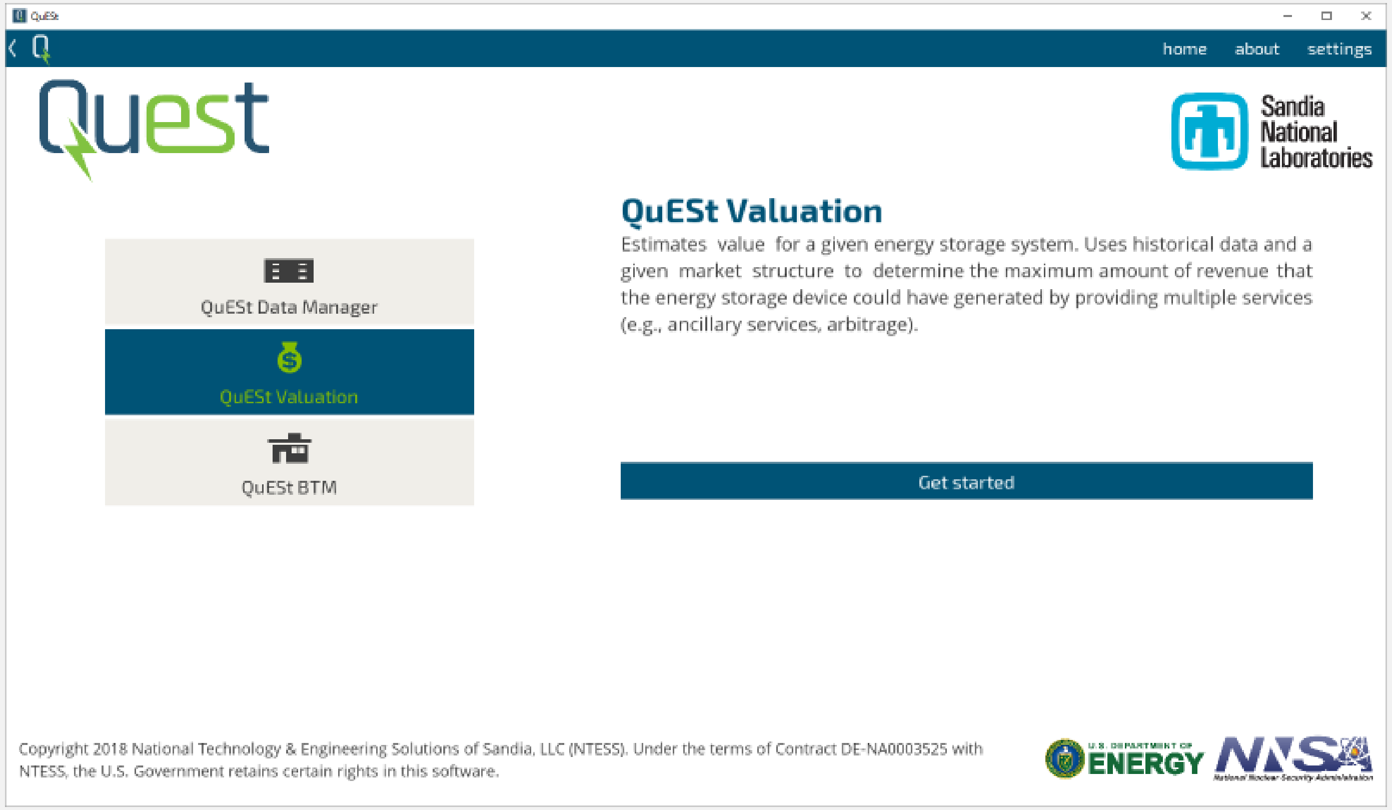
PHD IN ELECTRICAL & COMPUTER ENGINEERING – May 2020 The University of Texas at Austin (Austin, TX, USA)

MS IN ELECTRICAL ENGINEERING – May 2011 Montana Tech of the University of Montana (Butte, MT, USA)

BS IN ELECTRICAL ENGINEERING – May 2009 Montana Tech of the University of Montana (Butte, MT, USA)

OVERVIEW

- Energy storage analysis software application suite
- Developed as a graphical user interface (GUI) for the optimization modeling capabilities of Sandia's energy storage analytics group
- Version 1.0 publicly released in September 2018
- Version 1.2 available on GitHub
  - github.com/snl-quest/snl-quest or sandia.gov/ess (tools)



APPLICATIONS

Current Stable Version:

▪QuESt Data Manager – Manages acquisition of ISO market data, US utility rate data, commercial and residential load profiles, etc.

▪ QuESt Valuation – Estimate potential revenue generated by energy storage systems providing multiple services in the electricity markets of ISOs/RTOs.

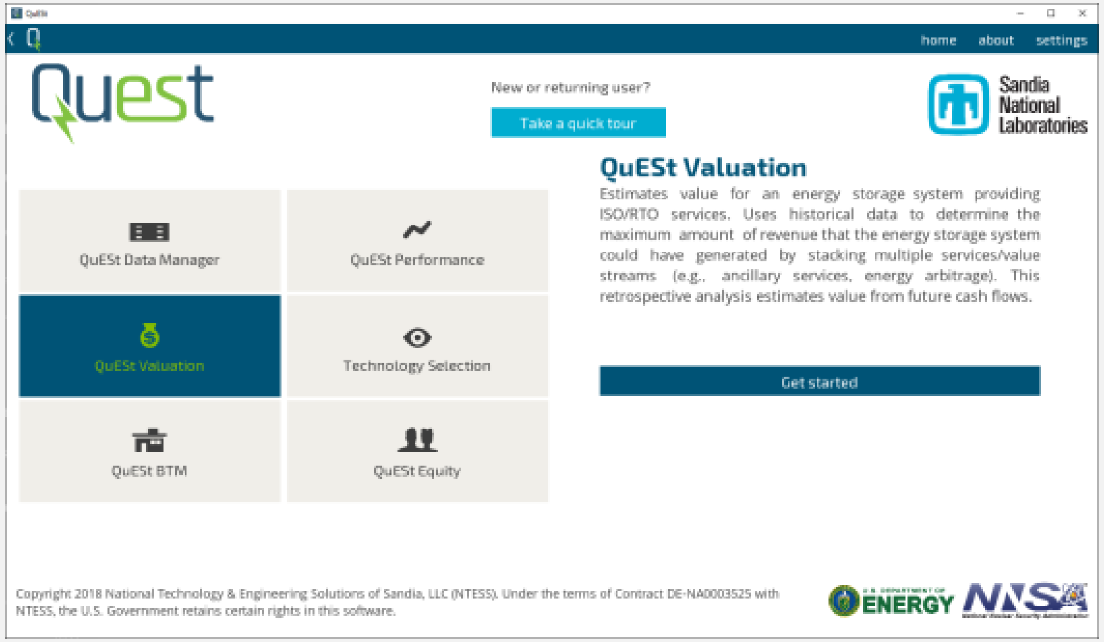
▪ QuESt BTM - Estimate the cost savings for time-of-use/net energy metering customers using behind-the-meter energy storage systems.

