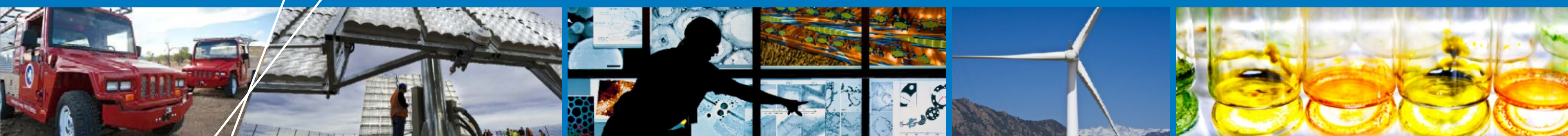
Enlarging Potential National Penetration for Stationary Fuel Cell through System Design Optimization



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National Renewable Energy Laboratory

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Project ID FC083

Overview

Timeline and Budget

Project start date: October 2011
Project end date: October 2014*

FY13 DOE Funding: $50k
Planned FY14 DOE Funding: $100k
Total DOE Project Value: $750k

*Project continuation is determined annually by DOE
**Funded under a separate project

Barriers

- Cost
- Durability
- Performance relative to incumbent

Partners

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

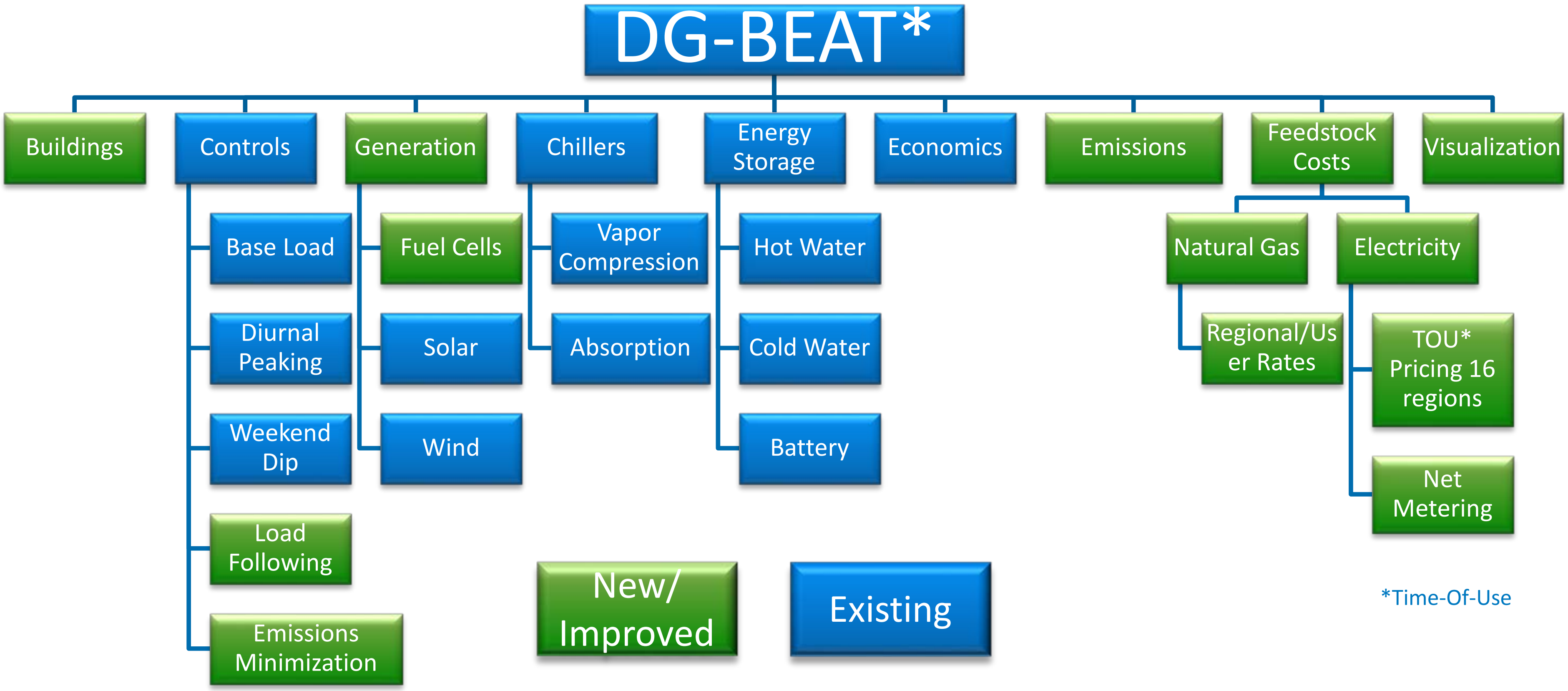
Relevance

Technical Challenges	
• Cost • Durability • Performance relative to incumbent	
DOE Goal	**Project Goal**
By 2020, develop medium-scale CHP fuel cell systems (100 kW–3 MW) that achieve 50% electrical efficiency, 90% CHP efficiency, and 80,000 hours durability at a cost of $1,500/kW for operation on natural gas, and $2,100/kW when configured for operation on biogas	Build an open-source tool (DG-BEAT*) that helps CHP fuel cell developers, end users, and other stakeholders to do the following for their systems, helping to drive economies of scale and cost reduction: • Determine the appropriate sizing to reduce cost • Integrate to commercial building control and HVAC systems to maximize durability • Compare performance relative to incumbent technologies • Determine optimum system configuration • Evaluate potential market penetration * Distributed Generation Build-out Economic Assessment Tool

Approach: Milestones

12/13 (complete)	Implement a control strategy which models fuel cell system response used for energy consumption calculations by accounting for system response lag.
3/14 (complete)	Implement a dispatch control for lowest GHG emissions (CO_2) and criteria pollutants (Ozone, SO_x, NO_x, PM10, CO), based on available regional electric grid emissions, and emissions profiles from stationary fuel cell systems.
6/14 (complete)	Identify and implement one additional set of commercial building energy usage profiles (16 types in 16 locations x 8760 hours each, in 15 minute time steps).
9/14	Deliver a compiled windows executable of the model to the user's group including 1024 building energy load profiles.

