

# Enlarging Potential National Penetration for Stationary Fuel Cells through System Design Optimization



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**National Renewable Energy Laboratory**

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**Project ID# FC083**

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# Overview

## Timeline

- Project start date: October 2011
- Project end date: October 2013\*

## Barriers Addressed

- Cost
- Durability
- Performance relative to incumbent

## Budget

- Total project funding
  - DOE share: \$650k
  - Contractor share: \$0k
- Funding received in FY12: \$300k
- Planned funding for FY13: \$50k

\*Project continuation is determined annually by DOE

\*\*Funded under a separate project

## Partners

- University of California, Irvine (UCI)
- Lawrence Berkeley National Lab (LBNL)\*\*
- Strategic Analysis, Inc.\*\*
- Battelle\*\*
- Acumentrics, Ballard Power Systems, ClearEdge Power, and PNNL (User's group)

# Relevance: Objectives

## Technical Challenges

- Cost
- Durability
- Performance relative to incumbent

### DOE 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

### Project Goal

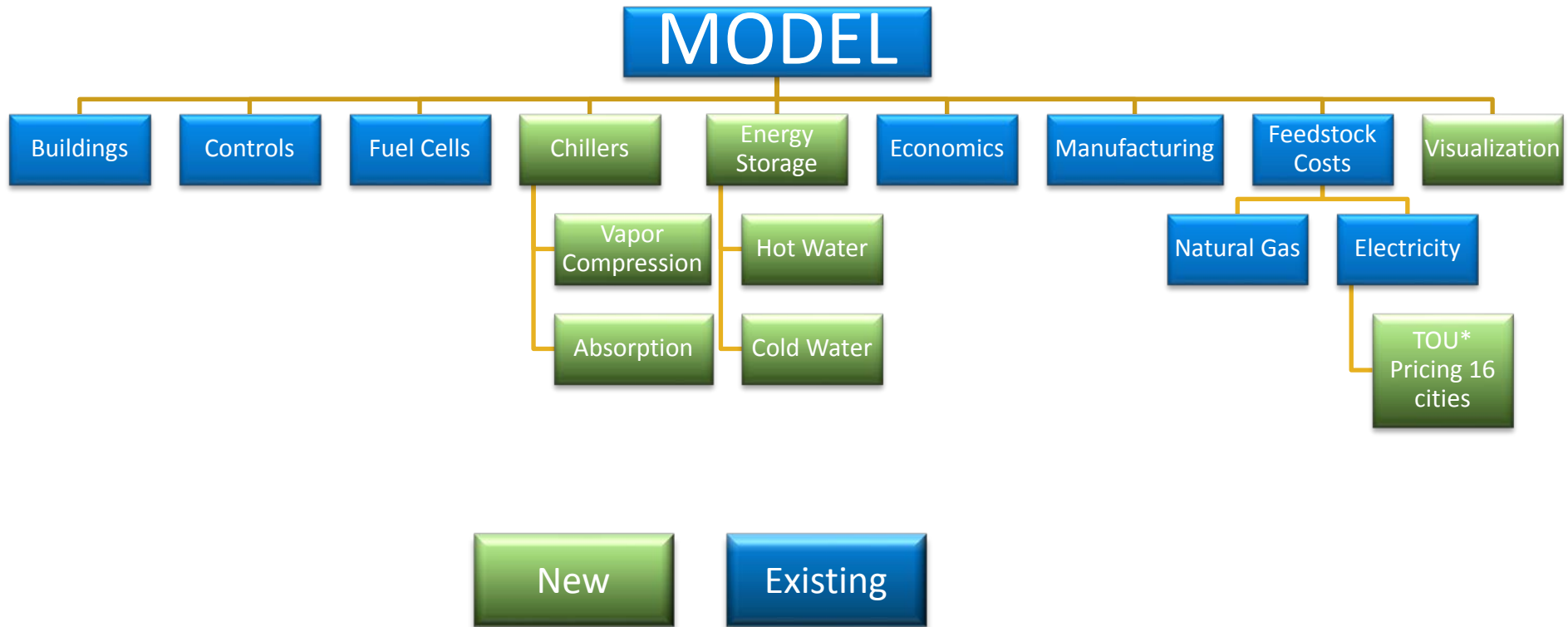
Build an open-source tool that helps CHP fuel cell developers, end users, and other stakeholders to do the following for their systems, helping to drive economies of scale and cost reduction:

- 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

# Approach: Milestones

02/13 (complete)	Implement updated strategies for cost-minimize, load follow, peak shave, and GHG-minimize dispatch and control into the Commercial Building Fuel Cell Model. UCI subcontract task 2.
4/13	Model verification against actual building/CHP installations
6/13	Scenario analysis
7/13	Demonstrate the fuel cell model to the fuel cell team. This demonstration will serve as the basis for a Go/No-Go decision on further work for the project.