Beta Release:

- QuESt Technology Selection
- QuESt Performance

Alfa Release:

- **QuESt Equity**



Energy Storage Valuation – Market Problem

Given an energy storage device, an electricity market with a certain payment structure, and market data, how would the device maximize the revenue generated and provide value?

$$\max \sum_i \Big(\underbrace{\lambda_i (q_i^d - \eta_c q_i^r)}_{\text{arbitrage}} + \underbrace{q_i^{ru}(\lambda_i^{ru} + \delta_i^{ru}\lambda_i)}_{\text{regulation up}} + \underbrace{q_i^{rd}(\lambda_i^{rd} - \delta_i^{rd}\lambda_i)}_{\text{regulation down}} \Big) e^{-Ri}$$

subject to:

$s_{i+1} = \eta_s s_i + \eta_c q_i^r - q_i^d + \eta_c \delta_i^{rd} q_i^{rd} - \delta_i^{ru} q_i^{ru}$ state of charge definition

$0 \le s_i \le \bar{S}$ state of charge limits

$q_i^d + q_i^r + q_i^{ru} + q_i^{rd} \le \bar{Q}$ power/energy charged limits

Other constraints, such as requiring the final SoC to equal the initial SoC or reserving energy capacity for resiliency applications can be set.

Varies based on market and available value streams

Energy Storage Valuation – BTM Problem

Given an energy storage device, a utility tariff structure, how would the device minimize the electricity bills for the customers?

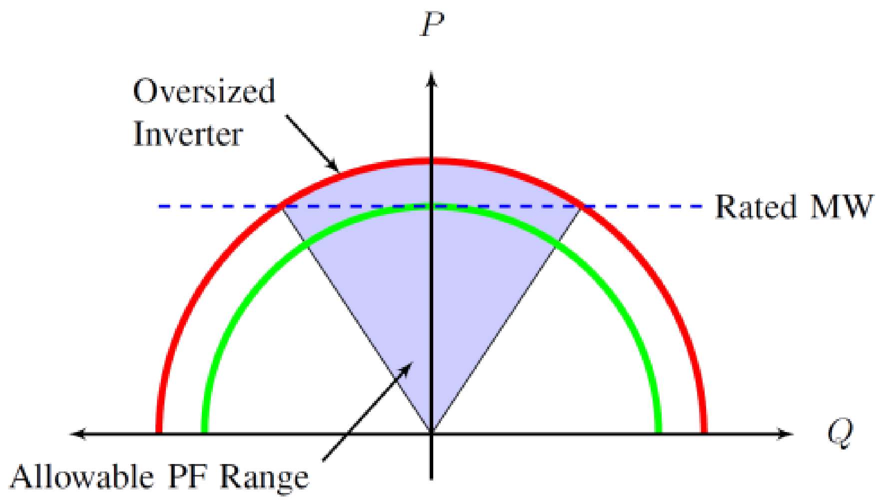
$$\min\{C_E^m + C_N^m + C_D^m\}$$

$s.t.$ *energy storage and inverter constraints*

C_E^m is the energy charge of period m

C_D^m is the demand charge of period m

C_N^m (≤ 0) is the net metering charge of period m.



Energy Storage Technology Selection

Goal: given a set of user selections, perform an initial screening to identify and rank feasible energy storage technologies for a given project.

ES technologies currently in the database:

- Pumped hydro storage (PHS)
- Compressed air energy storage (CAES)
- Sodium (Na)
- Zinc (Zn)
- Flywheel – Long duration (FWLD)
- Flywheel – Short duration (FWSD)
- Flow battery – Vanadium (FBV)
- Flow battery – Iron (FBFe)
- Flow battery – Zinc bromide (FBZnBr)
- Nickel (Ni)
- Lithium-ion – Energy (LiE)
- Lithium-ion – Power (LiP)
- Lead (Pb)
- Lead carbon (PbC)

User inputs:
- Grid location
- Application(s)
- System size (power)
- Discharge duration

ES technologies database
- discharge duration
- round-trip efficiency
- cycle life
- depth of discharge
- response time to full power
- cost
- maturity level
- …

Applications database
- minimum discharge duration
- minimum response time
- power vs. energy application
- deployment location restrictions
- …

Filter out ES techs that are not suitable for the selected grid location and/or do not meet the minimum application requirements (discharge duration, response time, electric output)

Score each feasible ES tech based on the following factors:
- Application requirements
- Location requirements
- Cost
- Technology readiness level

Output: ranked feasible ES techs

The final score for each ES tech is given as the weighted geometric mean of the four individual scores, so that the user can assign higher weights to the factors that they consider more relevant to the intended applications.

A short primer on peaker plants

What does a peaker plant do?

Peaker plants tend to operate intermittently.

They are a critical asset in defining the total electrical supply capacity in a area.

Peaker plants are being relied on more and more because of increasing intermittent renewable power penetration.

Note: in most of the country there is not a specific asset class for 'peaker plants' meaning the definition is fuzzy.

