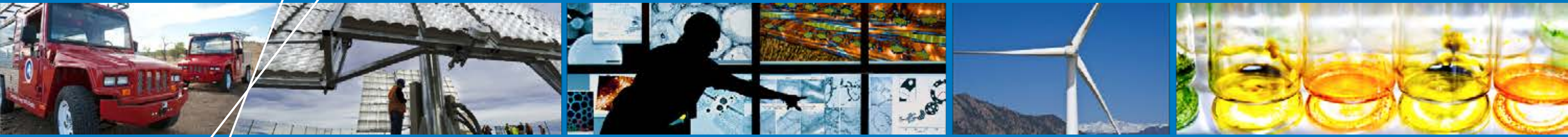
Optimal Stationary Fuel Cell Integration and Control



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National Renewable Energy Laboratory
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Project ID
FC083 & MT015

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline and Budget

- Project start date: October 2011
- FY14 DOE funding: $100k
- FY15 planned DOE funding: $100k
- Total DOE funds received to date: $850k

Barriers

- B. Lack of Data on Stationary Fuel Cells in Real World Operation
- E. Codes and Standards

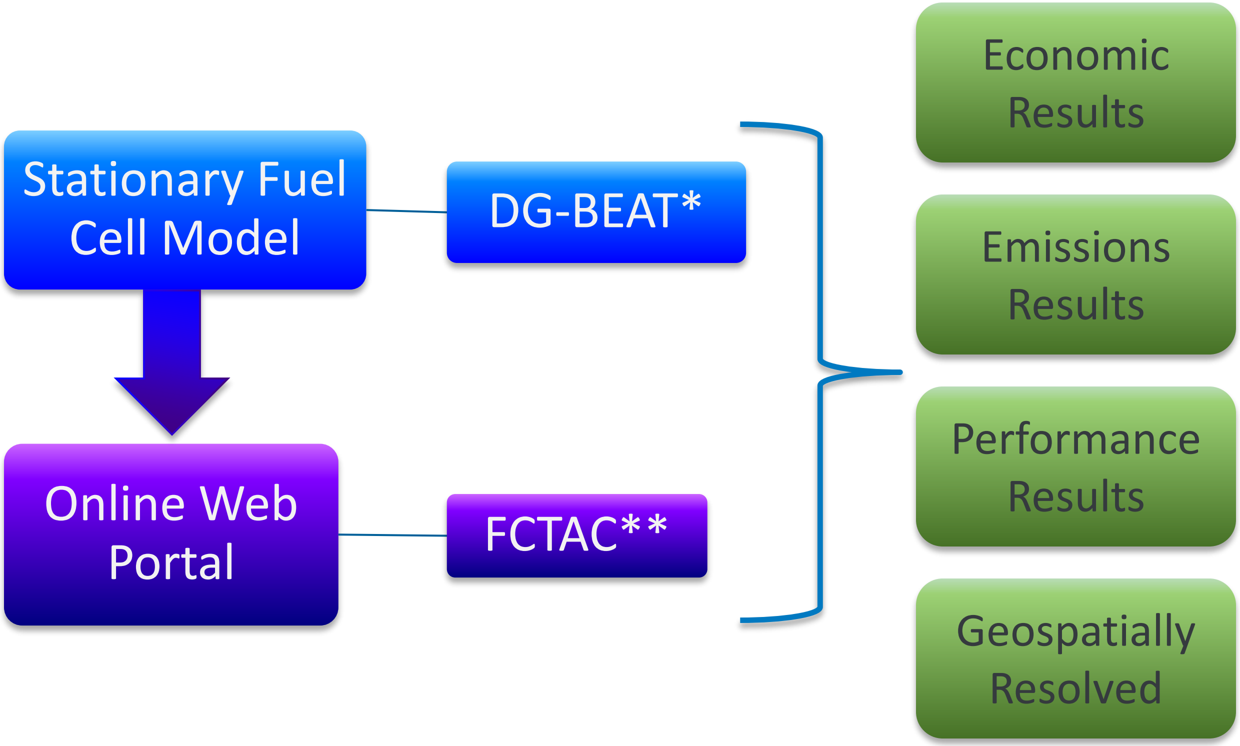
Partners

- University of California, Irvine (UCI)
- IDIQ *
- User's Group listed in Collaborations
- Lawrence Berkeley National Lab (LBNL)*
- Strategic Analysis, Inc.*
- Battelle*

* Separately funded projects

Relevance

Objective: Creation of tools that will enable research of the benefits of stationary fuel cells as a component in a modernized energy infrastructure and aid early market growth for the industry.



The results can examine:

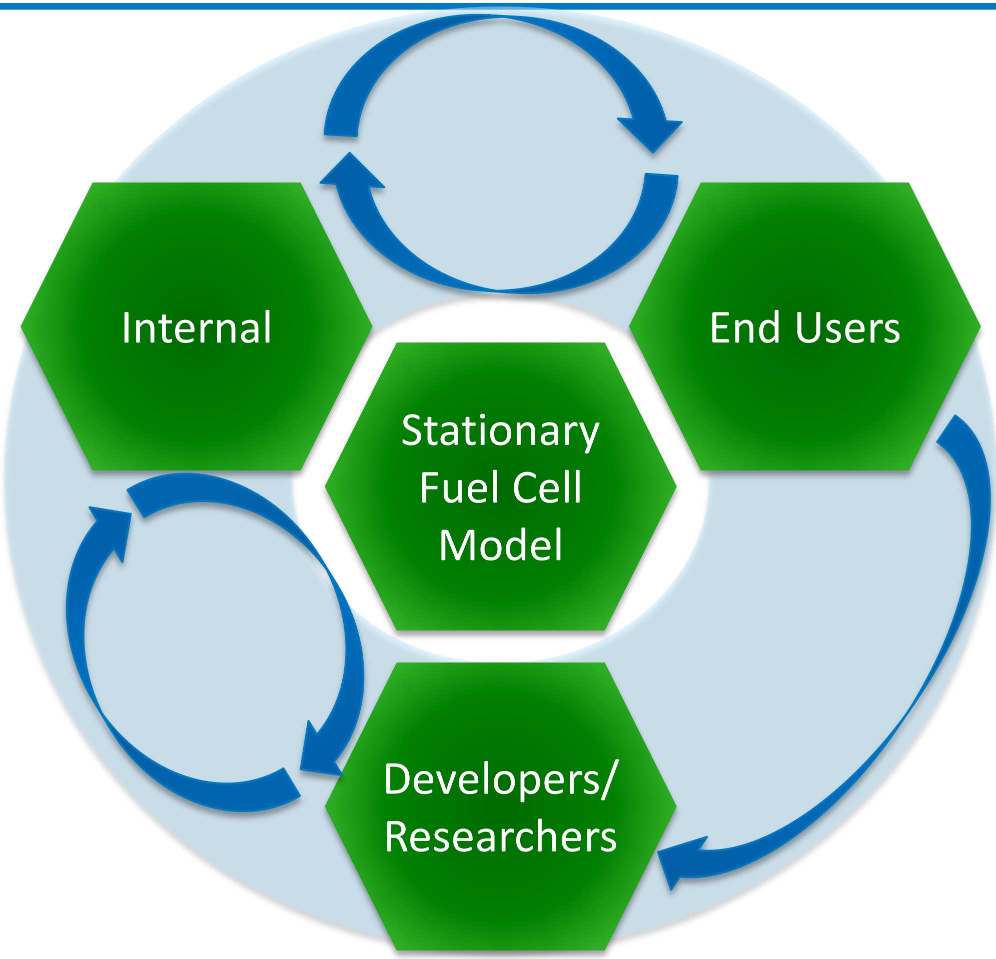
- FC sizing
- FC controls
- Regional cost implications
- Regional emissions
- Real or ideal building profiles
- Assess building or campus
- Inform market potential

* **D**istributed **G**eneration – **B**uild-out **E**conomic **A**ssessment **T**ool

** **F**uel **C**ell **T**ool for **A**ssessing **C**osts

Approach

- Full Model
- Case Studies
- Controls Optimization
- Sizing Optimization
- Hardware integration

