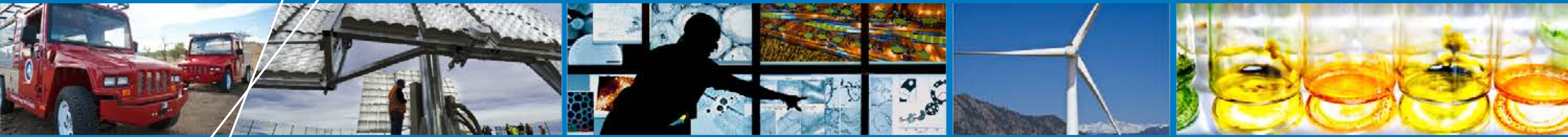
Enlarging Potential National Penetration for Stationary Fuel Cells through System Design Optimization



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National Renewable Energy Laboratory

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Project ID# FC083

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

Timeline

- Project start date: October 2011
- Project end date: October 2012*

Barriers Addressed

- Cost
- Building Integration
- Manufacturing economies of scale

Budget

- Total project funding
  - DOE share: $600k
  - Contractor share: $0k
- Funding received in FY11: $300k
- Planned funding for FY12: $300k

Partners

- University of California, Irvine (UCI)
- Lawrence Berkeley National Lab (LBNL)**
- Stationary Fuel Cell OEMs

*Project continuation is determined annually by DOE.

**Funded under a separate project.

Relevance: Objectives

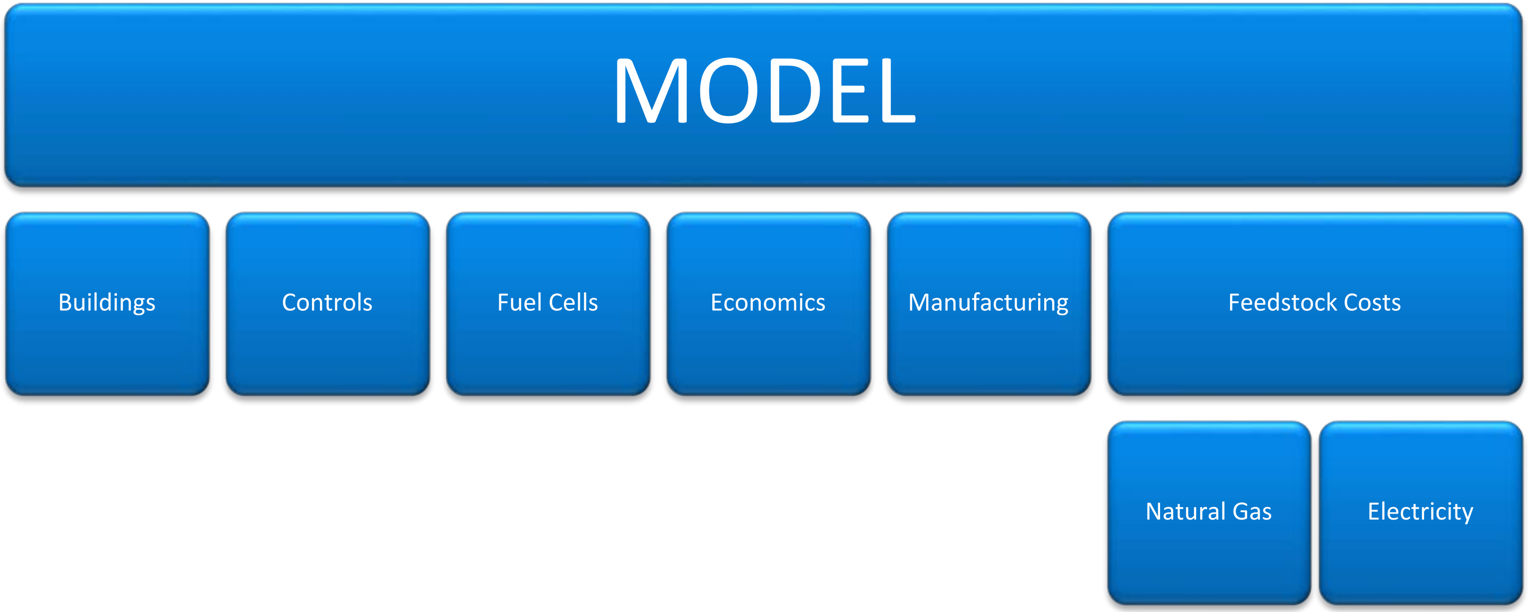
- Build a tool for optimizing fuel cell attributes, including control parameters, and system and component sizes for unique individual building characteristics. Tool will add flexibility for adding user-defined building, fuel cell, financial, control characteristics.
- Tool will be used to minimize lifecycle cost, lifetime GHG emissions, or installed capital costs of fuel cell installations.
- Characterize the largest segments of the U.S. building inventory for use in the tool, leveraging the CBECs building survey.
- Characterize building control systems and include in the tool, advanced control strategies for integrating fuel cell system and building control systems.
- Validate the model outputs against real-world data from stationary fuel cell installations.
- Exercise tool to determine the set of most-favorable system sizes and types to achieve national greenhouse gas (GHG) emissions and energy demand reductions.