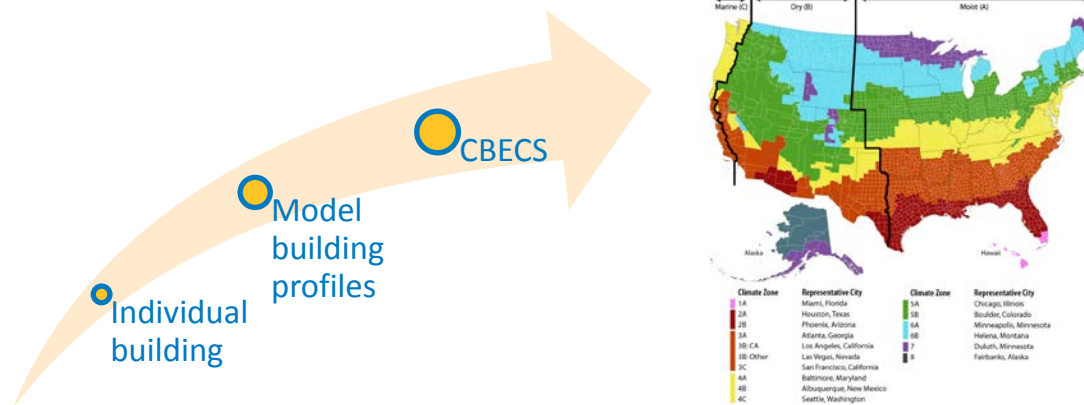
# Approach: Construction of the Model



\*Time-Of-Use

# Accomplishment: Input to CBECS

- Successfully lobbied for inclusion of relevant questions on building automation, controls, and onsite generation on the 2012 Commercial Building Energy Consumption Survey (CBECS), which is conducted usually every 3-5 years, but has not been updated in its entirety since 2003.
- CBECS 2012 will represent the energy usage data for >12,000 (2.3x the number in the 2003 survey) commercial buildings, with statistical extrapolations for the whole country.
- By integrating model building results with CBECS, national impact and potential market penetration can be estimated.