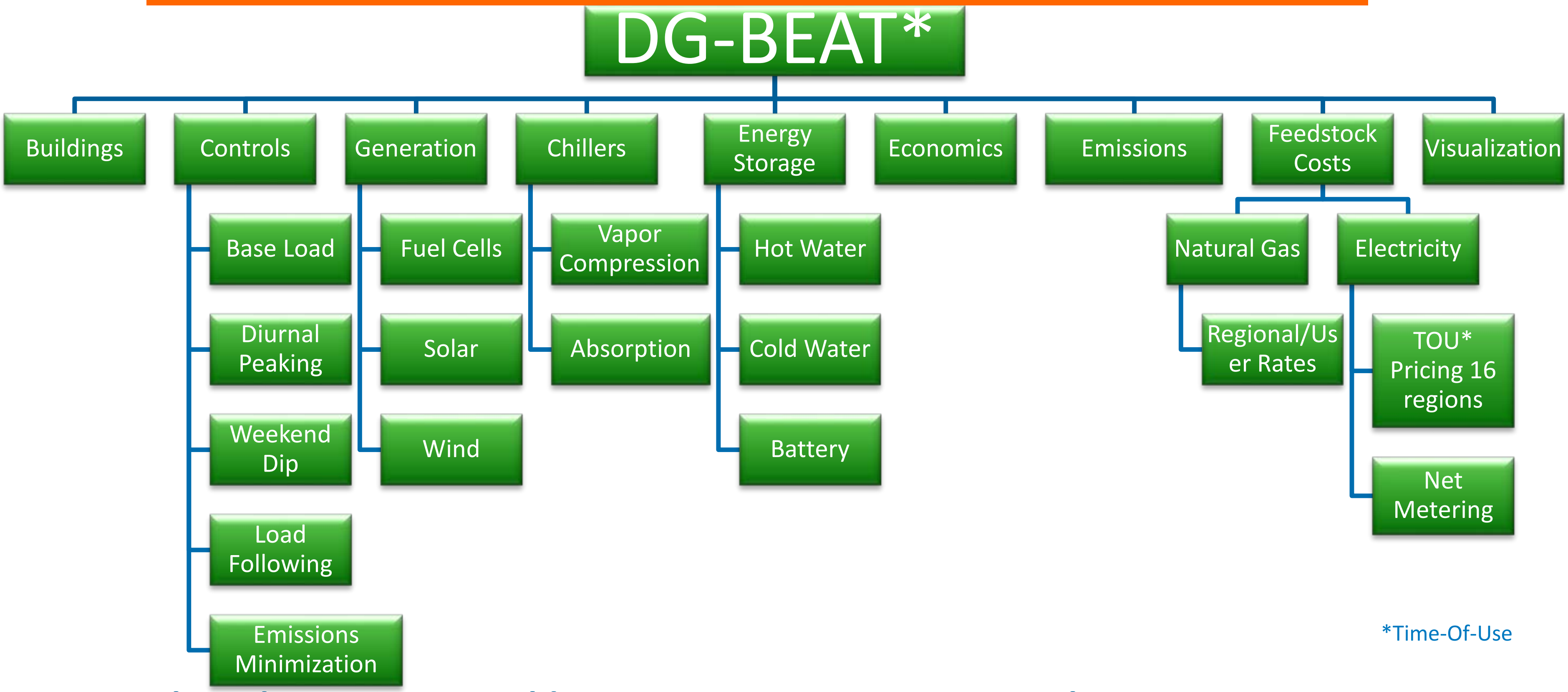


- Online Portal
- Simplified Design
- Initial Assessment

- Open Source Framework
- Modular Design
- Market research

Accomplishments: Construction of Model

- ✧ **Modular Design**
- ✧ **Building Integrated Systems**
- ✧ **Controls Optimization**
- ✧ **Component Sizing**



- **Distributed Generation Build-out Economic Assessment Tool**

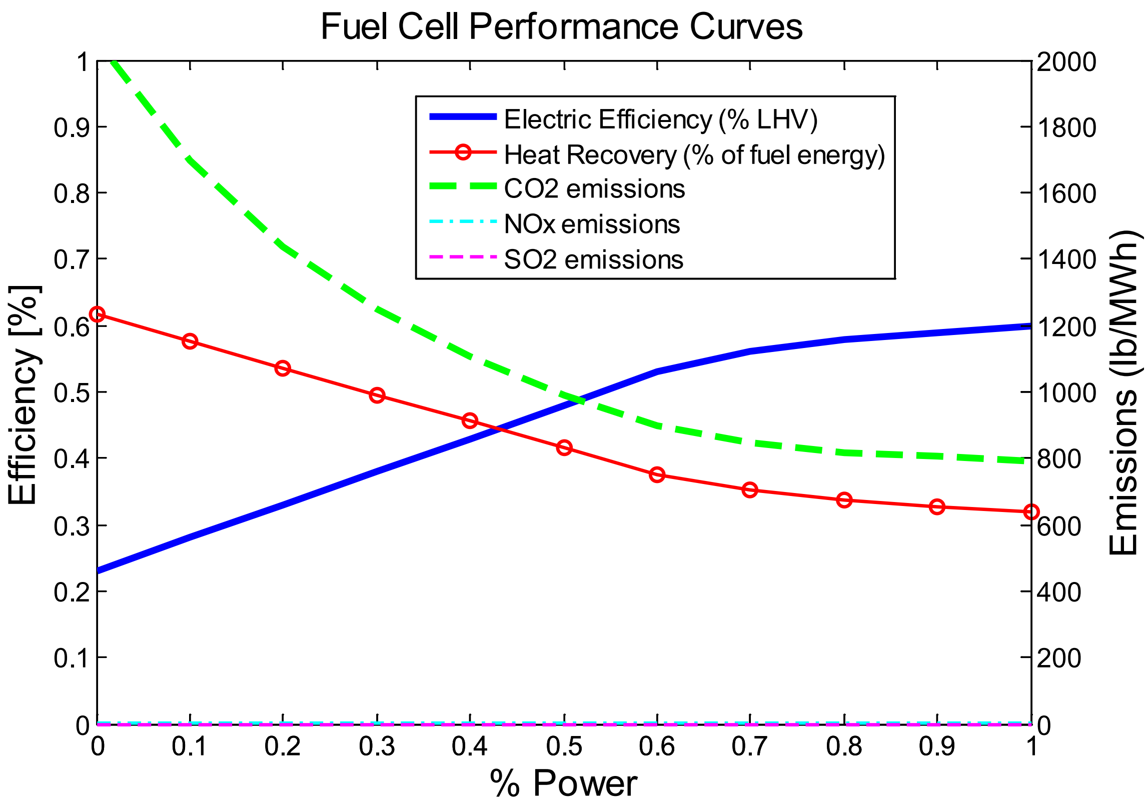
Codebase is hosted on GitHub (the largest code host in the world)

- Allows for distributed collaboration
- Open source, controlled access to fuel cell developers, NREL, UCI, and other stakeholders

Accomplishments: Component Performance

➢Pre-loaded or user defined component performance characteristics

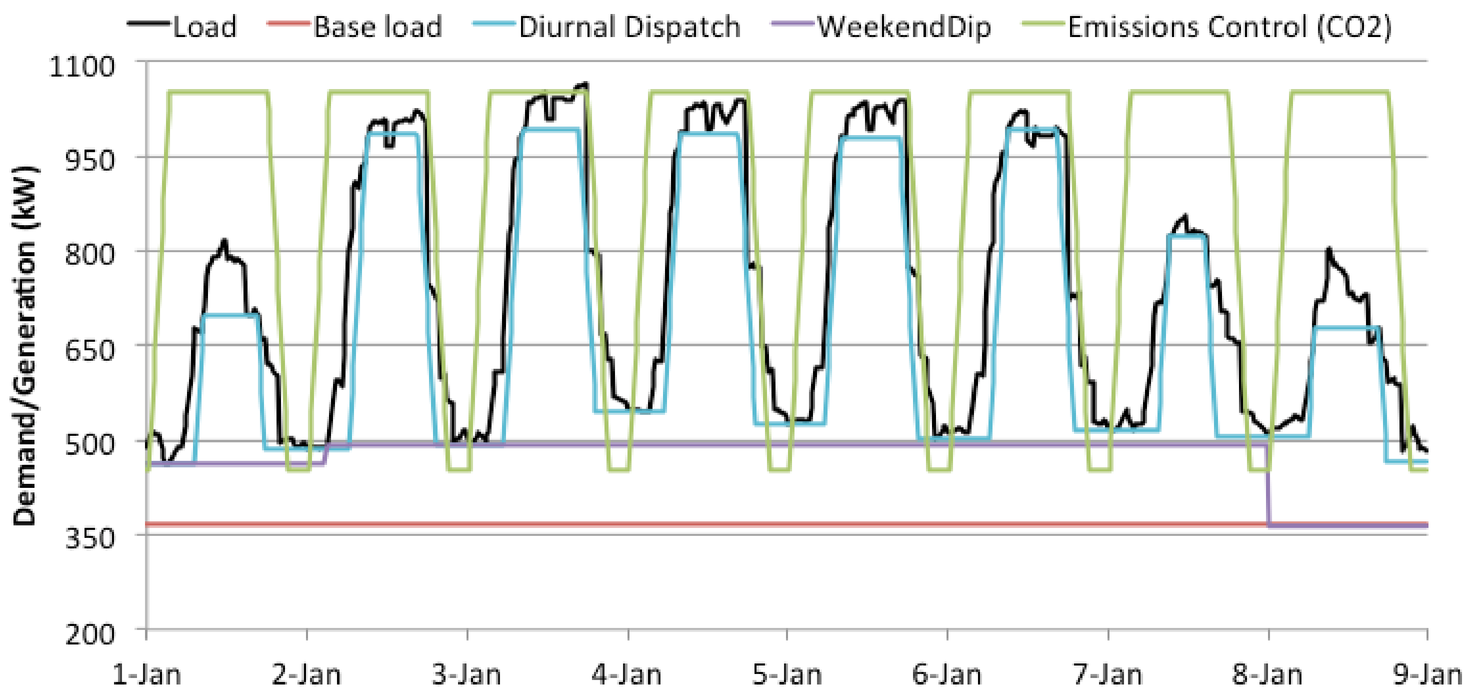
- **Fuel Cell**
  - Efficiency, heat recovery, emissions
  - Heat recovery by temperature
  - Max/min power, response rate, turndown ratio
- **Chiller (Absorption and Electric)**
  - COP by % output
  - Size (kW and Tons)
  - Heat/cold available
- **Thermal Storage (Cold and Hot)**
  - Tank Size (kWh and gal)
  - Reservoir Temperatures
  - Losses
  - Fill and discharge rates
- **Battery**
  - Type and size
  - Charge/discharge characteristics
  - Cell characteristics
- **Wind and Solar also available**



Accomplishments: Fuel Cell Dispatch and Sizing

- Currently 5 FC dispatch strategies and 4 FC sizing strategies
- Additional optimizations envisioned for both sizing and operations