Activity To Date

- **FY11**
  - Set goals for the project.
  - Developed a strategy to meet the objectives.
    - Develop an easy-to-use modular software tool that allows great flexibility and scalability for performing analysis.
  - Developed capabilities list for the model.
  - Developed GUI storyboard.
  - Developed GUI.
  - Developed Modules
    - Fuel Cell
    - Buildings
    - Controls
    - Economics & Costs
    - Feedstocks

Approach: Build a Tool to Enable Modeling

- **Build a flexible, modular software framework which allows the addition of a wide variety of modules.**
- **This allows scalability and flexibility when tackling the extremely diverse population of commercial buildings in the US.**



Approach: Buildings Module

- NREL is a nationally recognized leader in buildings research combining renewable energy with innovative technologies & strategies to significantly reduce energy consumption in buildings.
- The NREL Hydrogen Technology Systems Center is working closely with the NREL Electricity, Resources, and Building Systems Integration Center (ERBSIC) to enhance the depth and robustness of the model.

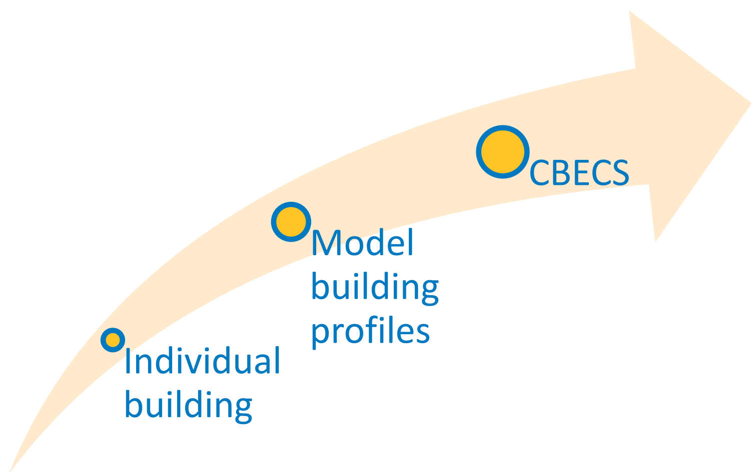
Approach: Buildings Module

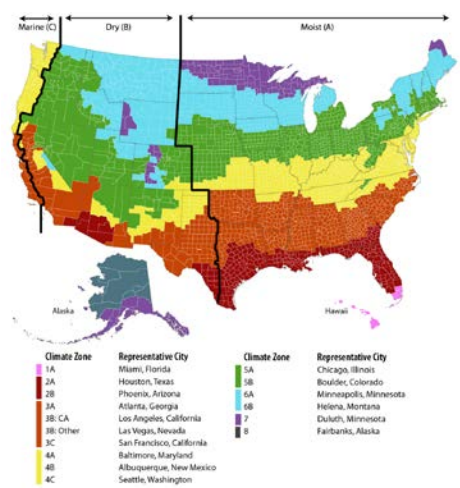
- **ERBSIC has developed hourly energy use profiles for 16 model building types in 16 climate zones, for three different vintages.**
- **Total: 768 building profiles.**
- **Represents about 67% of U.S. commercial inventory.**

Building types	Locations	Vintages
Restaurant: full-service (sit down) Restaurant: quick-service (fast food) 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 store 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 (ASHRAE 3B-Coast) Las Vegas (ASHRAE 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)	•New construction (compliant with ASHRAE 90.1-2004) •"Post-1980" construction (80s/90s, compliant with ASHRAE 90.1-1989) •"Pre-1980" construction

Approach: U.S. Inventory CBECS

- The Commercial Building Energy Consumption Survey (CBECS 2003) represents the energy usage data for ~5,200 U.S. commercial buildings, with statistical extrapolations for the whole country.
- Take advantage of once-in-a decade opportunity to actively participate in a CBECS survey.
- By integrating model building results with CBECS, national impact can be estimated.