Approach: Construction of Model



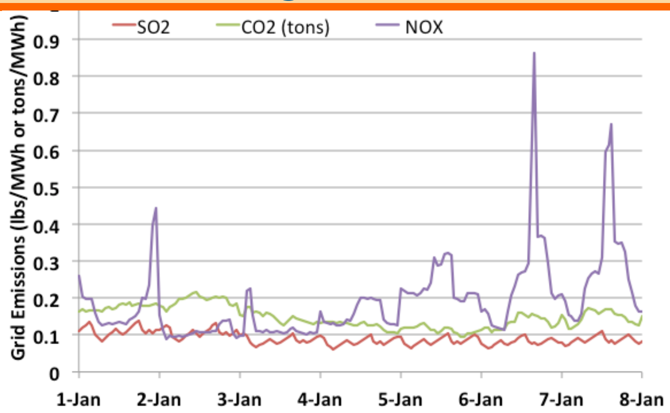
*** Distributed Generation Build-out Economic Assessment Tool**

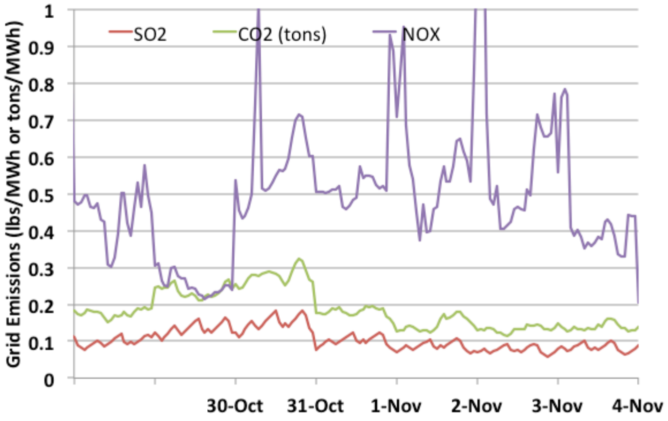
Codebase is hosted on GitHub (the largest code host in the world)

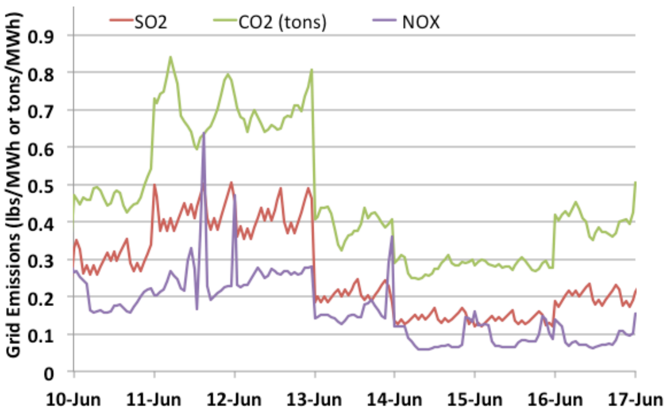
- Allows for distributed collaboration
- Open source, controlled access to fuel cell developers, NREL, UCI, and other stakeholders

Accomplishments: Emissions Control

- **Hourly emission data by state (CO_2, SO_2, NO_x)**
  - EPA Acid Rain Program and SIP NOx 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)

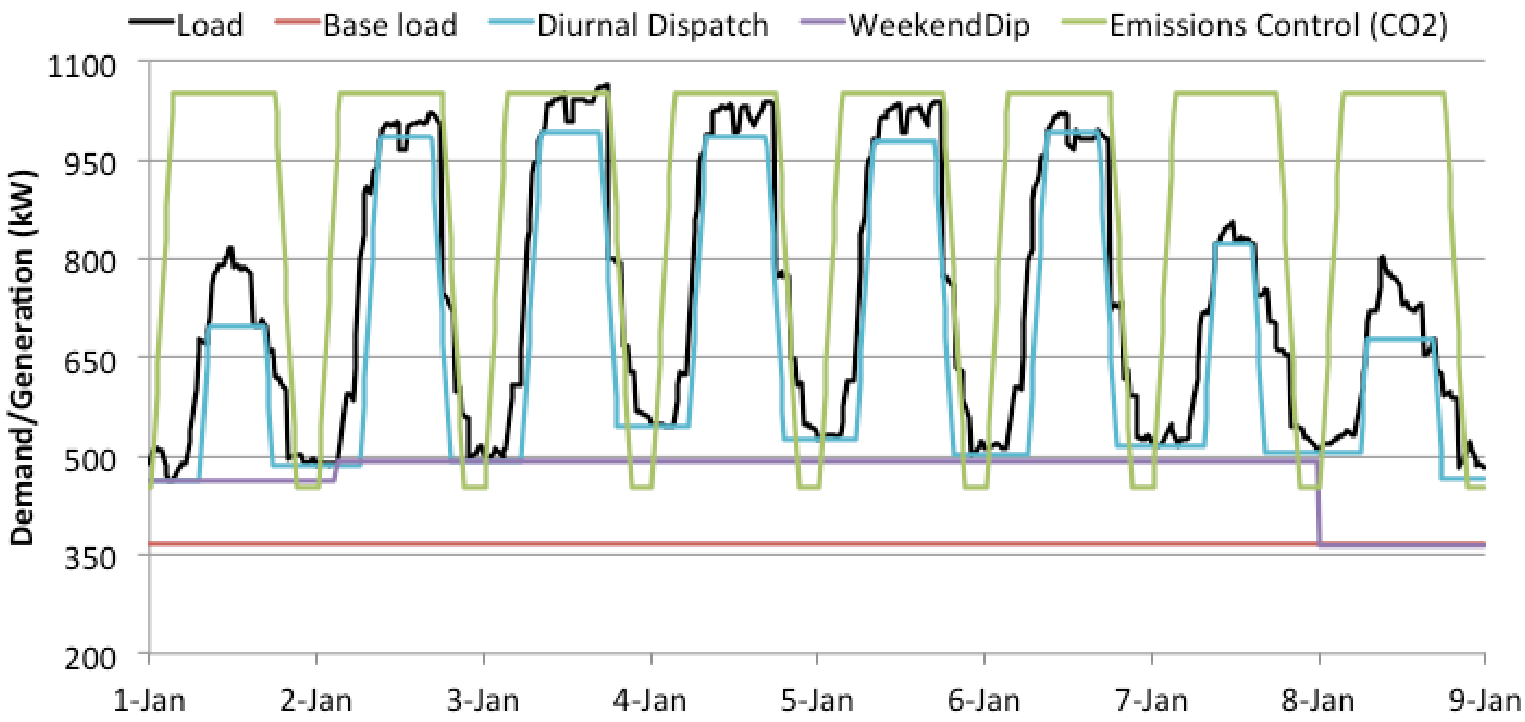
Hourly emissions profiles can be radically different in different seasons and days, detail that annual emissions alone can not show.