- **5 FC dispatch strategies**

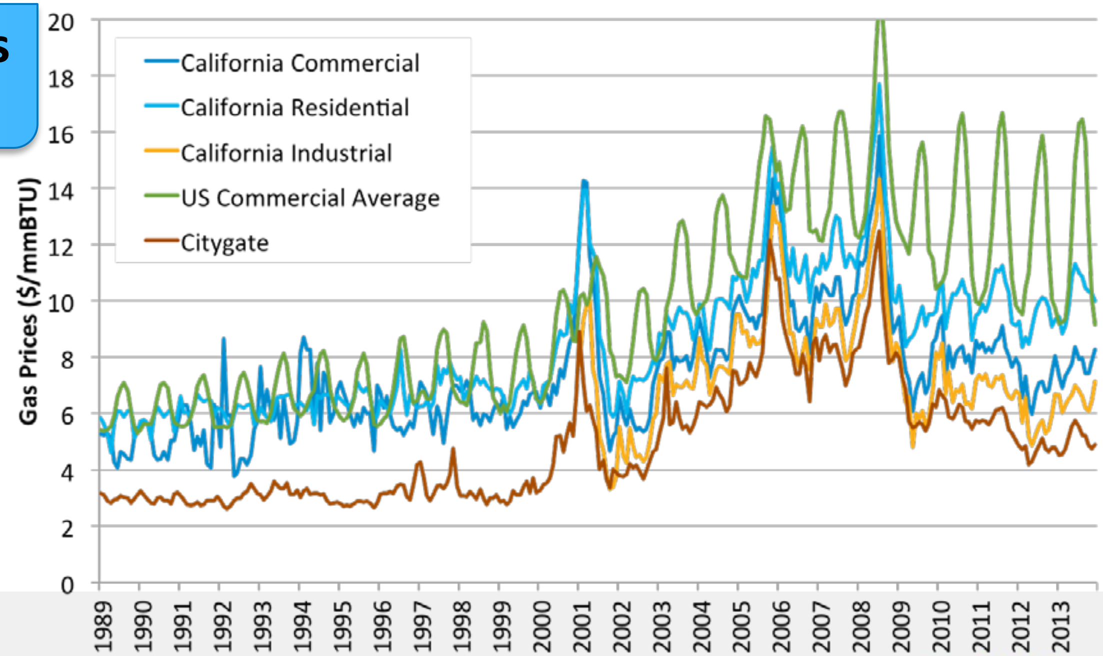


- **4 FC sizing options**
  - Fixed size: User specified
  - 100% size: Sized to meet ≈ peak summer demand (ignores outliers 2% of points)
    - Dependent on FC dispatch strategy chosen
  - Cost optimal size: Iterates between base load size and 100% size to find the best NPV*
  - Emissions optimal size: Iterates to find the lowest net annual emissions

* Net present value

Accomplishments: Regional Utility Costs

- **Preloaded regional utility profiles**
- **Input your own**

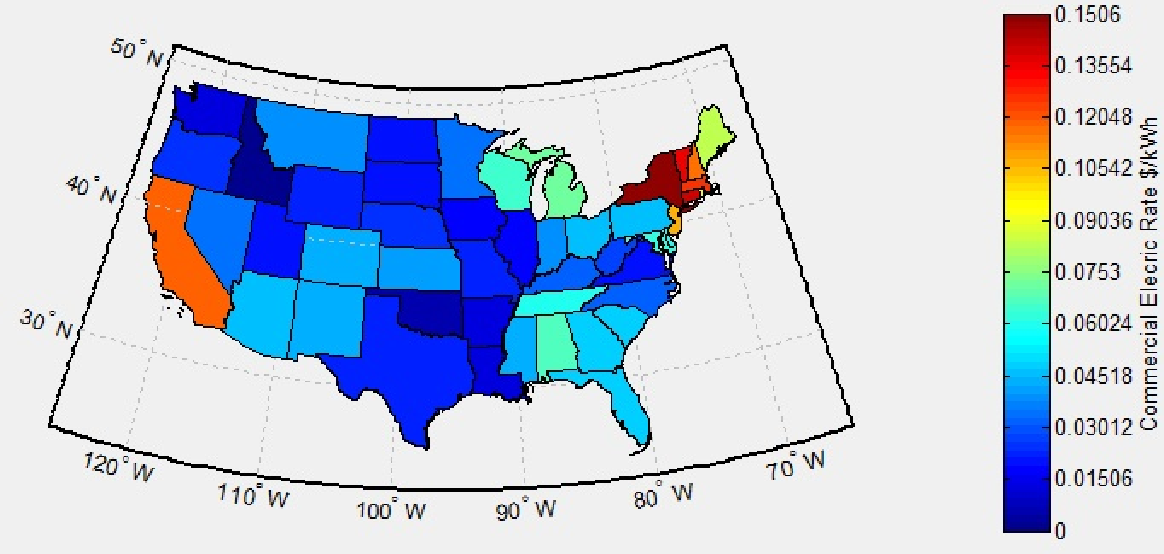


Natural gas cost

- EIA forecasted by state with seasonal variation
- Historical and forecasted rates

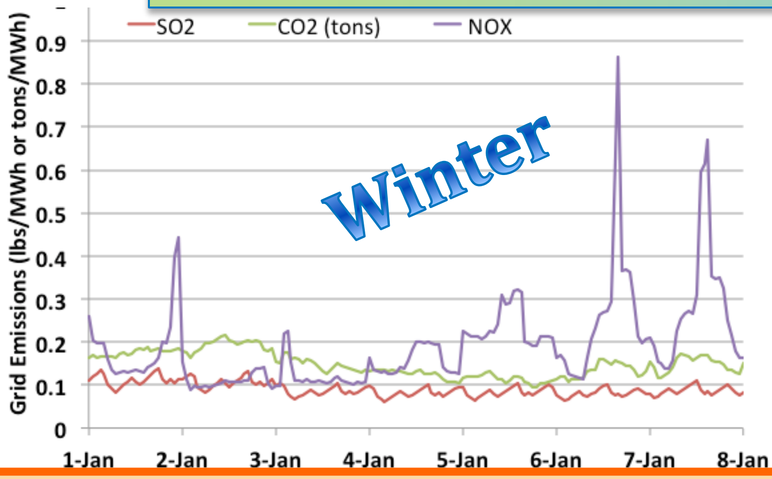
Electricity

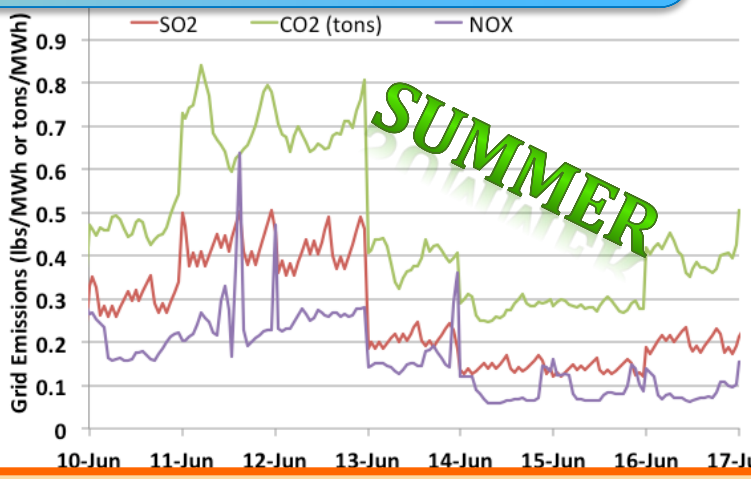
- TOU electricity rates
  - 20+ preloaded rate structures
  - State average energy costs
- Net-metering
  - No net metering
  - Fixed rate sellback
  - TOU sellback (% of incoming charge)



Accomplishment: Regional Emissions Reporting and Control

- Hourly emissions profiles can vary radically in different seasons and days, details that annual emissions alone cannot show.
- Obama's EO 13514 mandates 40% reduction in GHG





Expectation that sum of daily and seasonal variations corresponds to annual totals

- **Hourly emissions data by state (greenhouse gases [GHGs] such as CO_2, SO_2, NO_x)**
  - EPA Acid Rain Program and SIP NO_x Program
  - NO_x projected from daily totals by combustion power plant hourly emissions of CO_2
- **Comparison to annual factors from eGrid**
  - Annual emissions factors from the hourly profiles within ±5% of eGRID values
  - Annual total generation within 10% of state totals from eGRID for 48 states*

* Exceptions are California and Texas (55% and 70% of total, respectively)

Accomplishments: Example Analysis - MD

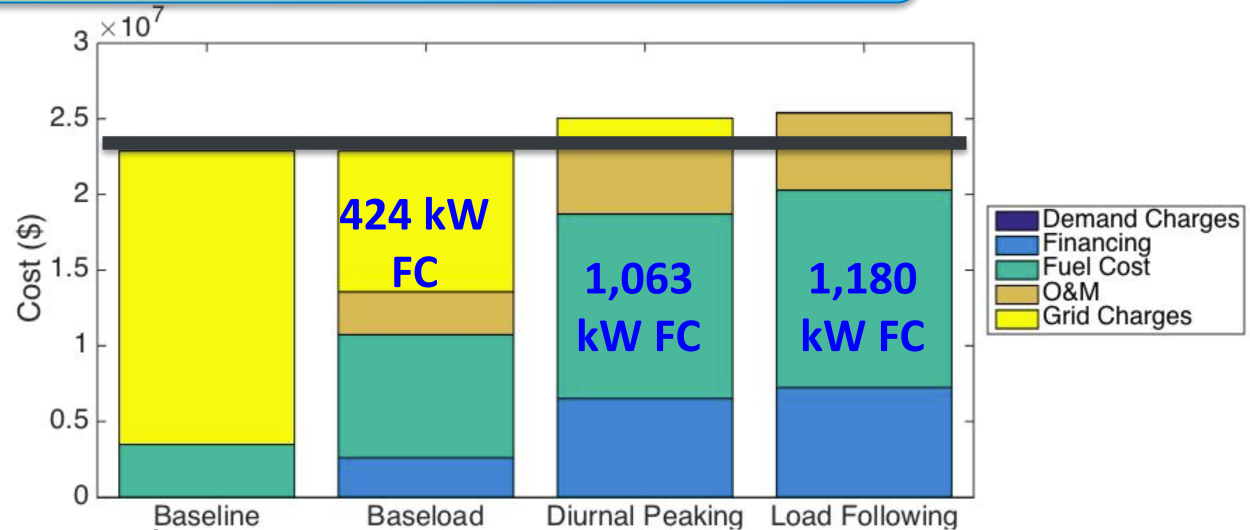
➢ In example cost between a base load fuel cell and not is similar, but significant emissions reduction with fuel cell.