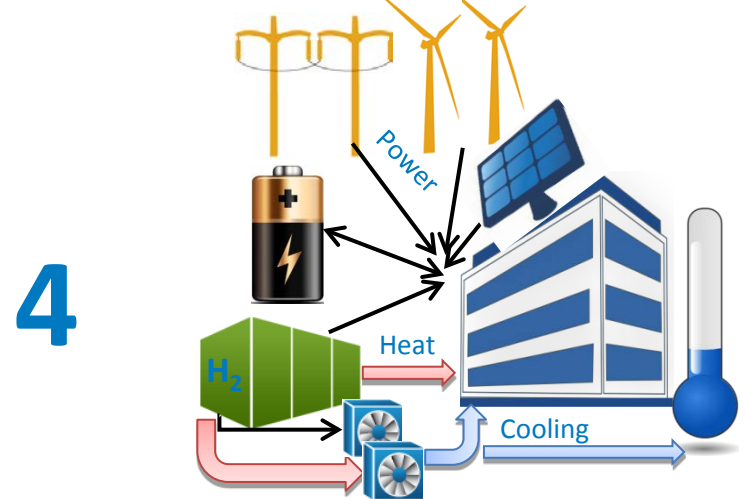
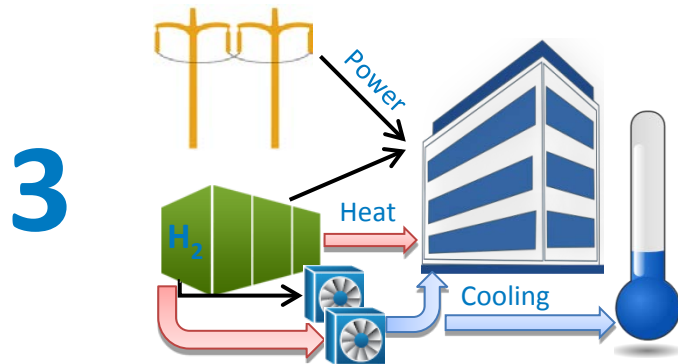
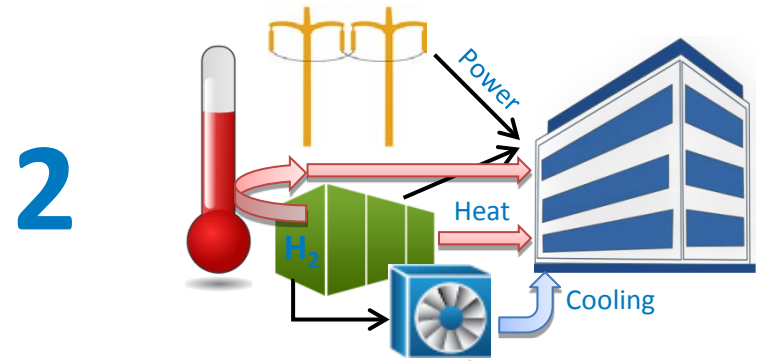
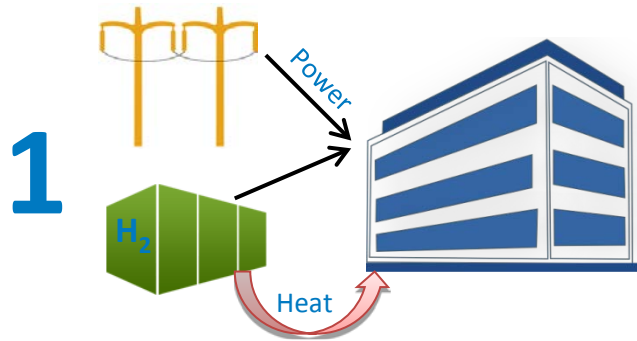
# Accomplishment: Building Modules

- 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
- Building modules were updated to 15-min time step, and building coil loads were added. This enabled modeling of energy storage systems.
- Represents about 67% of U.S. commercial inventory

• **Total:**  
**768 profiles**

Building types	Locations	Vintages
Restaurant: full-service (sit down) Restaurant: quick-service School: primary school School: secondary school Office: large office Office: medium office Office: small office Hospitality: large hotel Hospitality: small hotel/motel Health care: large hospital Health care: outpatient facility Retail: big-box, standalone retail Retail: retail strip mall Retail: supermarket Mid-rise apartment building Unrefrigerated warehouse	Miami (ASHRAE 1A) Houston (ASHRAE 2A) Phoenix (ASHRAE 2B) Atlanta (ASHRAE 3A) Los Angeles (3B-Coast) Las Vegas (3B-Inland) San Francisco (ASHRAE 3C) Baltimore (ASHRAE 4A) Albuquerque (ASHRAE 4B) Seattle (ASHRAE 4C) Chicago (ASHRAE 5A) Boulder (ASHRAE 5B) Minneapolis (ASHRAE 6A) Helena, MT (ASHRAE 6B) Duluth, MN (ASHRAE 7) Fairbanks, AK (ASHRAE 8)	<ul style="list-style-type: none"> <li>•New construction (compliant with ASHRAE 90.1-2004)</li> <li>•“Post-1980” construction (80s/90s, compliant with ASHRAE 90.1-1989)</li> <li>•“Pre-1980” construction</li> </ul>

# Accomplishment: New Control/Dispatch Cases



System	FC	Heat Recovery	Electric Chiller	Absorptive Chiller	Cold H <sub>2</sub> O Storage	Hot H <sub>2</sub> O Storage	Battery Storage	Renewable Generation
1	✓	✓						
2	✓	✓	✓			✓		
3	✓	✓	✓	✓	✓			
4	✓	✓	✓	✓	✓		✓	✓