Accomplishments: Sizing

Foundations for component sizing optimization are implemented

Fuel Cell

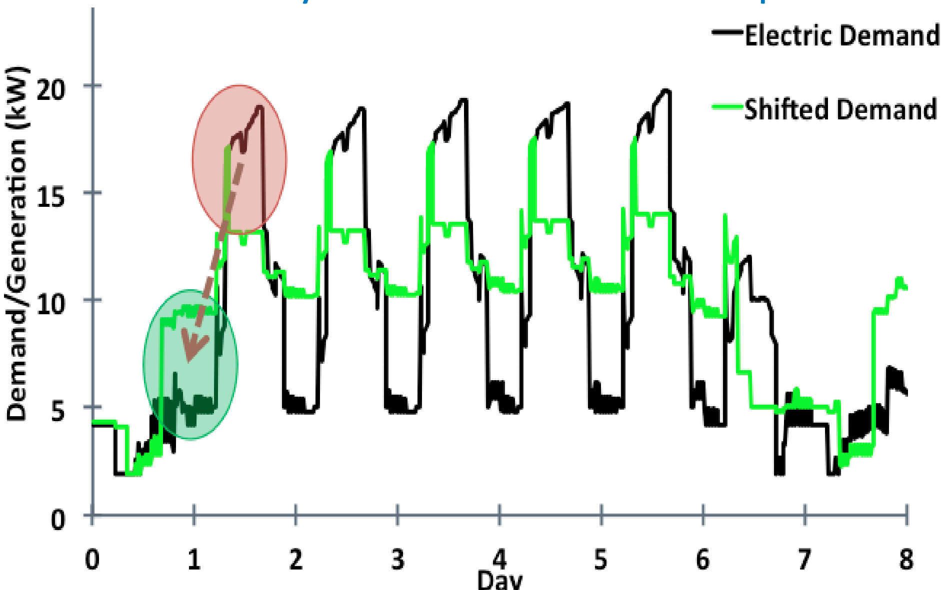
- Peak summer weekday demand: Average profile for non-holiday weekdays during summer
- Fixed size: Size set by specific FC system selected, i.e. DFC300
- 100% sizing: Sized to meet ≈ peak summer demand, (ignores outliers 2% of points)
- Cost optimal sizing: Iterates between base load size & 100% size to find the best NPV
- Emissions optimal sizing: Iterates to find the lowest net annual emissions