Scenario

- ➢ Maryland hospital
- ➢ FC and battery

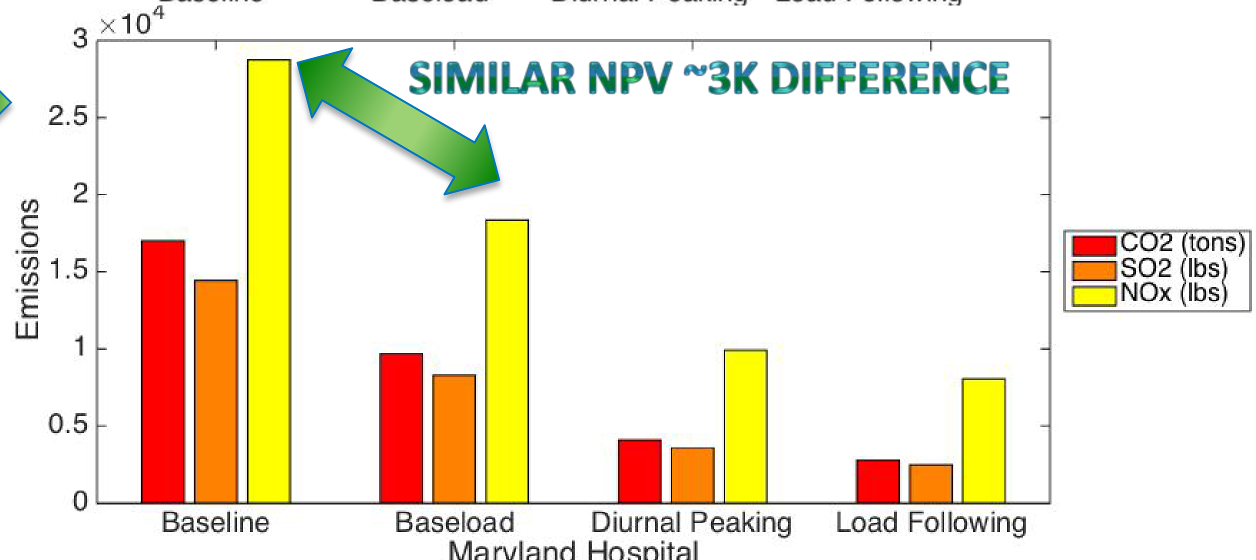
Cost Results

- ➢ Base load has similar NPV as baseline



Emissions Results

- ➢ Base load has similar NPV as baseline, but lower emissions
- ➢ Load following has lowest emissions (dirty grid)



Accomplishments: Example Analysis - CA

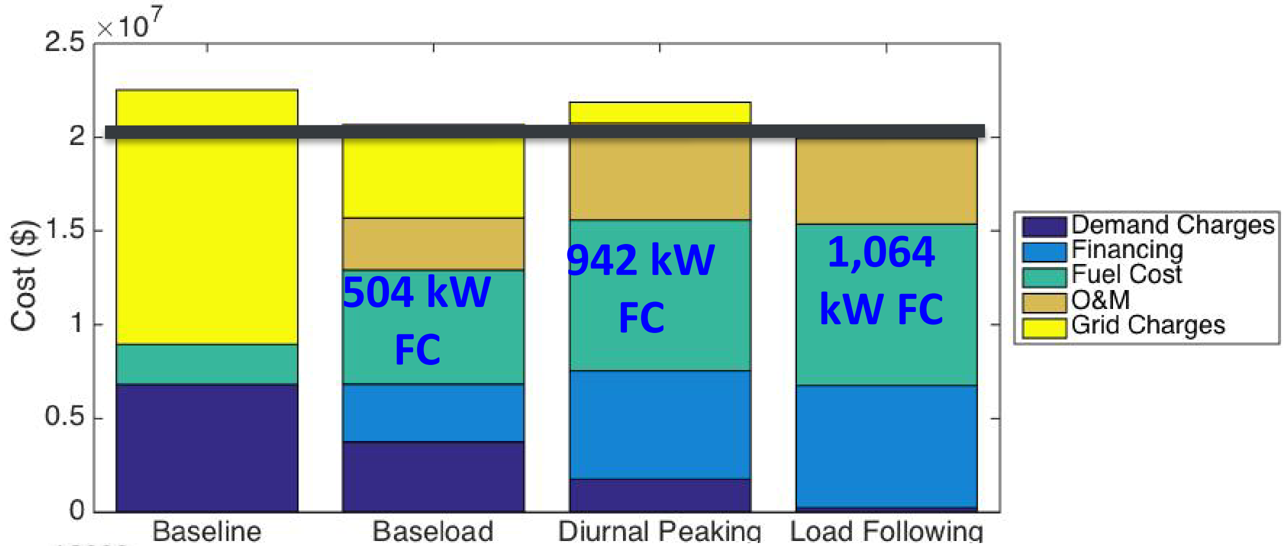
➢ In example a fuel cell for load following provides the lowest cost and emissions reduction.

Scenario

- California hospital
- FC and battery

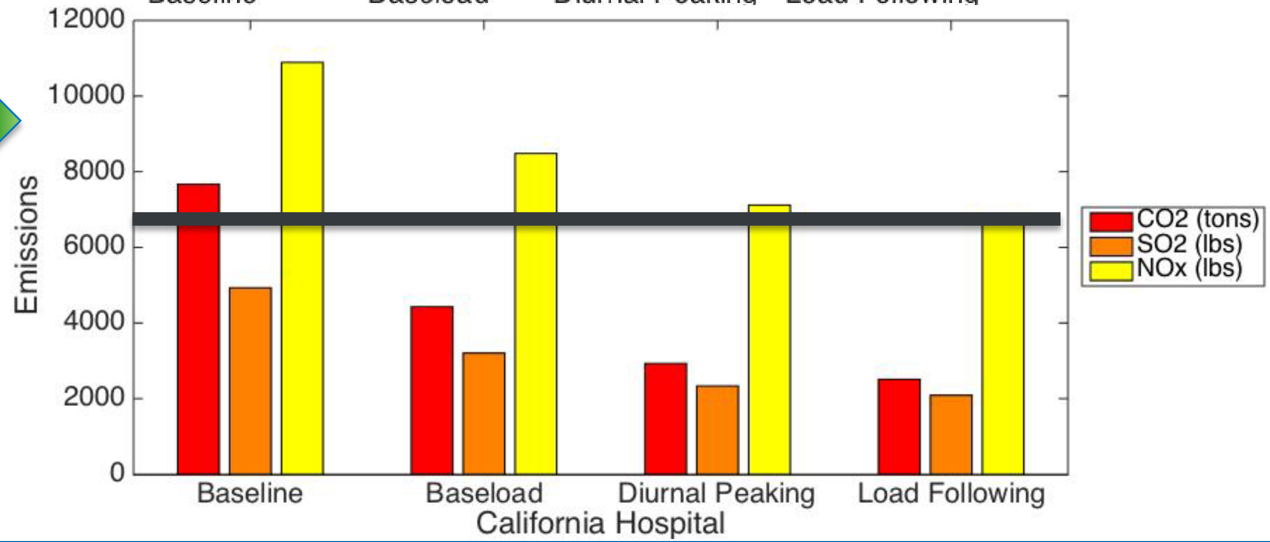
Cost Results

- Load following has the lowest NPV
- CA has better natural gas prices relative to buying grid electricity



Emissions Results

- Load following has the lowest NPV and emissions
- CA has cleaner grid and lower natural gas prices than MD

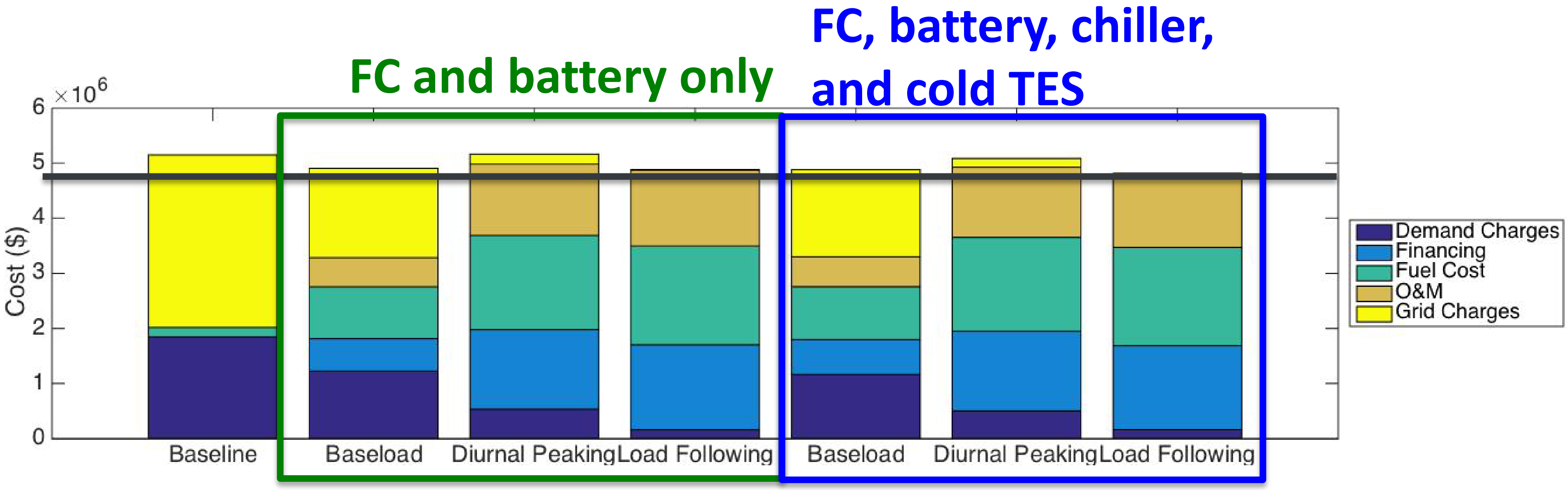


Accomplishments: Thermal Storage Comparison—Cost

- ➢In example fuel cells have cost savings over non CHP baseline
- ➢Thermal storage reduces costs further by ~1%.