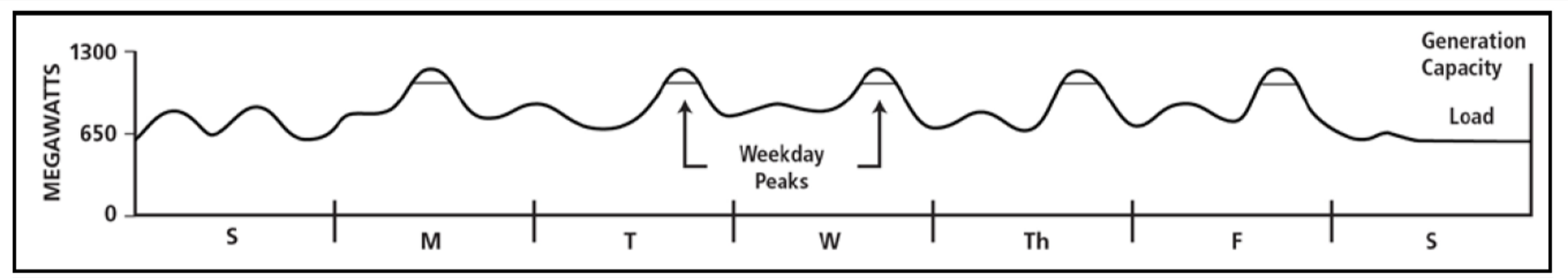
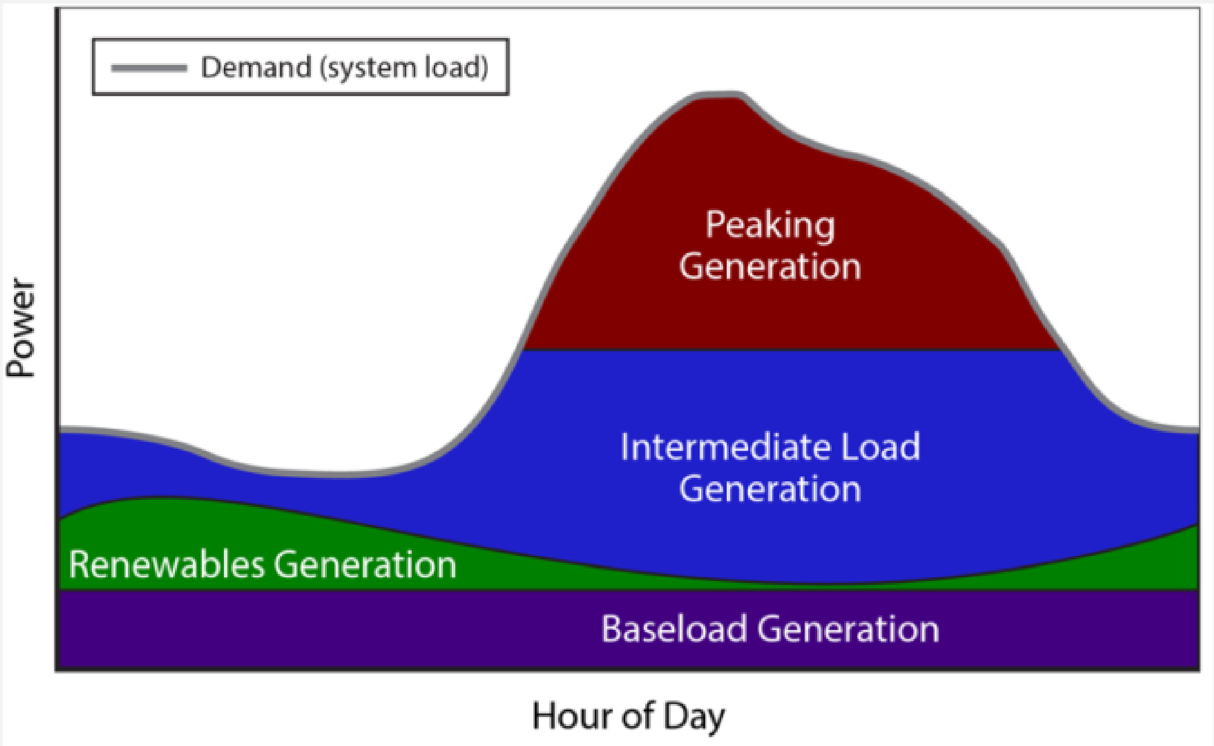


Figure From 2015 DOE/EPRI Energy Storage Handbook in Collaboration with NRECA

What does a peaker plant do?

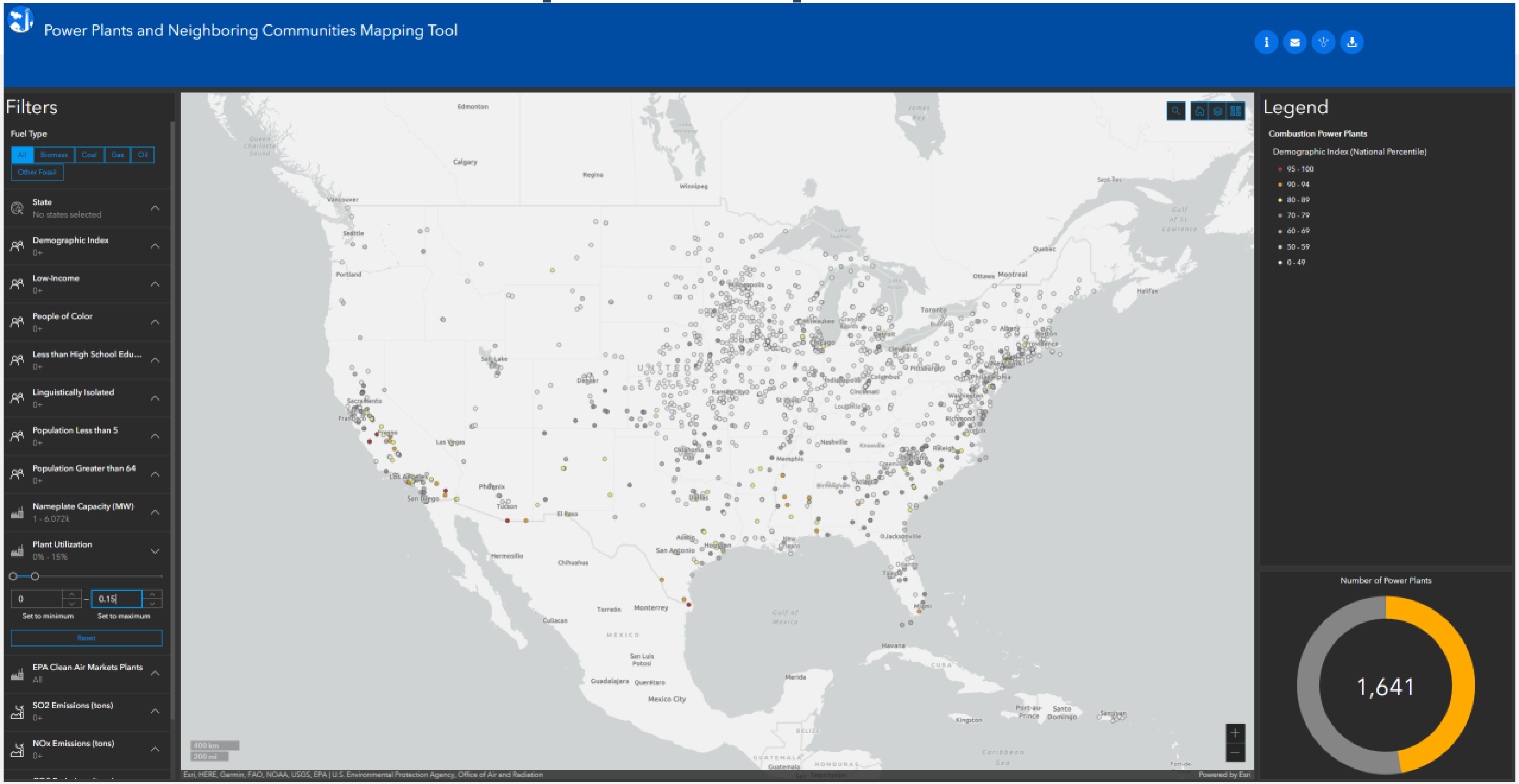
Peaker plants provide power to the grid at peak times of the day (or year).