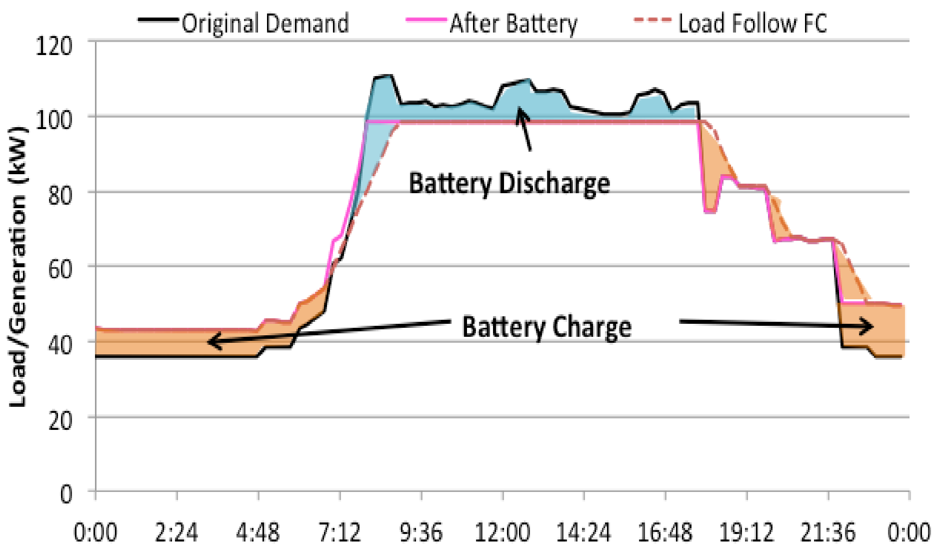


Accomplishments: Sizing

Foundations for component sizing optimization are implemented

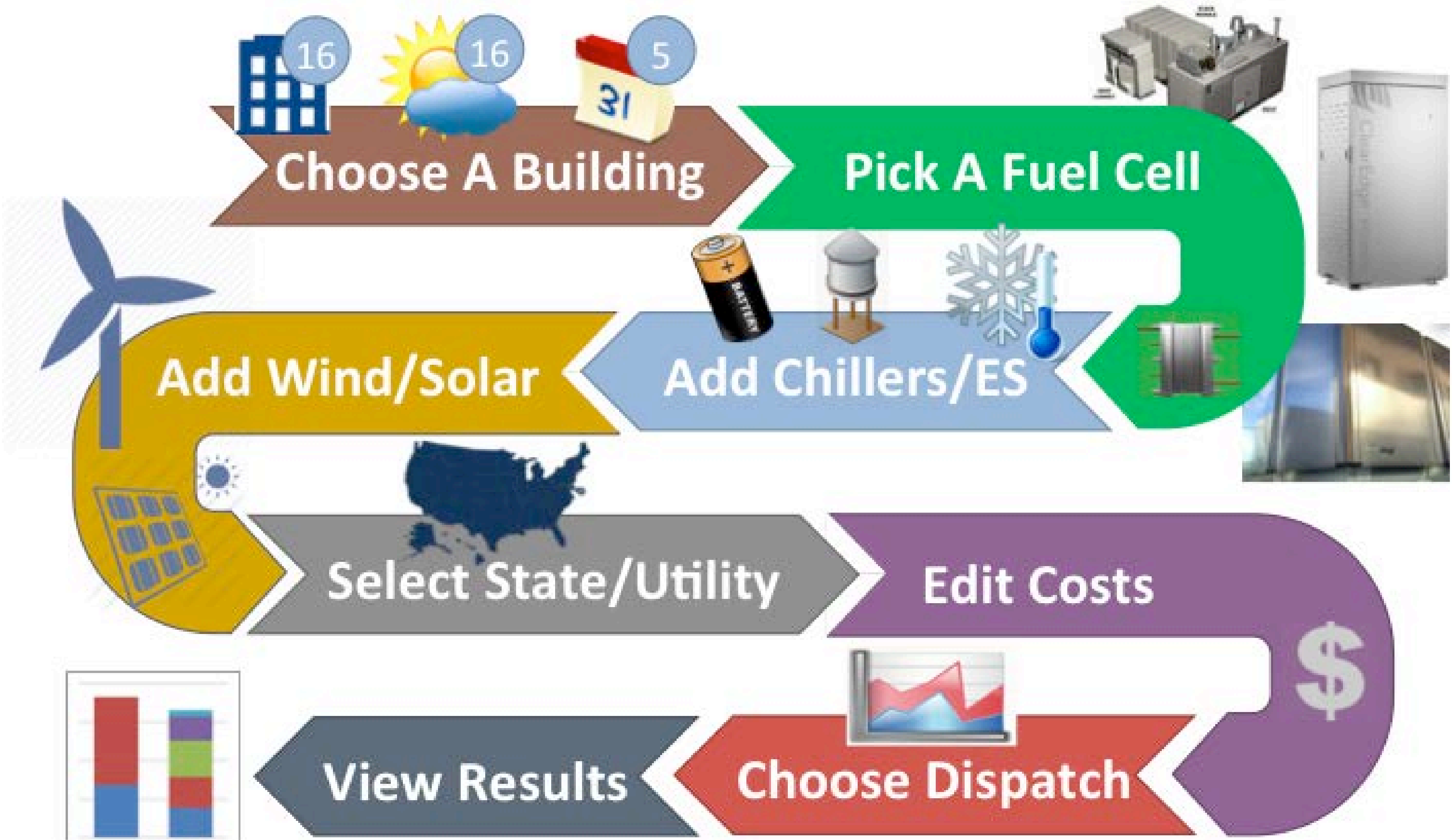
- Electric and Absorption Chillers
  - Absorption Chiller sized based on heat available or demand whatever lowest
  - Electric chiller required to meet 100% of remaining peak summer demand
- Thermal Energy Storage (TES)
  - Sized to shift 100% of cooling from peak hours to off-peak
  - Sized for hottest 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





Accomplishments and Progress: Live Demo

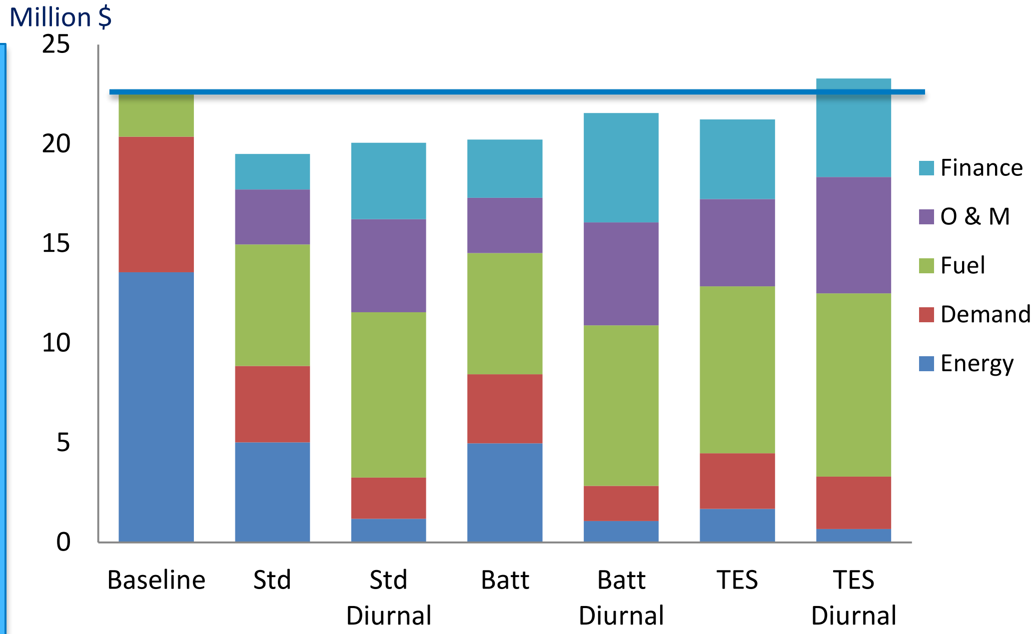
Model demo of scenario with 2010 Hospital in Los Angeles