California Supermarket

- **Cost results**
  - FC base load and load following with and without storage have 5%+ cost reduction from baseline (no combined heat and power) costs
  - TES reduces costs 0.5%–1.4% from no storage scenarios



Accomplishments: Thermal Storage Comparison—Emissions

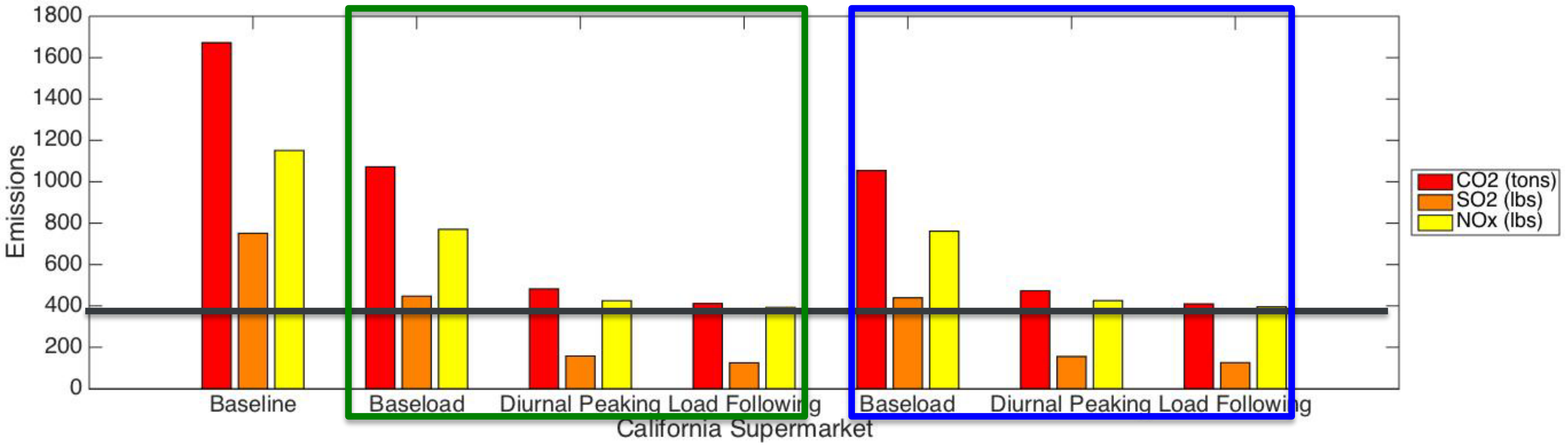
- In example several more dynamic fuel cell sizing and dispatch strategies decrease CO_2 emissions by more than 70%.
- Thermal storage can reduce emissions further by ~1%

California Supermarket

- **Emissions results**
  - FC diurnal peaking and load following reduce CO_2 emissions by more than 70%
  - TES reduces CO_2 emissions by 0.5%–1.1% from no storage scenarios

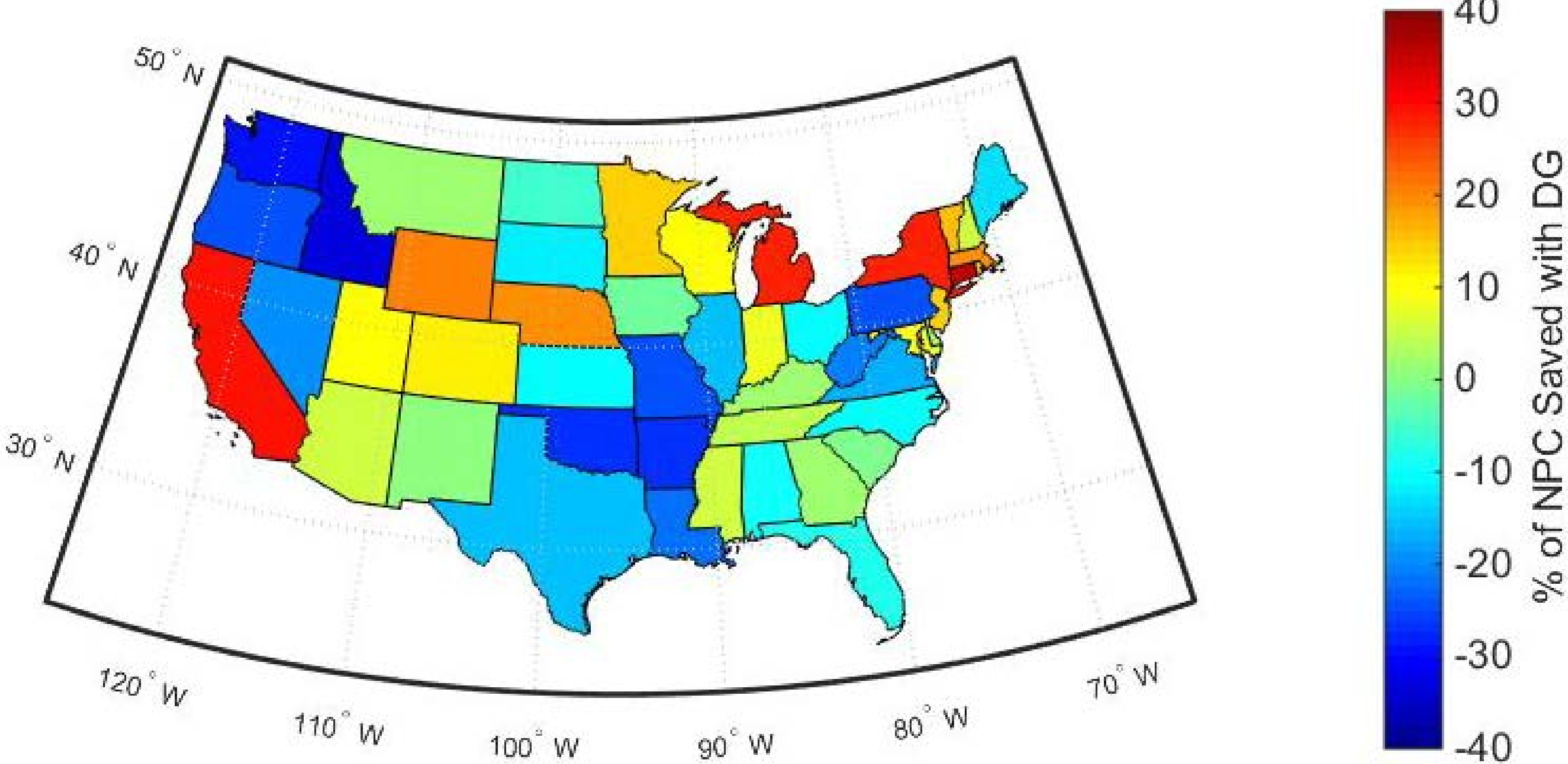
FC and battery only

FC, battery, chiller, and cold TES



Accomplishments: Example National Survey—Cost

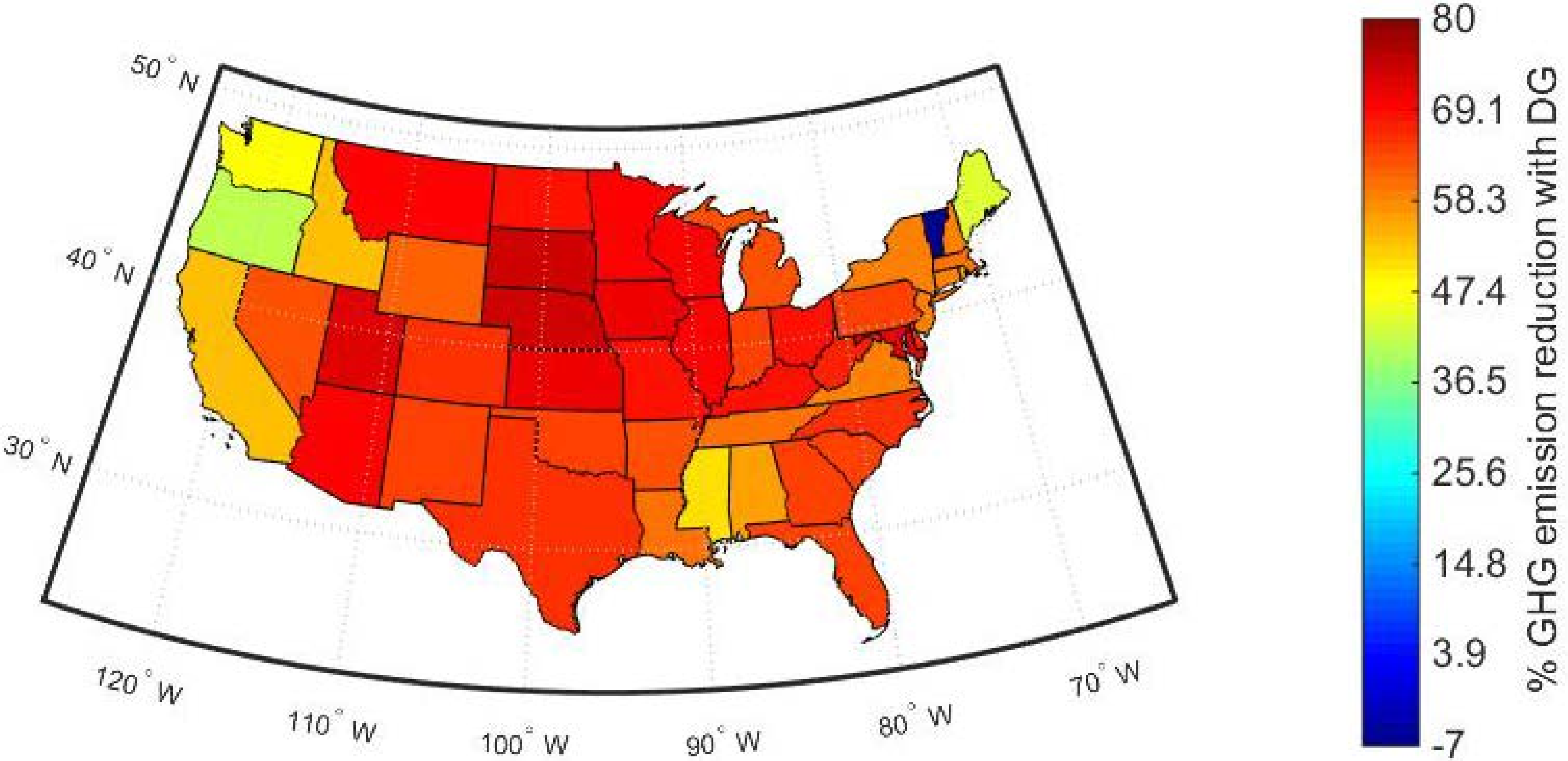
- **Hospital with FC only**
  - Load following with 100% component sizing
  - **Takeaway**: By region, only the South didn't showed cost savings, but the state-by-state variation is greater.
  - **Takeaway**: Cost savings are very dependent on electricity and natural gas prices.