They are generally: fast ramping, expensive per kW, and located near to load centers.



2015 DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA

What does a peaker plant do?



From: EPA Clean Air Markets Power Plants and Neighboring Communities
https://www.epa.gov/airmarkets/power-plants-and-neighboring-communities

Case Study: Ravenswood Generating Station

Location:	New York, NY
Maximum Power:	2,957 MW
Age:	59 years
Capacity Factor:	8.9%
Population (3 miles):	1.214 M

2019 Emissions (tons)
CO_2 - 1,250,144
NOx - 361.3
SO_2 - 30.6
PM2.5 - 87.8

Ravenswood Generating Station
https://en.wikipedia.org/wiki/Ravenswood_Generating_Station

What does a gas peaker plant do?

Benefits

Direct Economic Benefits (to Owner/Operator)

- Revenue from Wholesale Power Markets

Distributed Benefits

- Reliable Electric Power
- Low Energy Prices

These are not the same people

Costs

- Direct Economic Costs (form Owner/Operator)
  - Fuel
  - Operations and Maintenance
  - Capital cost (new / replacements)
- Distributed Costs
  - Climate Change Impacts of CO_2
  - Regional Health Impacts from pollution
  - Localized Health Impacts from pollution
  - Water Usage
  - Geopolitical Interdependence on Gas

Can a battery give the same benefits, without some of the costs?

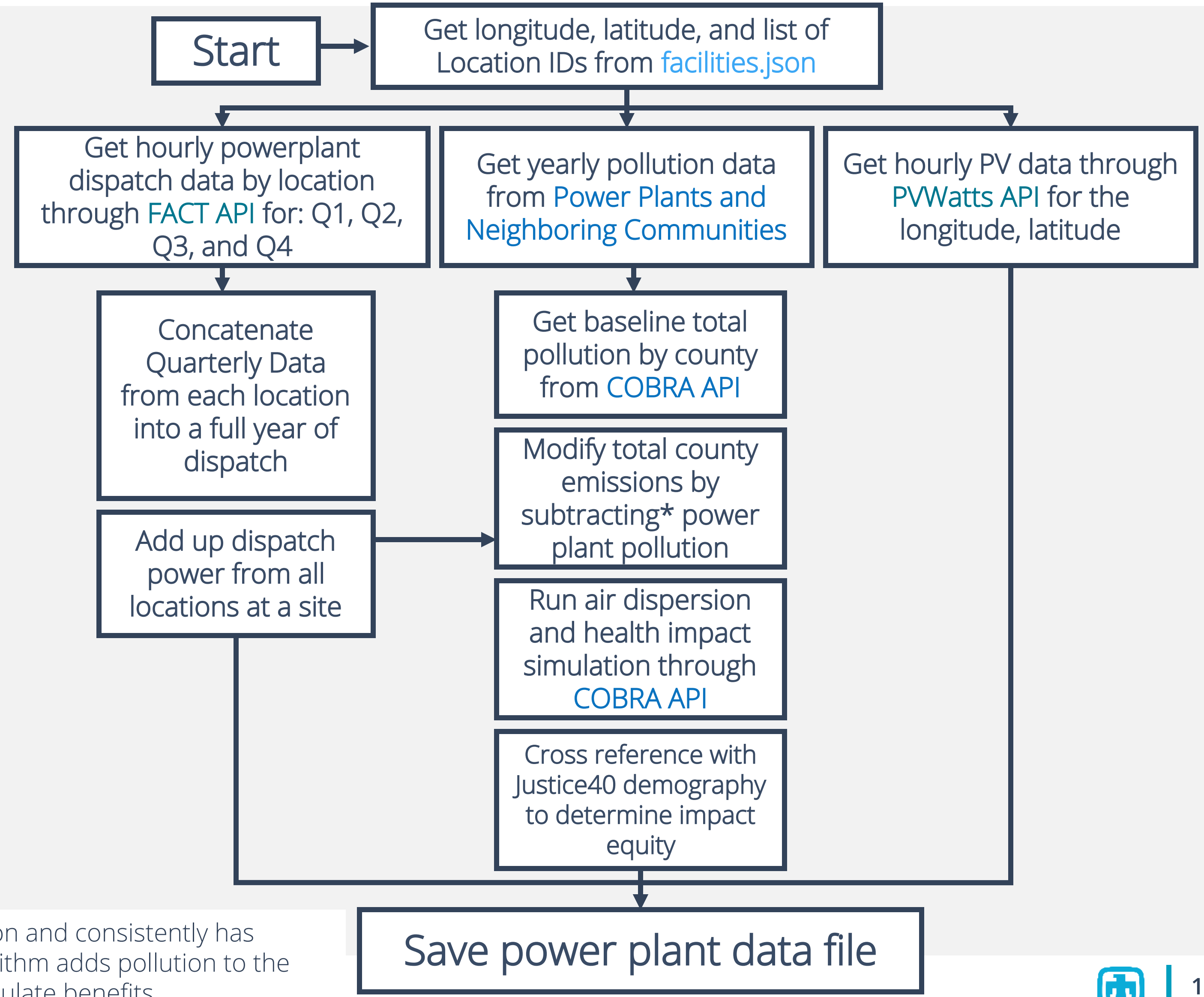
While there is overlap in these two populations, the people who get reliable electric power and low energy prices are not always the same people who are impacted by climate change, air pollution, or geopolitical interdependence

QuESt Equity : Powerplant Replacement Tool

Data Collection

Inputs

- Input 1: ORIS ID, Location ID (use 0 for all locations), and Year for selected powerplant
- Input 2: Database with powerplant units, locations, and hourly dispatch: EPA Field Audit Checklist Tool (FACT)
- Input 3: Database with hourly PV Data PVWatts
- Input 4: Database with 2019 powerplant pollution mass tons/MWh, ORIS ID: PM2.5, NOX, SO2: Power Plants and Neighboring Communities
- Input 5: Database with county level demography for “disadvantaged” and “low-income” status: Justice40 Climate and Economic Justice Screening Tool
- Input 6: Modeling tool for estimating the value of pollution reductions per county CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)



*COBRA baseline is a 2023 forecast from 2016 pollution and consistently has insufficient pollution to subtract from. Hence the algorithm adds pollution to the baseline and multiplies the resulting costs by -1 to calculate benefits.