Accomplishment: Example Results

Scenario: 2010 Los Angeles Hospital

- Systems
  - Baseline: Conventional technology, no fuel cell
  - Standard (Std): Fuel cell with no complementary technology
  - Thermal Energy Storage (TES): Fuel cell with cold water storage and chiller
  - Battery (Batt): Fuel cell with battery storage
- Dispatch
  - Baseload
  - Daily Peaking (Diurnal)
- Results
  - Economic
  - CO2, NOx, SO2 emissions



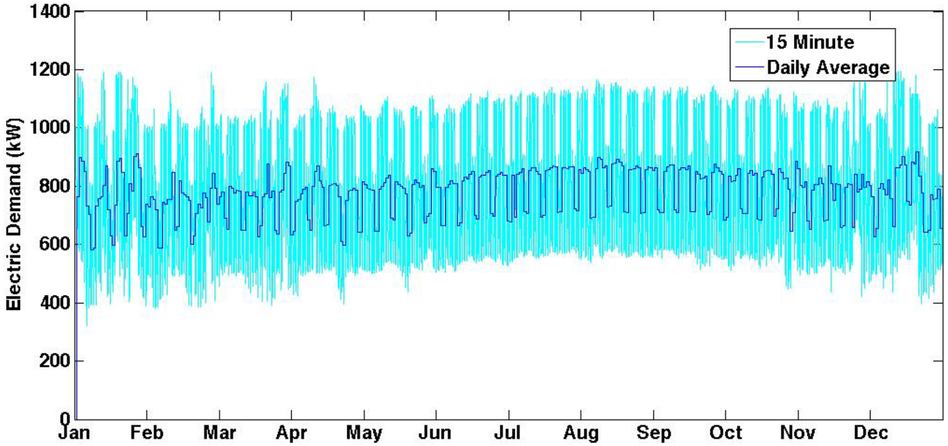
Financial Assumptions

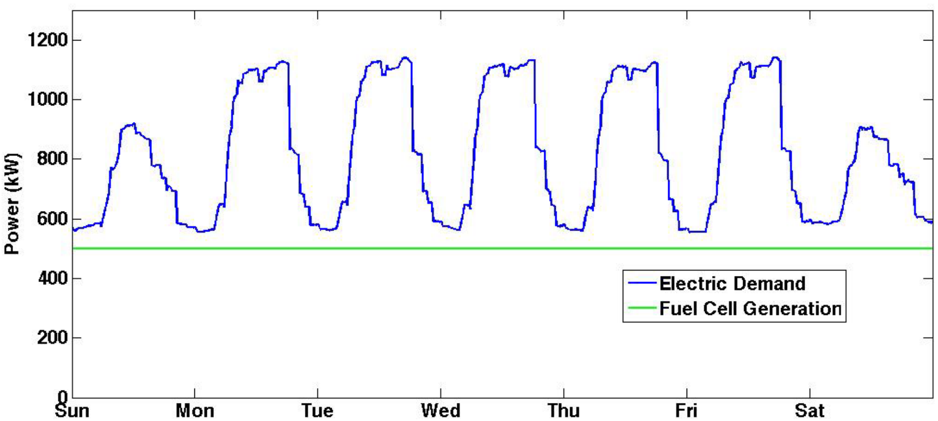
- **Fuel Cell: $3,000/kW**
  - 5 yr lifespan & $1,200/kW replacement
- **Electric Chiller: $350/ton**
- **TES (Cold Water Storage) : $80/ton**
- **Battery: $500/kWh**
- **15 yr financing period**

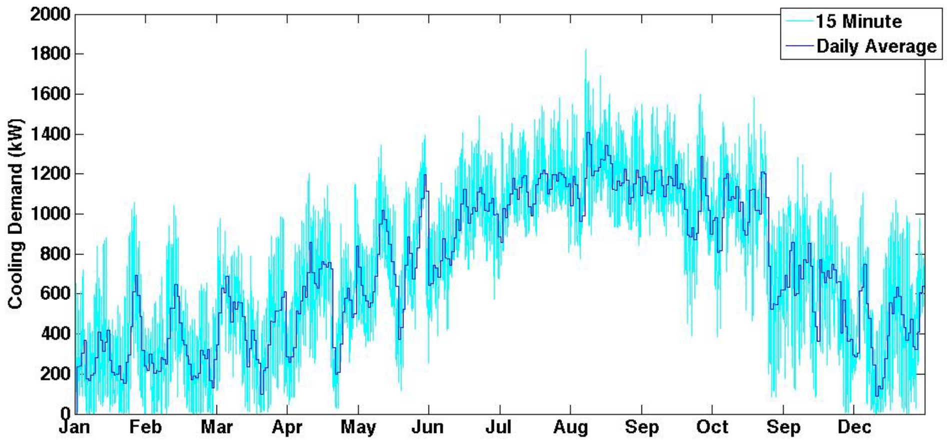
Accomplishments: Example Demand Profiles