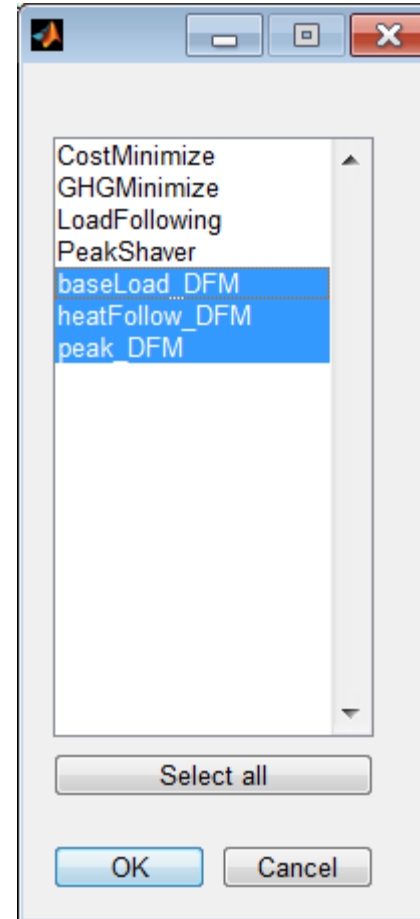
New Elements to Model



# Accomplishment: New Control/Dispatch Cases

UCI added the following control strategies:

- Baseload
- Heat follow
- Peak, which follows the anticipated daily load in order to minimize system power cycling to help reduce related degradation



# Accomplishment: Building Chiller Integration

New integration with building energy systems

- Electric or absorption chillers

The screenshot displays the ChillerSetup software interface. The 'Chiller Inputs' section includes fields for Name (ElectricChiller), Type (Chiller), Version (componentVersion), and Description (Generic electric chiller). The Chiller Type is set to Electric Chiller. Input fields for SIZE (kW) are 93.2701, 26.5209, 6, and 100, with corresponding labels: SIZE (kW), SIZE, Nominal, and % Max Cool Demand. A table shows Cooling Output % Nominal values from 0 to 0.8000. A schematic diagram of a chiller cycle is shown, and a graph titled 'Chiller Efficiency' plots Chiller Coefficient of Performance (COP) against Power [%], showing a linear increase from approximately 3.0 at 0% power to 6.0 at 100% power.

	Cooling Output % Nominal
1	0
2	0.1000
3	0.2000
4	0.3000
5	0.4000
6	0.5000
7	0.6000
8	0.7000
9	0.8000

Power [%]	Chiller Coefficient of Performance
0	3.0
0.1	3.3
0.2	3.6
0.3	3.9
0.4	4.2
0.5	4.5
0.6	4.8
0.7	5.1
0.8	5.4
0.9	5.7
1.0	6.0



# Accomplishment: Optimization of Systems

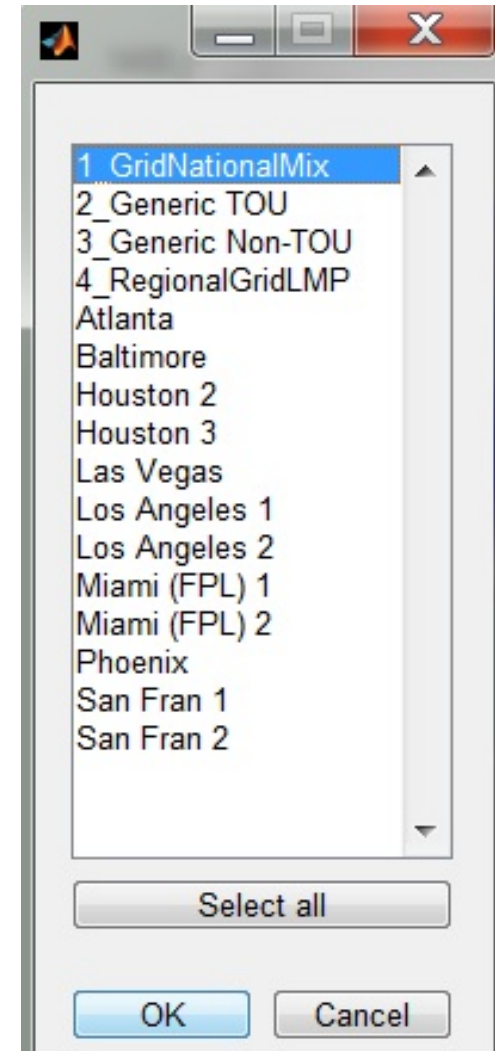
Ability to analyze all climate zones, building types, and vintages, with either fixed CHP system size or optimal size (lowest energy cost)