Accomplishments: Example National Survey—Emissions

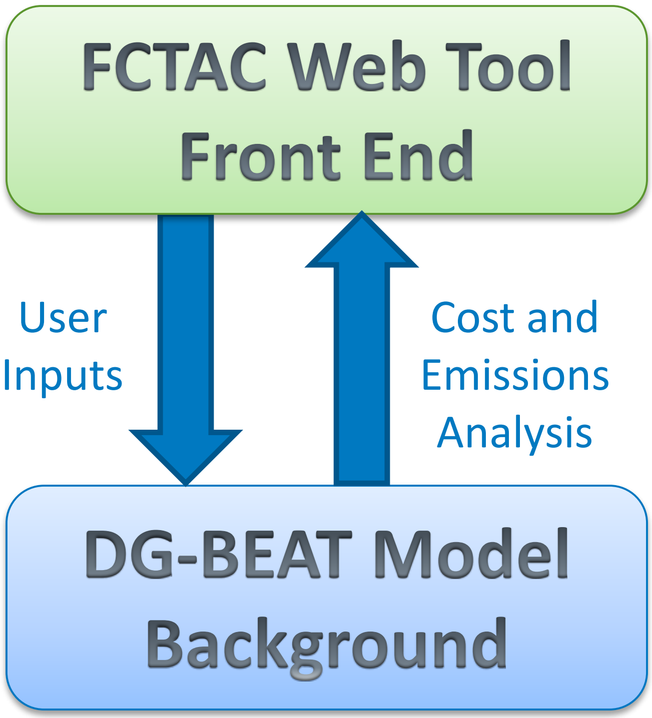
➢ Hospital with FC only

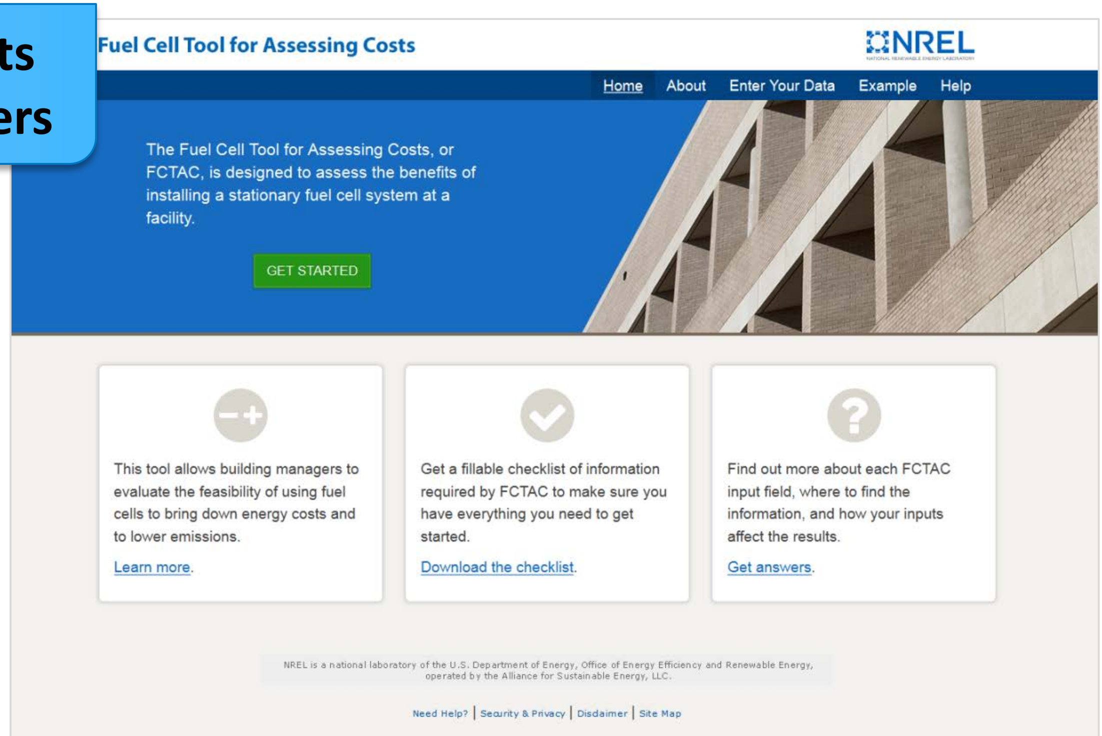
- ✧ GHG emissions minimization control strategy and component sizing
- ✧ **Takeaway**: Most regions have >50% emissions reductions from hospitals by adding an FC, but there is state-by-state variation.
- ✧ **Takeaway**: Emissions savings are dependent on the state grid emissions.



Accomplishments: FCTAC - Online Web Portal

- **Easily accessible initial assessments**
- **Targeted at federal facility managers**





fctac.nrel.gov

- **FCTAC* was deployed in May 2014.**
- **The home page is easy to use and has links to everything users need to get started.**
- **437 page views since Sept 1, 2014 (16% new users)**

* **F**uel **C**ell **T**ool for **A**ssessing **C**osts

Accomplishments: FCTAC – Online Web Portal

➢Creation of a simple Web tool backed by a complex model

- **FCTAC is based on DG-BEAT, an all-encompassing model**
  - DG-BEAT was developed under the NREL Fuel Cell program.
  - The scope of the DG-BEAT model can be intimidating to many users.
  - FCTAC narrows the scope of DG-BEAT to be a first step toward making a decision about going forward with a stationary fuel cell installation.
- **Narrowing down the inputs**
  - The inputs were reduced to the 12 with the most impact.
  - Default values were carefully chosen for all other inputs, including installation costs, load requirements, and combined heat and power (CHP) usage.
  - Assumptions were made that will cover most users needs.
- **Narrowing down the outputs**
  - The three outputs chosen for FCTAC are a net present value cost analysis, greenhouse gas emissions analysis, and criteria pollutant emissions analysis.
  - In all three cases, FCTAC compares the building’s performance with standard equipment to the building’s performance with a solid oxide fuel cell sized to handle the building base load energy use.

Accomplishments: FCTAC - Online Web Portal

- **Easily read results, visual and tabular**

Analysis Information for Your Facility

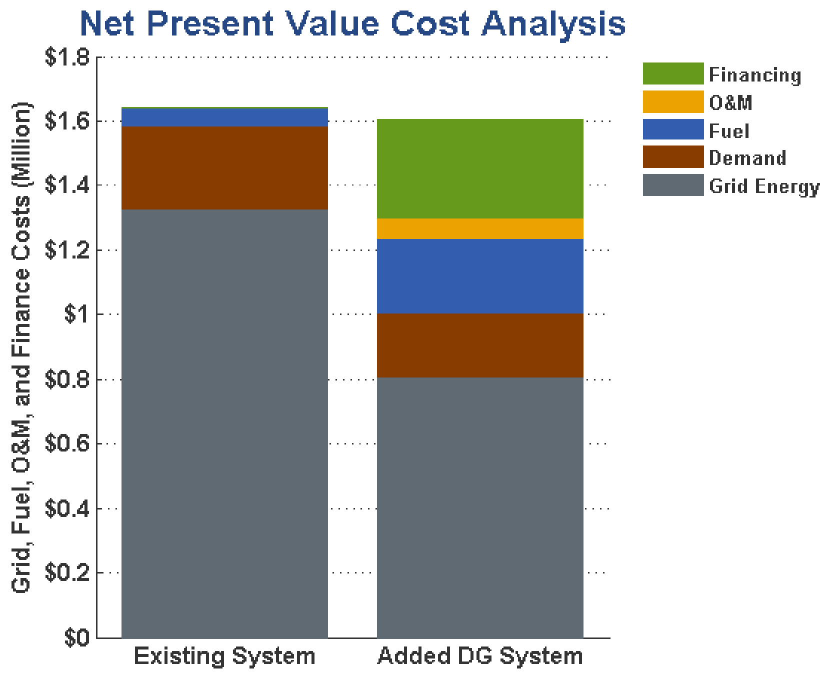
Climate Zone: Baltimore (ASHRAE 4A)