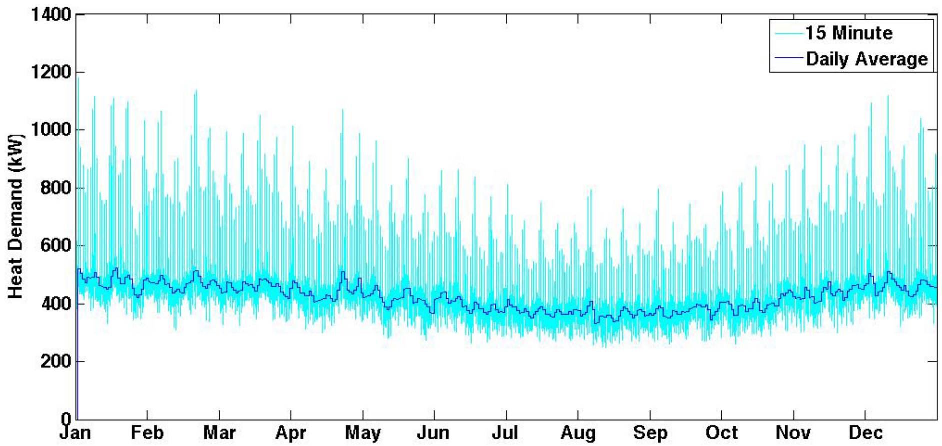
2010 Hospital in Los Angeles

- **Baseload fuel cell makes most sense economically due to relatively high, steady electric demand**

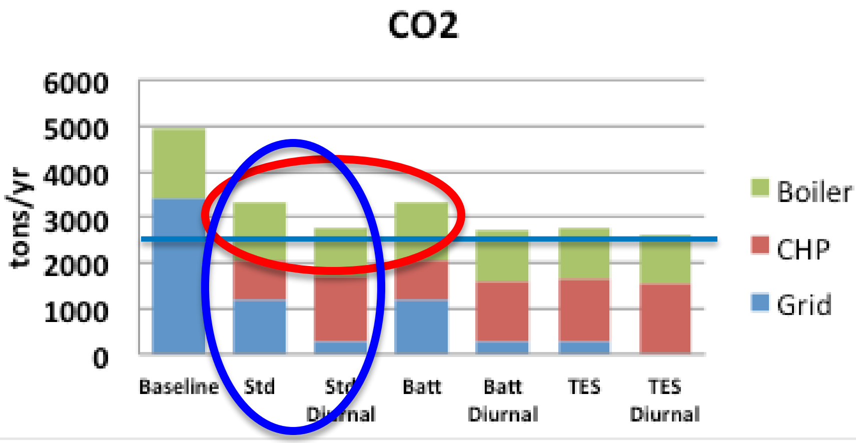








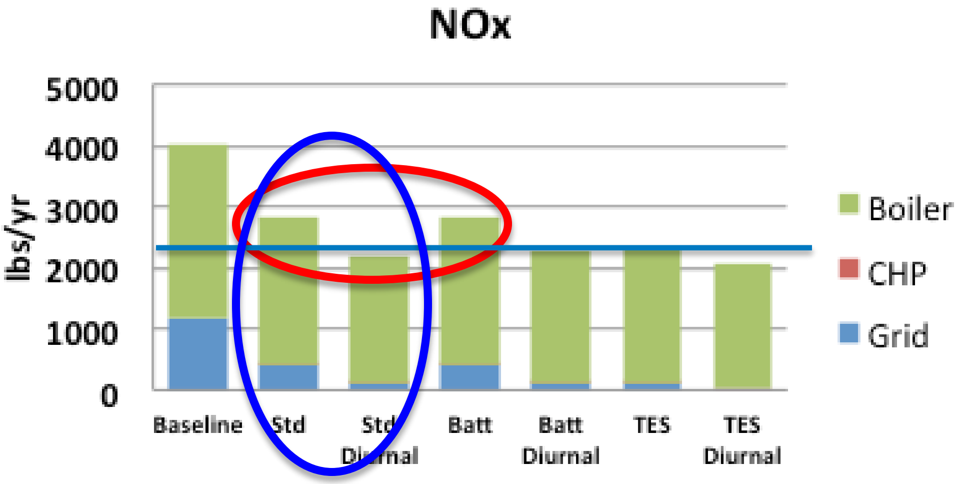
Accomplishments: Example Emissions Results

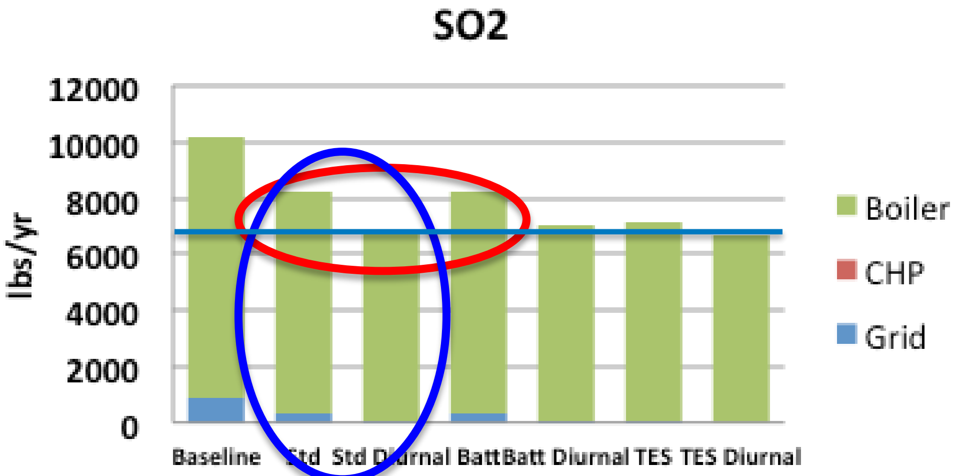


2010 Hospital in Los Angeles

- FC Baseload, FC Diurnal Peaking, and FC Baseload with Battery were least cost results ($19.5M, $20.1M,$20.2M respectively)
  - least cost results highlighted with red oval
- Least cost results ≠ least emissions
- There is a small cost premium going to diurnal operation, but an emissions reductions by operating a larger FC.
  - diurnal vs baseload emissions shown in blue oval