The screenshot shows the 'MultiBuildingAnalysis' software window. It features three main sections: 'System Sizing', 'Vintage', and a grid of building and climate zone options. The 'System Sizing' section has two radio buttons: 'Fixed Size' (selected) and '% Optimal Size'. The 'Vintage' section has three checked checkboxes: 'Pre - 1980', 'Post- 1980', and 'New - 2004'. The 'Building' section contains 12 checked checkboxes for various building types. The 'Climate Zone/' section contains 12 checked checkboxes for various climate zones. At the bottom, there are two buttons: a red 'Cancel' button and a green 'Run Analysis' button.

System Sizing	Building	Climate Zone/	
<input checked="" type="radio"/> Fixed Size	<input checked="" type="checkbox"/> Restaurant-Full ser...	<input checked="" type="checkbox"/> Miami	
<input type="radio"/> % Optimal Size	<input checked="" type="checkbox"/> Restaurant-Fast F...	<input checked="" type="checkbox"/> Houston	
	<input checked="" type="checkbox"/> School- Prim...	<input checked="" type="checkbox"/> Phoenix	
	<input checked="" type="checkbox"/> School Secon...	<input checked="" type="checkbox"/> Atlanta	
<b>Vintage</b>	<input checked="" type="checkbox"/> Office - large	<input checked="" type="checkbox"/> Los Ang...	
<input checked="" type="checkbox"/> Pre - 1980	<input checked="" type="checkbox"/> Office - medi...	<input checked="" type="checkbox"/> Las Vegas	
<input checked="" type="checkbox"/> Post- 1980	<input checked="" type="checkbox"/> Office - s...	<input checked="" type="checkbox"/> San Franci...	
<input checked="" type="checkbox"/> New - 2004	<input checked="" type="checkbox"/> Mid-rise Apartm...	<input checked="" type="checkbox"/> Warehouse...	<input checked="" type="checkbox"/> Baltimore
	<input checked="" type="checkbox"/> Hotel - la...	<input checked="" type="checkbox"/> Albuquerque...	
	<input checked="" type="checkbox"/> Hotel - s...	<input checked="" type="checkbox"/> Seattle	
	<input checked="" type="checkbox"/> Hospital	<input checked="" type="checkbox"/> Chicago	
	<input checked="" type="checkbox"/> Clinic	<input checked="" type="checkbox"/> Boulder	
	<input checked="" type="checkbox"/> Big Box R...	<input checked="" type="checkbox"/> Minneap...	
	<input checked="" type="checkbox"/> Small Re...	<input checked="" type="checkbox"/> Helena MT	
	<input checked="" type="checkbox"/> Superma...	<input checked="" type="checkbox"/> Duluth MN	
	<input checked="" type="checkbox"/> Warehouse...	<input checked="" type="checkbox"/> Fairbank...	

# Accomplishment: Utility Pricing

- **National average**
- **Generic TOU or non-TOU**
- **16 cities/climates**
  - Some with multiple rates for small/large users
- **EIA NG forecasts or \$0.88/therm**



# Accomplishment: Web-Based Visualization

Web-based visualization of an analysis case with a fuel cell system, chiller (vapor compression), and thermal energy (cold water) storage

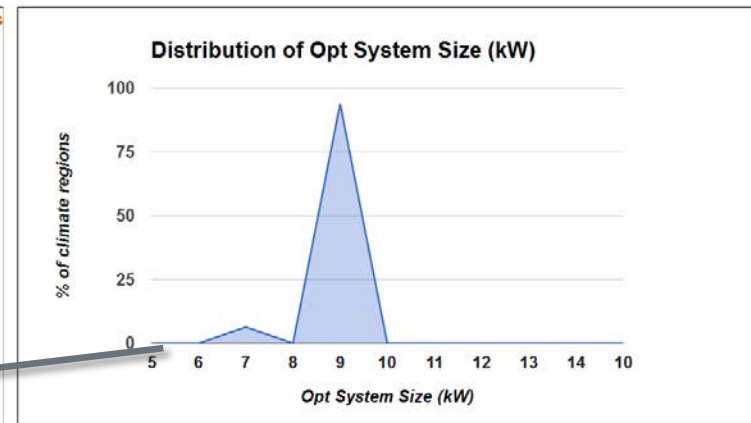
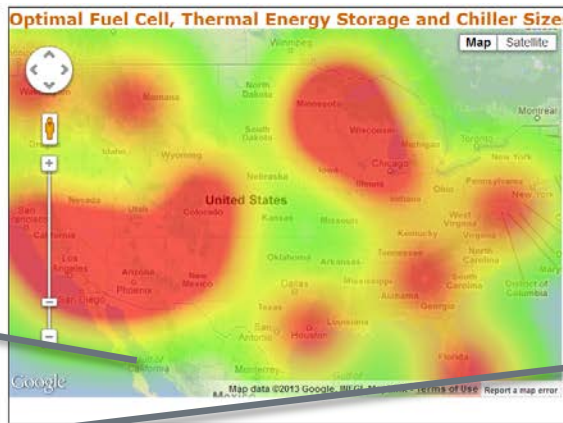
- Can show which applications/markets make sense for fuel cells
- Allows simple non-expert exploration of the analysis