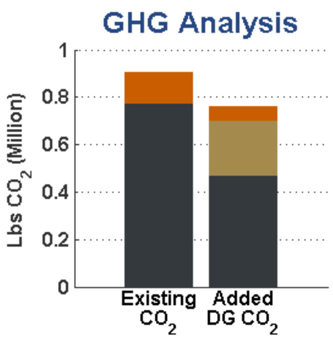
eGrid Zone: SERC Virginia/Carolina

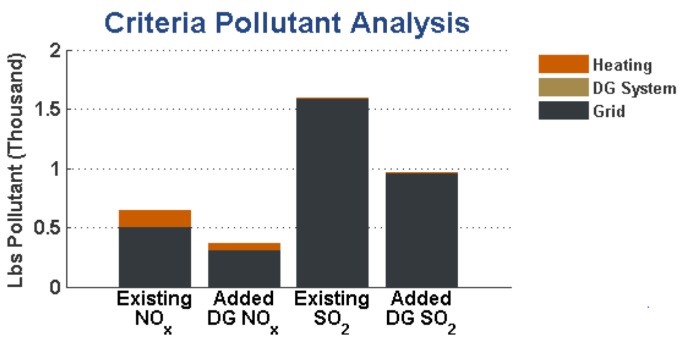
System Size: 35kW HTFC

Analysis Period: 20 years

Payback: 15 years







Annual GHG and Pollutant Production (lbs)

	CO_2		NO_x		SO_2	
	Existing	Added DG	Existing	Added DG	Existing	Added DG
Heating	125,184	53,375	134	57	1	0
DG System	0	233,297	0	3	0	0
Grid	776,901	471,769	510	310	1,590	965
Total	902,085	758,441	644	370	1,591	965

Net Present Value Cost Analysis (US$)

	Existing System	Added DG
Finance	$0	$304,874
O&M	$0	$65,294
Fuel	$56,103	$229,988
Demand	$254,178	$196,954
Grid	$1,329,502	$807,348
Total	$1,639,783	$1,604,458

$35,325 reduction (2%) over the 20 year analysis period.

Remaining Challenges and Barriers

➢ **Project strategy is being realigned following a move under the Technology Validation AOP.**

- **DG-BEAT**
  - The project plan is being aligned better with grid integration activities.
  - There has been a challenge in coordinating with the diverse projects to form a cohesive plan surrounding technology validation in fuel cell grid integration activities.
  - Revision of project scope and vision is under re-evaluation.
- **FCTAC**
  - Modifications that do not compromise the accessibility or ease of the web tool while increasing its validity of use.
  - Better represent currently available stationary fuel cell systems.
  - Distinguish between electric only and CHP stationary fuel cells.

Proposed Future Work

➢Project plans are being refocused

- **Grid integration**
  - Assess and develop metrics for grid and auxiliary services that fuel cells can provide
  - Assess and integrate other building system components for flexible operation
  - Communication with Distributed Management Systems for grid modernization
  - Real-time price signals and operation signals
- **Optimal real-time controller**
  - Tightly integrate building systems to allow participation in energy markets
  - Algorithms for assessing economics of flexible dispatch
- **Optimal component sizing**
  - Evaluate component sizing based on controller strategies
- **Open-source code**
  - Allow new module creation
  - More communication with developers and researchers for increasing fuel cell feasibility
- **Hardware simulation**
  - Use of model for real-time hardware simulation
- **FCTAC**
  - Continue to refine web portal for initial assessments maintaining the easy accessibility

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **The model is sophisticated. However, it is hard to see a "general" strategy amongst all the many data**
  - The general strategy is aimed at looking at how fuel cells are sized and operated within building systems that might help identify potential markets. It also exposes facility managers to the benefits of fuel cells, helps them to identify good candidate sites, and educates the users.
- **The broad involvement of industrial users to provide feedback is very valuable. However, it is not clear what open-source software is used and if all members of the selected user group have the necessary computer capabilities and commitment.**
  - DG_BEAT was developed through GitHub which allows multiple code developers to collaborate. The code repository access is by invitation and currently only open to the active coding developers at NREL and UCI. A future activity could be to make the model fully open-source, but this would require more work and funding. The larger User's Group has access to a windows executable with both 32 and 64-bit versions. The distributable does require the Matlab Compiler Runtime (MCR) which is distributed along with the DG_BEAT executable and installation instructions.
- **Alignment with the DOE objectives is not fully clear or quantified.**
  - The stated goals were selected from the Fuel Cell section of the MYRDD which is where the project had previously been funded. This is being addressed by moving the project to Technology Validation. DG-BEAT can be used to help identify good potential stationary project sites for further validation of stationary fuel cell technical targets.

Collaborations

- **User's Group**
  - Acumentrics, Ballard Power Systems, CEA, CERL, Chrysler, ClearEdge Power, IDIQ, JSR Corp, NetGain Energy Advisors, Ontario Fuel Cell Centre, PNNL, Stark State College, Tetramer, and URS.
- **Controls and integration**
  - UCI
- **Building profiles and analysis**
  - NREL Electricity, Resources, and Building Systems Integration Center (ERBSIC)
- **FCTAC Web Portal**
  - Fuel Cell Technologies Office Market Transformation team (IDIQ)
- **Manufacturing cost analysis (separately funded projects)**
  - LBNL
  - Strategic Analysis, Inc.
  - Battelle

Summary

- **DG-BEAT is a full-featured model**
  - Integrates fuel cells into a building environment using time-series data for building loads, emissions, electricity, and natural gas.
- **The code is modular**
  - Many building components already included.
- **Geographic analysis available**
  - Uses regional data for buildings, utilities, and emissions.
- **Results include economic and emissions data**
  - Comparisons to incumbent technologies.
- **The web portal allows a simple initial assessment**
- **Grid integration refocus of project**
  - Optimized fuel cell controls
  - Open source code further

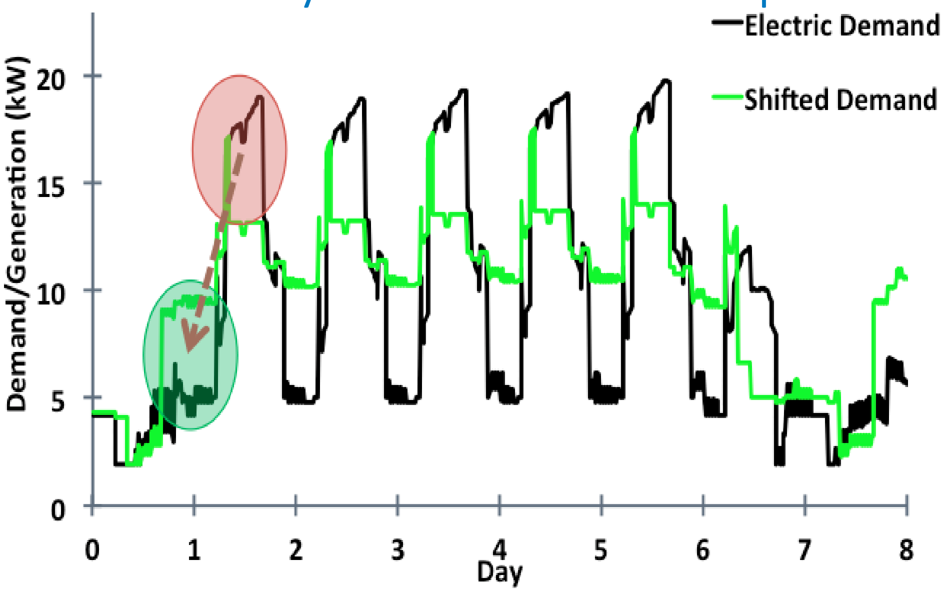
Technical Back-Up Slides

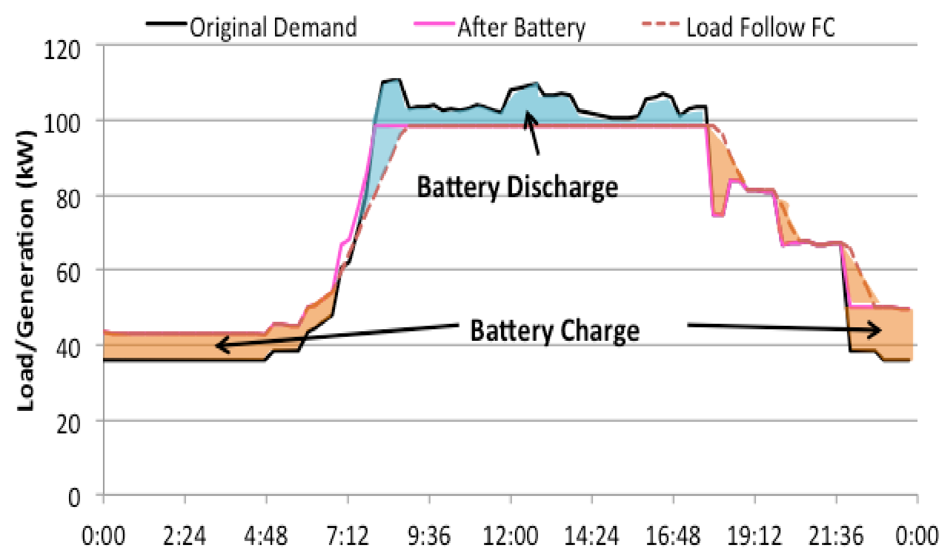
Accomplishments: Component Sizing

- ➢ **Foundations for additional component sizing are implemented**
- ➢ **Modular designs allows additional component creation**

- **Electric and Absorption Chillers**
  - Absorption Chiller sized based on heat available or demand whatever lowest
  - Electric chiller required to meet 100% of remaining peak summer demand
- **Thermal Energy Storage (TES)**
  - Sized to shift 100% of cooling from peak hours to off-peak
  - Sized for hottest day during summer on-peak months
- **Battery**
  - Primary purpose is to reduce demand charges during on-peak hours
  - Set by total kWh or hours of peak demand

Wind and Solar components also available!