Going from FC baseload to diurnal operation
- Cost premium: $559k (NPV)
- Emissions Savings : 556 tons/yr (CO_2), 655 lbs/yr (No_x) , 1389 lbs/yr (SO_2)

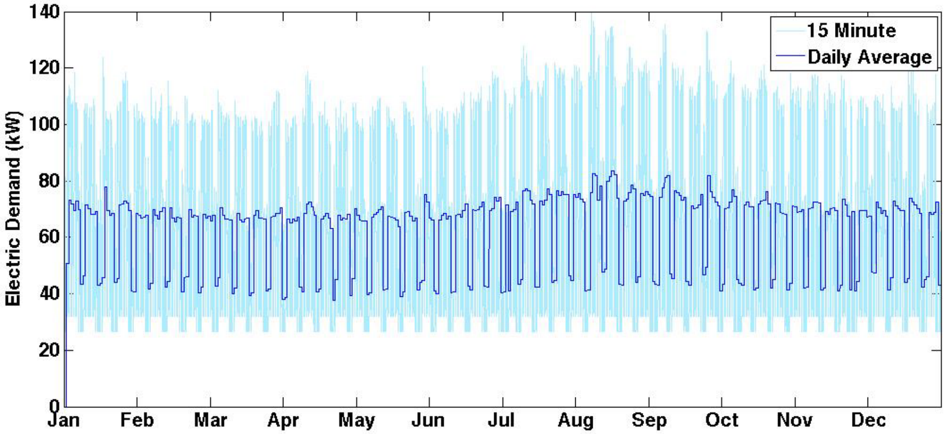


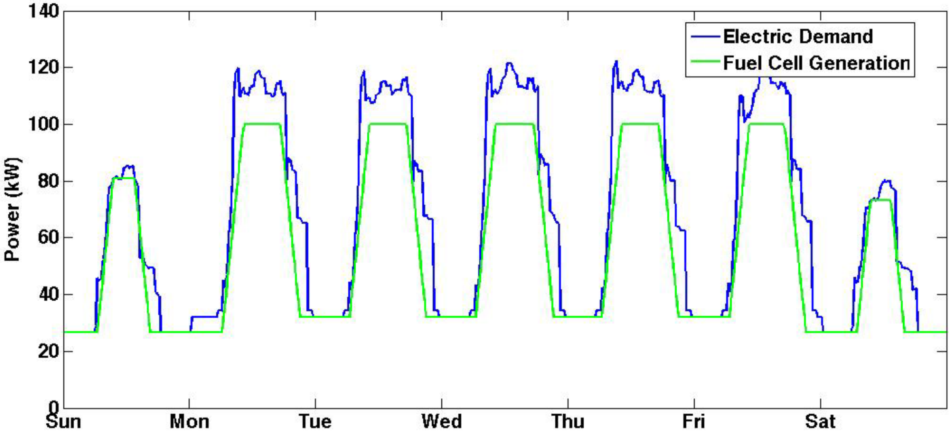


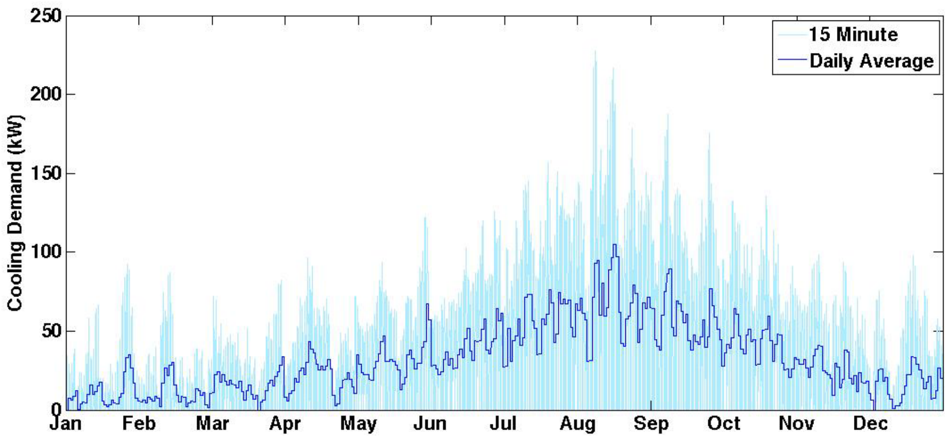
Accomplishments: Example Demand Profiles