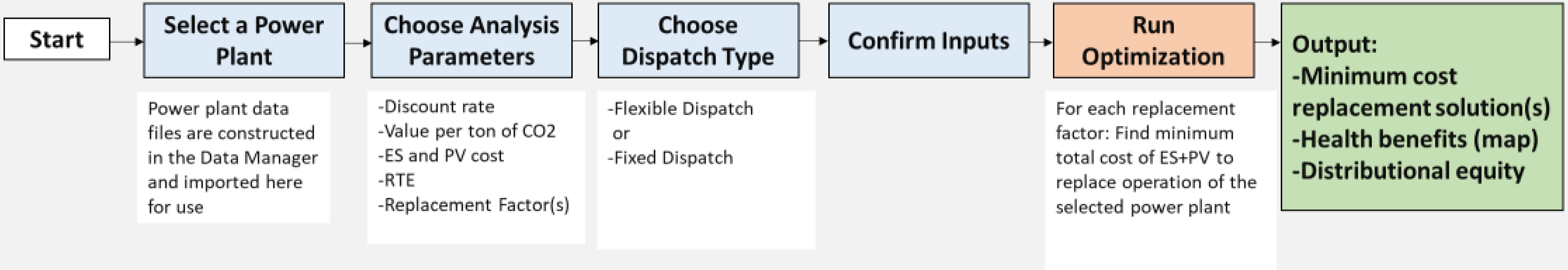
Powerplant Replacement Analysis

Inputs

- Powerplant Data File
- Battery and Analysis Parameters
- Dispatch Type Assumption

Outputs

- Minimum capital cost solution(s)
- Health Benefits
- Distributional Impacts



Optimization Algorithm (Flexible Dispatch)

Inputs

- Input 1: power plant data file
- Input 2: Cost of PV per MW (with 0MW cost)
- Input 3: Cost per MW and MWh of BESS (with 0MW/0MWh cost)
- Input 4: BESS Round Trip Efficiency
- Input 5: Replacement Fraction ρ [0.5, 1]

$$\min_{\mathbf{x}\in\mathbb{R}^{3n+3}} C_{PV}^{MW} P_{PV} + C_{ES}^{MW} P_{ES} + C_{ES}^{MWh} E_{ES} + \Pi|\mathbf{g}|_1$$

$$D\boldsymbol{\varsigma} = \eta\mathbf{p}^+ + \mathbf{p}^-$$

$$\mathbf{p}^+ + \mathbf{p}^- + P_{PV}\mathbf{p}_{pv} \geq \mathbf{p}_{plant}\mathbf{g} \;\; \forall i \in P_{peek}$$

$$\mathbf{p}^+ - \mathbf{p}^- \leq P_{ES}$$

$$0 \leq \boldsymbol{\varsigma} \leq E_{ES}$$

$$\mathbf{p}_{plant}^{\top}\mathbf{g} \geq \rho\sum\mathbf{p}_{plant}^{\top}$$

$$\mathbf{x} \in \{\boldsymbol{\varsigma}, \mathbf{p}^+, \mathbf{p}^-, \mathbf{g}, P_{PV}, P_{ES}, E_{ES}\} \in \mathbb{R}^{3n+3} \times [0,1]^n$$

Capital Cost

RF Regularization

Energy Reservoir Model

Peaker Power Matching

Battery Management System Limits

Replacement Fraction

Results (Calpine Hidalgo Energy Center Powerplant)

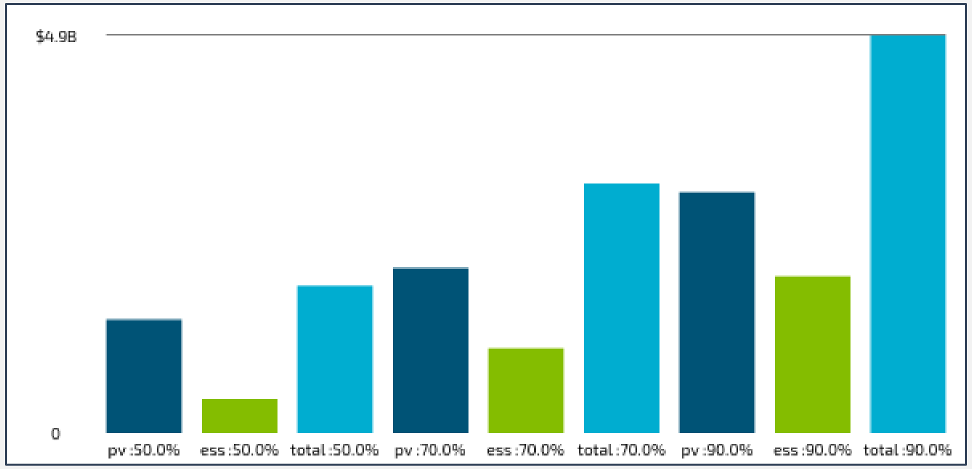
The following summarizes the results of the analysis to replace 50%, 70% , and 90% of the energy of the Calpine Hidalgo Energy Center powerplant with a combination of energy storage and PV.

50% replacement would need 1,160 MW of PV, and a 482 MW / 1,207 MWh energy storage system. This would cost **$1.81B** and would provide between $4.0M and $9.0M in health benefits to people living in the U.S. per year and a SCC of $49.1M per year. The total sNPV would be **$826.0M**.

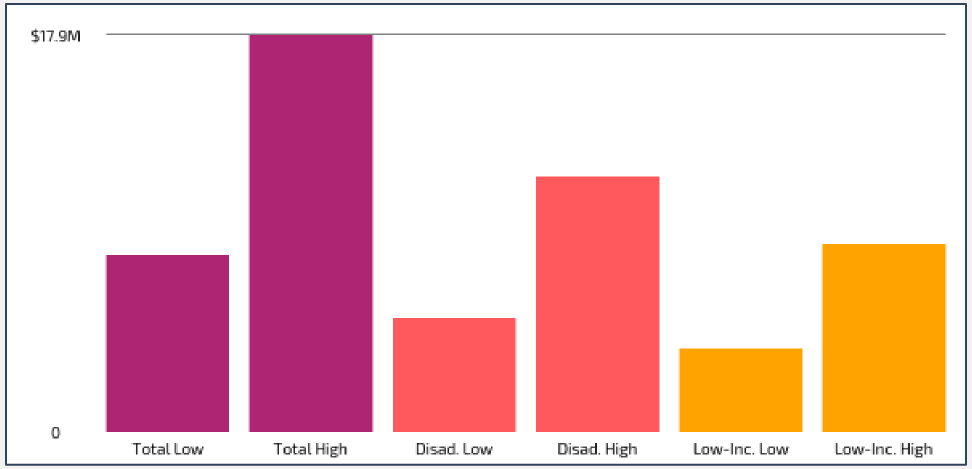
70% replacement would need 1,689 MW of PV, and a 852 MW / 3,036 MWh energy storage system. This would cost **$3.06B** and would provide between $5.6M and $12.53 M in health benefits to people living in the U.S. per year and a SCC of $68.7M per year. The total sNPV would be **$1.16B.**

90% replacement would need 2,456 MW of PV, and a 1,384 MW / 5,654 MWh energy storage system. This would cost **$4.88B** and would provide between $7.2M and $16.1M in health benefits to people living in the U.S. per year and a SCC of $88.3M per year. The total sNPV would be **$1.49B.**

In each case 64.4% of the health benefits accrued to people living in disadvantaged communities and 47.4% of the health benefits accrued to people with incomes below 200% of the poverty line.