Building type and output variable selection

**Available Data**  
Opt System Size ▾  
**Building Types**  
FFRest\_New2004.csv ▾

**Statistics**  
**Mean: 9.3**  
**Median: 9.5**  
**Max: 10.0**  
**Min: 5.0**

Broad output statistics



Heat map showing intensity of the selected variable

Histogram of the output data

# Accomplishment: Open Source Collaboration

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

The screenshot displays the GitHub interface for the repository 'NREL/FCModel'. The user 'Chris Ainscough' is currently viewing a commit with the message 'New building profiles'. The commit details include a description: 'These profiles contain cooling demand in addition to the electricity needed to meet that demand. They also run at 15 minute time steps, rather than 1 hour, as the old ones did.' Below this, a list of files is shown, including various '.mat' files in the 'component library\Building\FFRest' directory.

On the right side, the 'unsynced commits' section shows the current commit: '0aa7139: New building profiles' from 'Today'. The 'history' section lists previous commits, including updates by 'Dustin McLarty' and 'Chris Ainscough'.

Commit Hash	Author	Message	Date
0aa7139	Chris Ainscough	New building profiles	Today
...	Dustin McLarty	General Updates to Multi-Building	Feb 25
...	Chris Ainscough	Merge branch 'master' of https://github.com...	Feb 25
...	Chris Ainscough	Updated UI on web viewer	Feb 25
...	Dustin McLarty	Updated Visuals	Feb 25
...	Chris Ainscough	Added web-base visualization	Feb 21
...	Chris Ainscough	Merge branch 'master' of https://github.com...	Feb 21
...	Chris Ainscough	Multiple updates	Feb 21
...	Dustin McLarty	Added regional grid rates & visualization of...	Feb 20
...	Dustin McLarty	Adding Electric Grid Profiles & De-bugging	Feb 20
...	Dustin McLarty	Changes to GridAnalyzer & debug of MultiBu...	Feb 19
...	Dustin McLarty	Fixed bug in optimal Chiller & TES size	Feb 13
...	Dustin McLarty	Still a bug with Chiller & TES size	Feb 13

# Collaborations: User's Group

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- **Formed a User's Group to guide further development of the model**
  - Currently includes Acumentrics, Ballard Power Systems, ClearEdge Power, and PNNL
  - Members have access to the model and building profiles for their own use, and will be able to contribute code and other modules to the effort
  - All industry stakeholders are invited to participate



# Collaborations: Development

- **Controls and integration work**
  - 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)

# Proposed Future Work

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- **FY13/14**
  - Go/No-Go
  - Use the tool to evaluate/optimize CHP systems relative to output data from the output of the 2012 CBECS survey
  - Work with fuel cell OEMs on improvements and customizations to the tool
  - Validate model against real-world data

# Summary

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**RELEVANCE** This project addresses barriers of cost, durability, and performance relative to incumbent technologies.

**APPROACH** The approach includes an open source tool that fuel cell OEMs are invited to contribute to and use for their own purposes.

**ACCOMPLISHMENTS** We have expanded analysis capabilities and integration with commercial building control systems, developed visualizations, and made the code open source.

**COLLABORATION** Strong collaboration is occurring with industry, academia, and national labs. Open source code allows for contributions from other collaborators.

**FUTURE WORK** Future work is subject to a go/no-go decision.