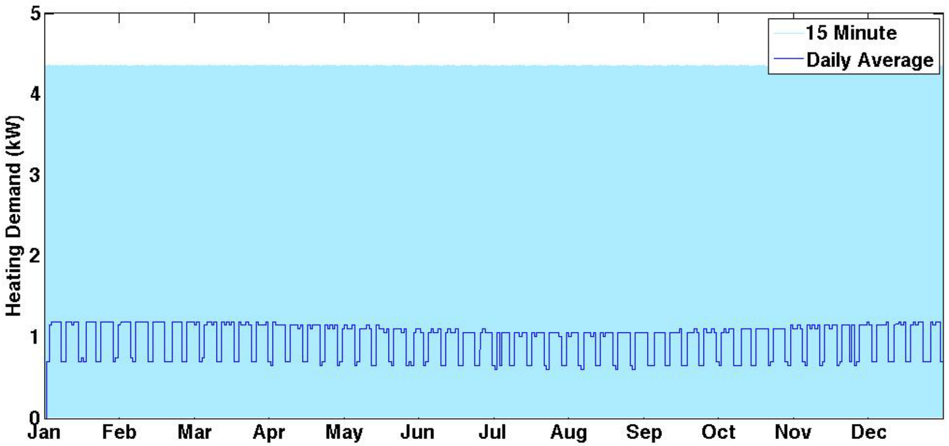
2010 Office in Los Angeles

- **Diurnal operation fuel cell makes most sense economically in this example**
  - NPV results: $1.6M (no FC), $1.5M (FC baseload), $1.4M (FC diurnal)
- **Different building profiles benefit from a range of control strategies.**









Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **"However, assuming a constant cost for fuel cell systems over a wide range of rating (100 kW-3 MW) may not be valid."**
  - Different costs can now be included and changed in the model.
- **"The model is not flexible enough to incorporate technical aspects of individual developers: some can load follow better than others, some cannot load follow, etc."**
  - The electrical efficiency at power level intervals, turndown ratio, response rate can all now be specified. The heat recovery also can be given at different operating temperatures and power levels. These factors allow most fuel cells to be simulated effectively.
- **"There is need for such an evaluation model for business users who are seeking to determine if stationary fuel cell power makes sense for their commercial buildings."**
  - DG-BEAT has been used as the back-end model in methodology and calculations for a separately funded web-portal project (FC TAC - Fuel Cell Tool for Assessing Costs). This group has provided valuable feedback as a user group.
  - DG-BEAT now includes a fleet analysis tool which individually evaluates all of the buildings in a managers portfolio for FC applications.

Collaborations

- **User's Group**
  - Acumentrics, Ballard Power Systems, CERL, CEA, ClearEdge Power, IDIQ, NetGain Energy Advisors, Ontario Fuel Cell Centre, PNNL, and Tetramer
- **Controls and integration**
  - UCI
- **Manufacturing cost analysis (separately funded projects)**
  - LBNL
  - Strategic Analysis, Inc.
  - Battelle
- **Building profiles and analysis**
  - NREL Electricity, Resources, and Building Systems Integration Center (ERBSIC)
- **Web Portal (separately funded project)**
  - IDIQ (FC TAC - Fuel Cell Tool for Assessing Costs)

Remaining Challenges and Barriers

- Quality control of the different modules is on-going, but many of the larger issues have been fixed.
- Engaging the user's group in a meaningful dialog in which feedback can be evaluated and implemented as needed or included in future work proposals.
- Development of validation procedures for assessing the fidelity of the model and data.

Proposed Future Work

FY14/FY15

- Assess requirements for an encompassing optimization strategy for sizing building components and implement dynamic control strategies.
  - Foundations in place for better assessing fuel cell system response lag in load following strategies.
- Implement a strategy for engaging the user’s group in a more organized manner which includes regular beta software releases and collection of feedback for model development both functionality and input data.
- Work towards a national survey of buildings to help target where fuel cells may make the most sense and impact.
- Continue to refine and gather input data.
- Investigate code requirements for including the OpenEI utility rate database
- Develop presentation materials from which introductions, exhibits, and model examinations can be easily assembled.
- Update documentation to include most recent additions, updates, and source material references.

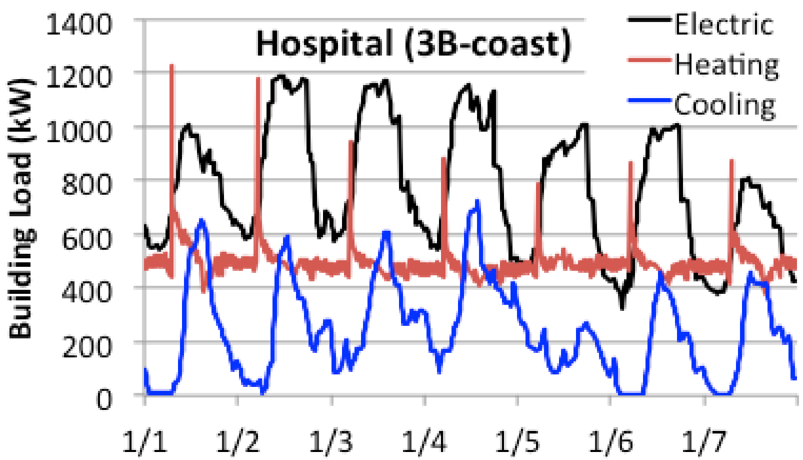
Summary

- GHG and criteria pollutants emissions reporting was implemented. This includes hourly emissions profiles and an emissions minimization control strategy.
- Non-predictive load following strategy was implemented. Foundations in place higher resolution demand profiles (<1 min) for better examination of system response lag.
- New building profiles for 16 building types in 16 climate regions and 3 building vintages have been implemented.
- Model refinement and bug fixes are on-going.
- A strong foundation has been built for implementing component sizing optimization strategies.

Technical Back-Up Slides

Accomplishments and Progress: Building Profiles

There is a challenge in finding good quality generic building load data in time steps needed for energy storage modeling.



NREL's Electricity, Resources, and Building Systems Integration Center has updated energy use profiles for 16 model building types in 16 climate zones, for three different vintages

- 768 new profiles in addition to 512 previous profiles for 1280 total
- Load profiles include electricity, heating, cooling (as thermal kW & electric kW), electric refrigeration, and exterior lighting
- 15 min time interval data for a entire year

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