Capital Costs

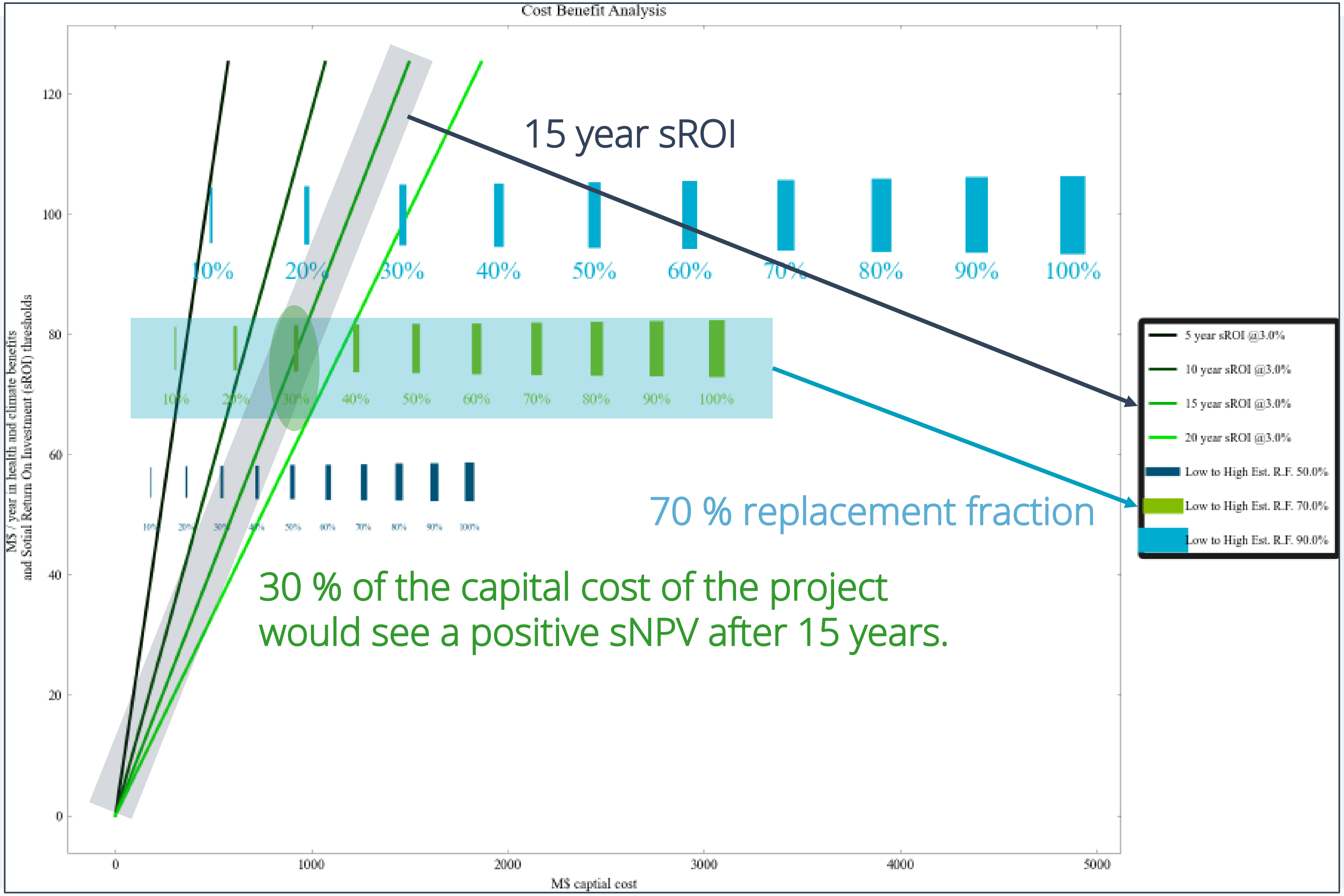


Health Benefits per Year
(100% replacement)

Public Investment Driven by Distributed Benefits

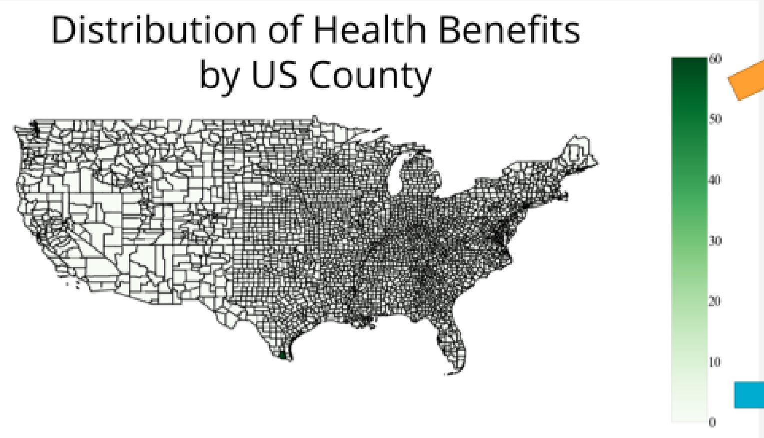
This plot illustrates the distributed benefits verses concentrated costs of candidate projects.

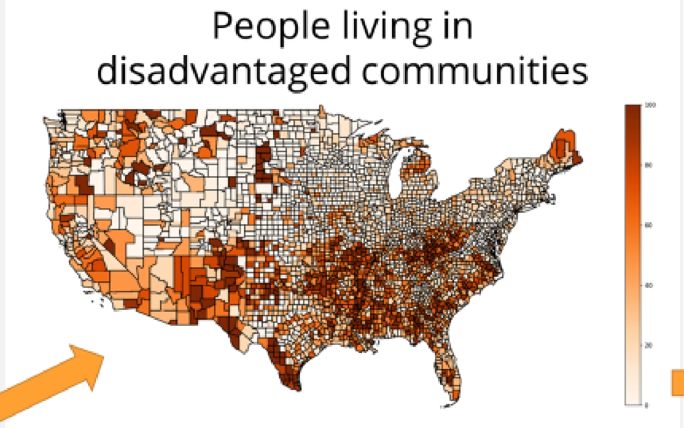
A local, state, or federal entity can select a replacement fraction, and desired ROI, and this plot will tell them the level of cost share that will present a positive social NPV.