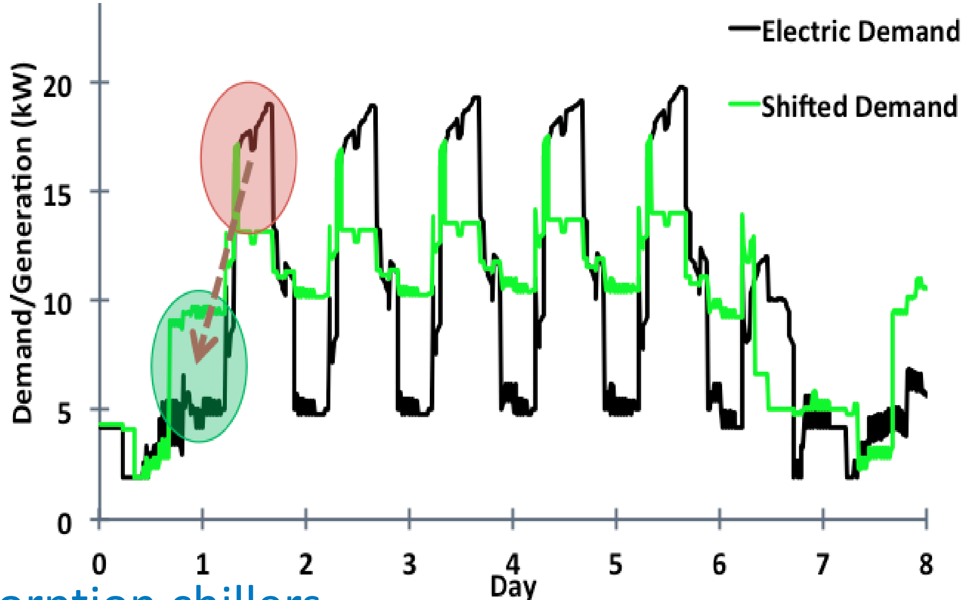




Accomplishments: Thermal Energy Shift

➢ Objectives

- ✧ Shift daytime cooling demand to previous night
- ✧ Flatten electricity demand profile by operating chillers at steady state

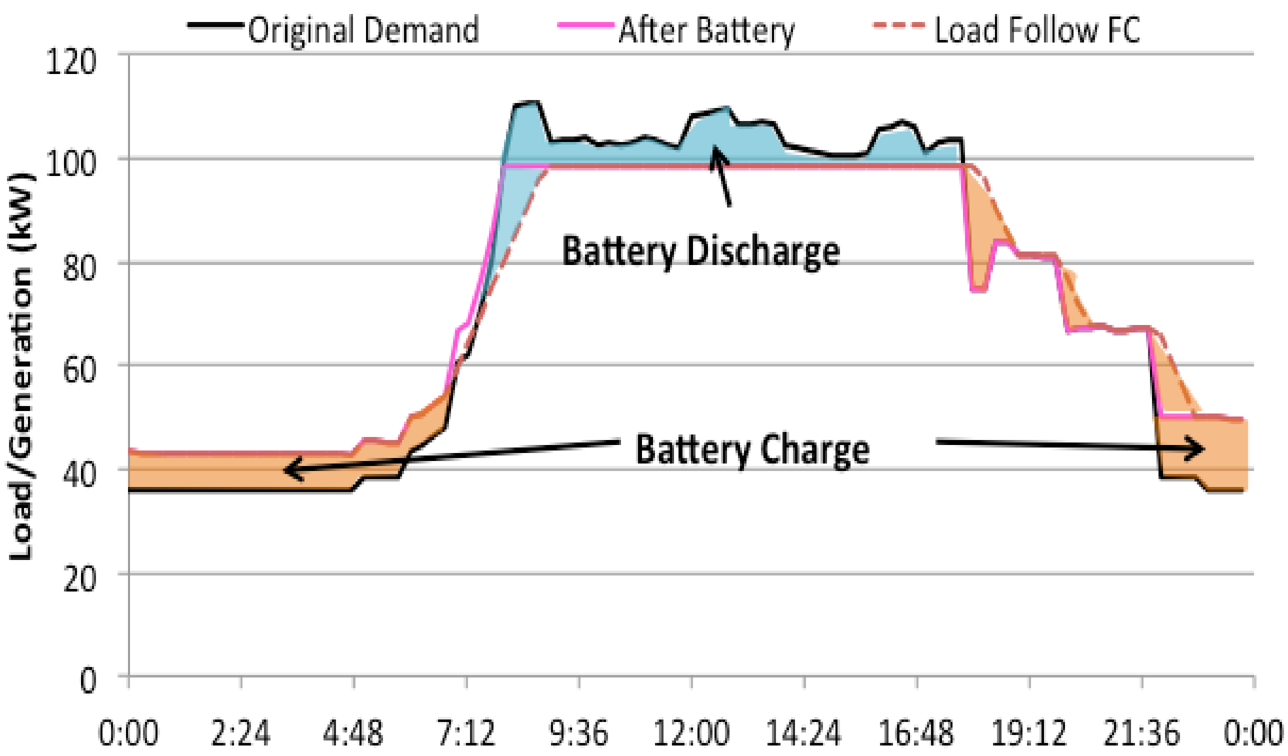


➢ Sizing

- ✧ Electric and absorption chillers
  - Absorption chiller sized based on heat available or demand, whatever is lowest
  - Electric chiller required to meet 100% of remaining peak summer demand
- ✧ TES
  - Sized to shift 100% of cooling from peak hours to off-peak on hottest day in summer on peak months

Accomplishments: Battery Shift

- **Objective**
  - Primary purpose is to reduce demand charges during FC ramping



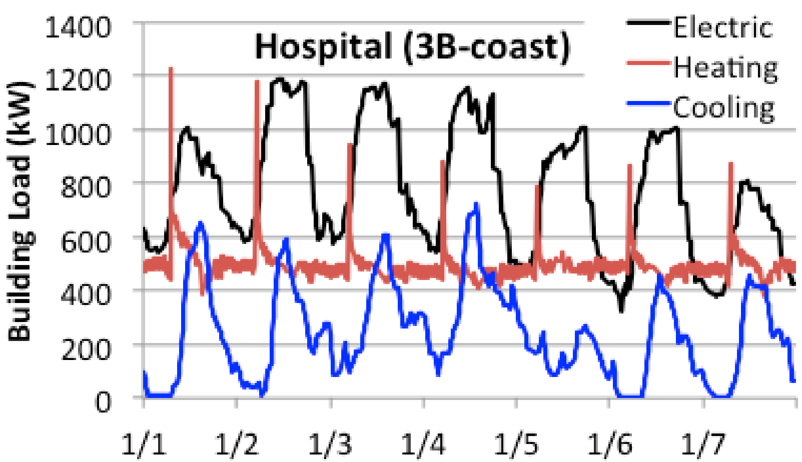
- **Sizing**
  - Set by total kWh or hours of peak demand

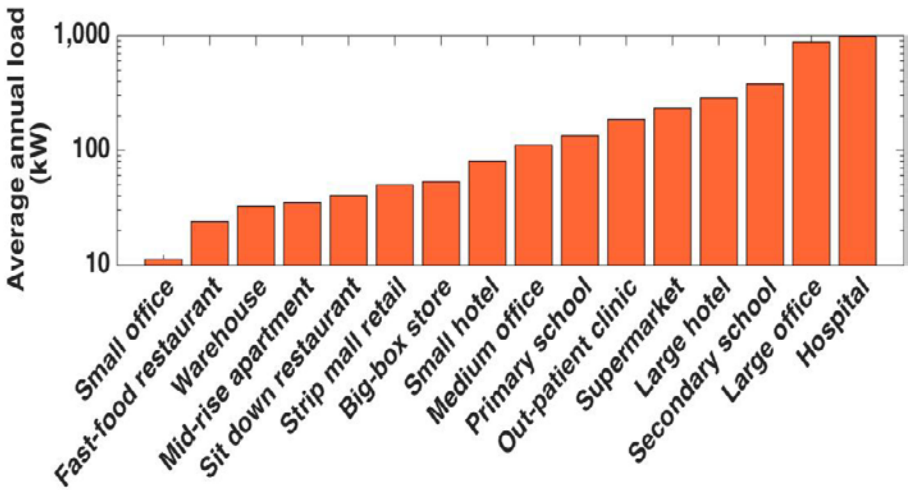
Accomplishments: Regional Building Profiles

NREL's Electricity, Resources, and Building Systems Integration Center has provided energy use profiles* .

- 1280 total building profiles
- Load profiles include electricity, heating, cooling (thermal kW & electric kW), electric refrigeration, and exterior lighting
- 15 min time interval data for a year

✧ Can also use real building data if available





Building types	Locations
Restaurant: full-service (sit down)	Miami (ASHRAE 1A)
Restaurant: quick-service (fast food)	Houston (ASHRAE 2A)
School: primary school	Phoenix (ASHRAE 2B)
School: secondary school	Atlanta (ASHRAE 3A)
Office: large office	Los Angeles (ASHRAE 3B-Coast)
Office: medium office	Las Vegas (ASHRAE 3B-Inland)
Office: small office	San Francisco (ASHRAE 3C)
Hospitality: large hotel	Baltimore (ASHRAE 4A)
Hospitality: small hotel/motel	Albuquerque (ASHRAE 4B)
Health care: large hospital	Seattle (ASHRAE 4C)
Health care: outpatient facility	Chicago (ASHRAE 5A)
Retail: big-box, standalone retail store	Boulder (ASHRAE 5B)
Retail: retail strip mall	Minneapolis (ASHRAE 6A)
Retail: supermarket	Helena, MT (ASHRAE 6B)
Mid-rise apartment building	Duluth, MN (ASHRAE 7)
Unrefrigerated warehouse	Fairbanks, AK (ASHRAE 8)
Vintages	2010, 2007, 2004, Post-1980, Pre-1980

* Using data from the Commercial Buildings Energy Consumption Survey (CBECS)