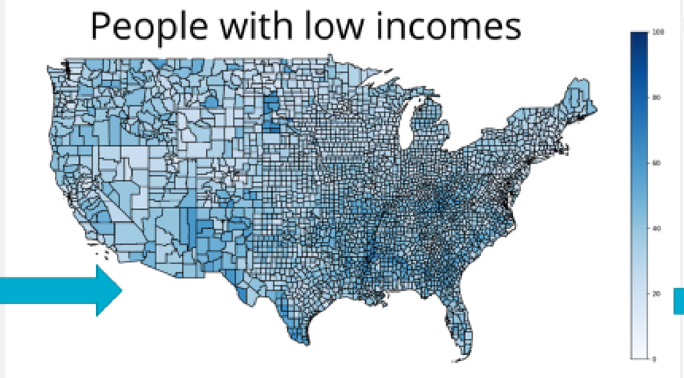


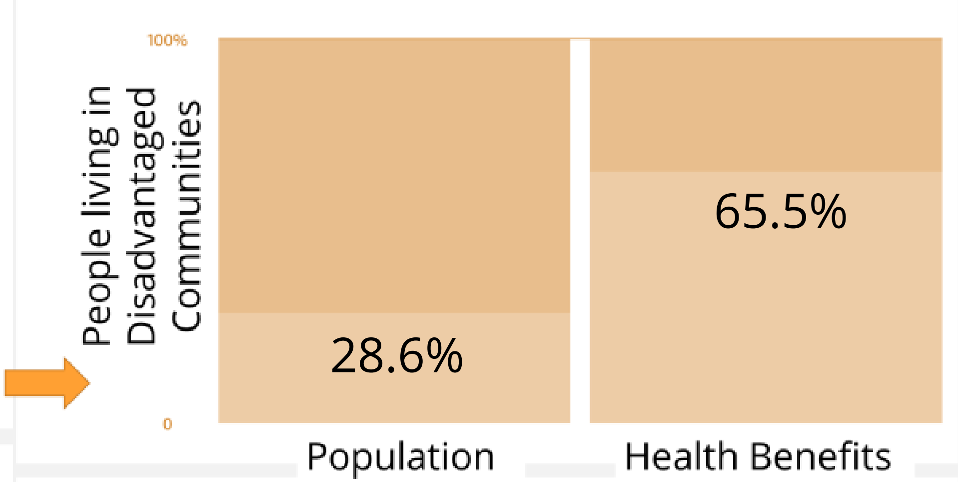
Locational Impacts of Power Generation

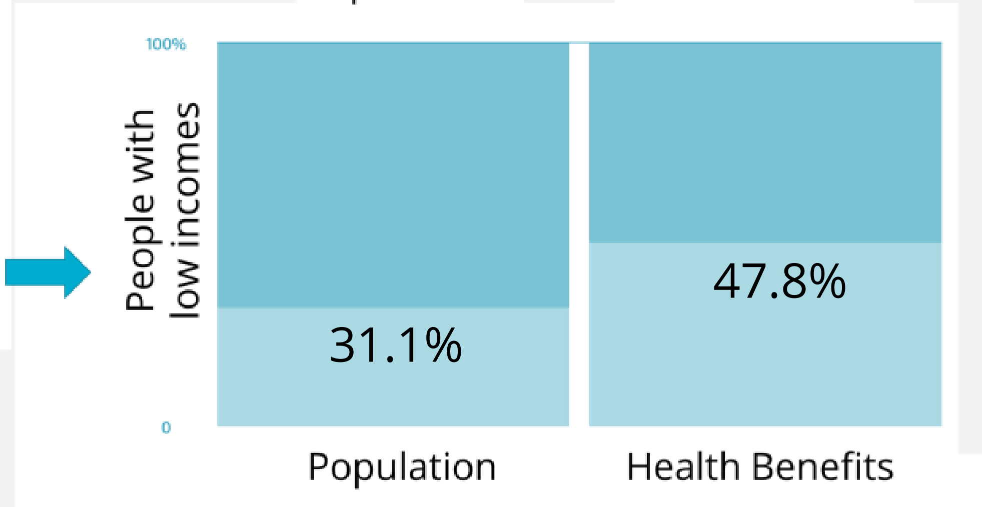
Mapping the county level benefits on to county level demographics yields the distributional impacts.











COBRA
Co-Benefits Risk Assessment
Health Impacts Screening and Mapping Tool

Conclusions and Next Steps

QuESt Equity provides a tool to analyze powerplant replacement with energy storage and PV. The tool calculates the aggregate social benefits along with the distributional impact equity to assist project developers.

Next Steps

- The QuESt Equity application is currently in Beta testing along with QuESt Technology Selection and QuESt Performance.
- In FY23 we will conduct a survey of powerplants in the continental US to identify those with the highest social benefit to cost ratio.

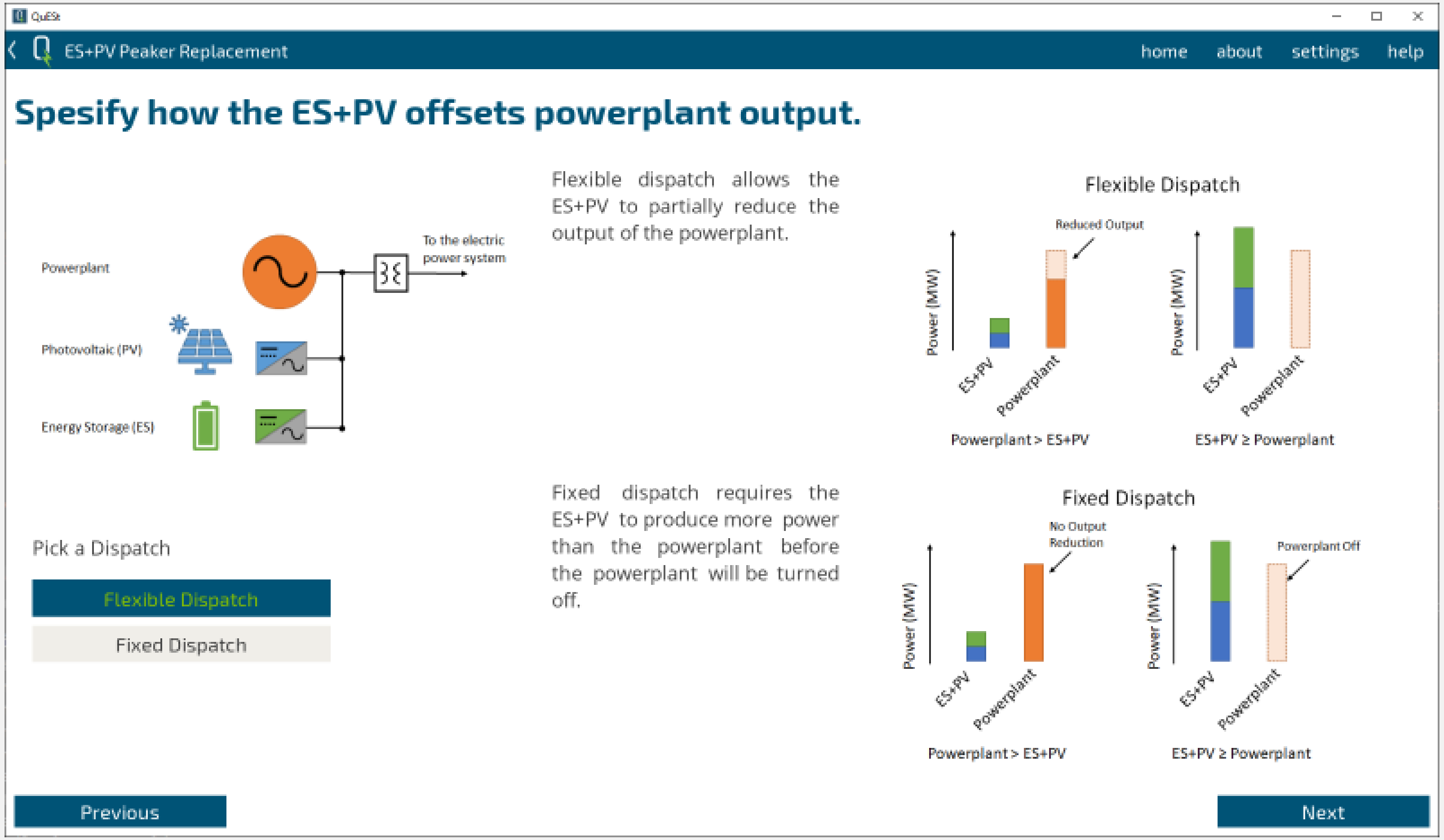
Acknowledgements

This work was funded by the DOE OE Energy Storage Program.

The project team would like to thank Dr. Imre Gyuk for his support of energy storage analytics research in the national interest.

Questions

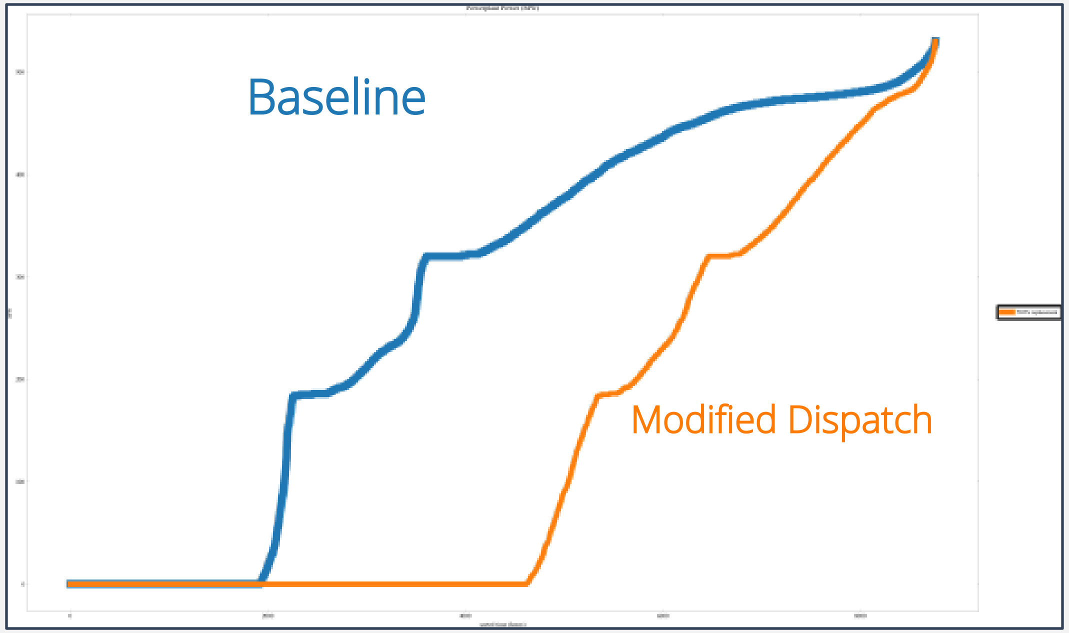
Backup Slides : Dispatch Assumption Options



Backup Slides : Dispatch Profiles

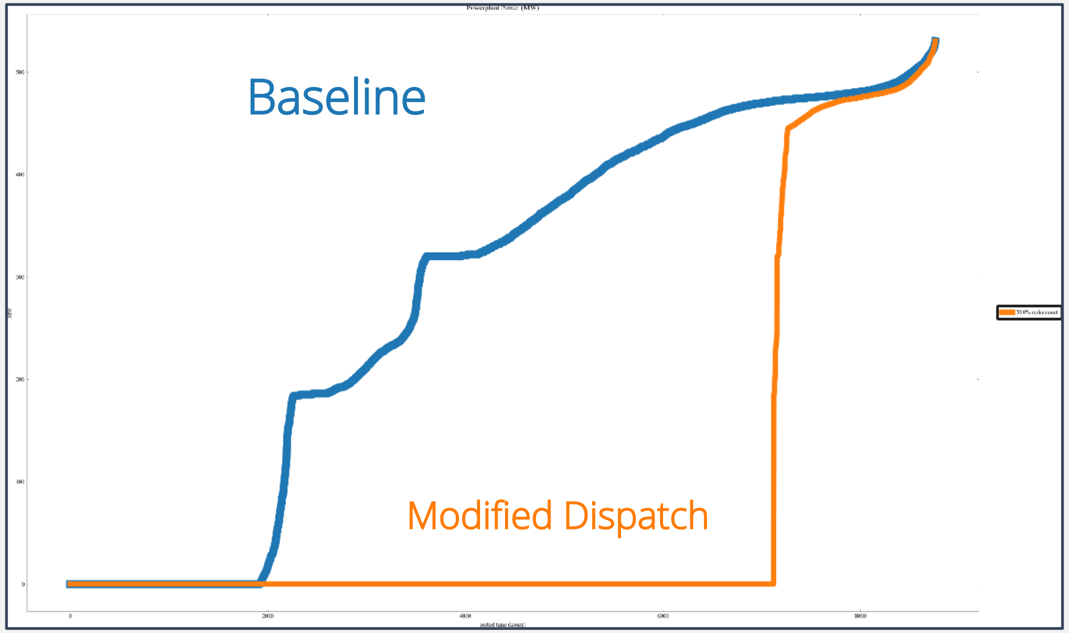
50% Replacement Fraction

Flexible Dispatch



Total Cost : $1.81B

Fixed Dispatch



Total Cost : $9.41B