Approach: Control Strategies Module

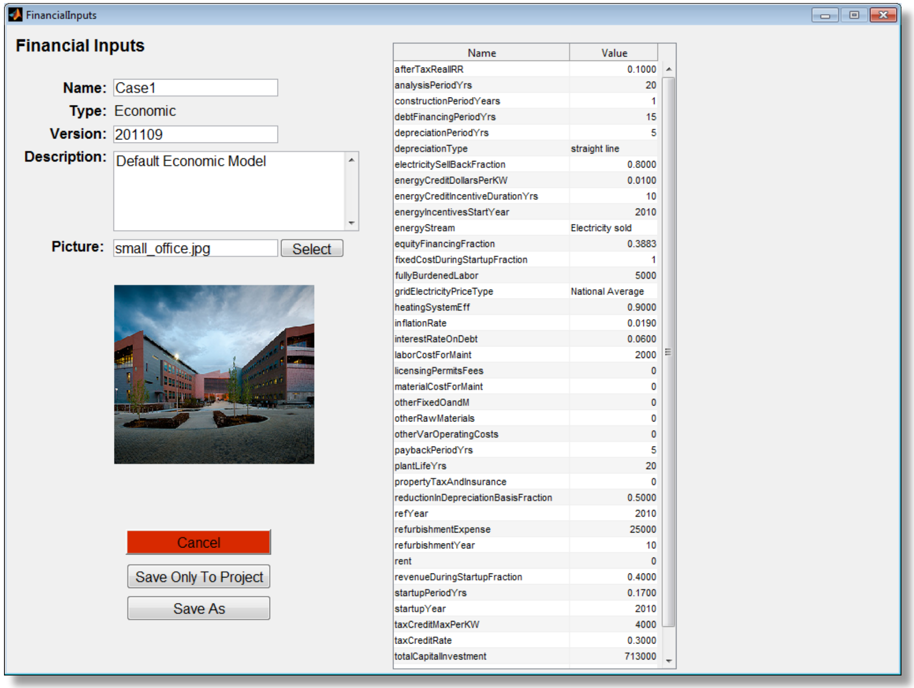
- Fuel cell characteristics such as min/max power, CHP temperature, and ramp rate determine the power and heat available for the next hour.
- Determine the marginal cost of electricity and value of CHP heat offset from grid and fuel pricing.
- Dispatch fuel cell to achieve the desired dispatch goal.
- Partner UCI will help develop/refine/validate dispatch strategies.

Approach: Manufacturing Costs Module

- Synchronizing activity with DFMA® cost modeling performed by LBNL.
- Reviewing results from and working with Strategic Analysis (SA) (formerly DTI) and Battelle.
- Mapping cost vs. manufacturing volume vs. power.
- Initial targets: PEM, high temperature PEM (PBI), and SOFC in the 1–250-kW range.

Approach: Economic Module

- **Model leverages the Fuel Cell Power Model and H2A method financial calculations.**
- **This makes it easy to compare analyses and results across different tools such as H2A and the POWER model.**



Approach: Grid Pricing Module

- **Grid pricing specified as winter/summer peak, partial peak, and off-peak**

ModifyElectricGridRate

Grid Inputs

Name: National Mix
Type: Grid
Version: version1
Description: Electric Grid Rates
National Mix 2009
Picture: UtilitiesGrid.jpg [Select]

Demand Charges

Usage	dollars/kW
Summer Peak	12.4000
Summer Partial Peak	2.4800
Summer Monthly Max	6.2000
Winter Peak	0
Winter Partial Peak	0.6200
Winter Monthly Max	6.2000

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Winter

1. Off-Peak 0.072
2. Partial Peak 0.08
3. Peak 0.088

Hour of Day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sunday	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Monday	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
Tuesday	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
Wednesday	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
Thursday	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
Friday	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1
Saturday	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Summer

From month 5 / day 1 To month 8 / day 31

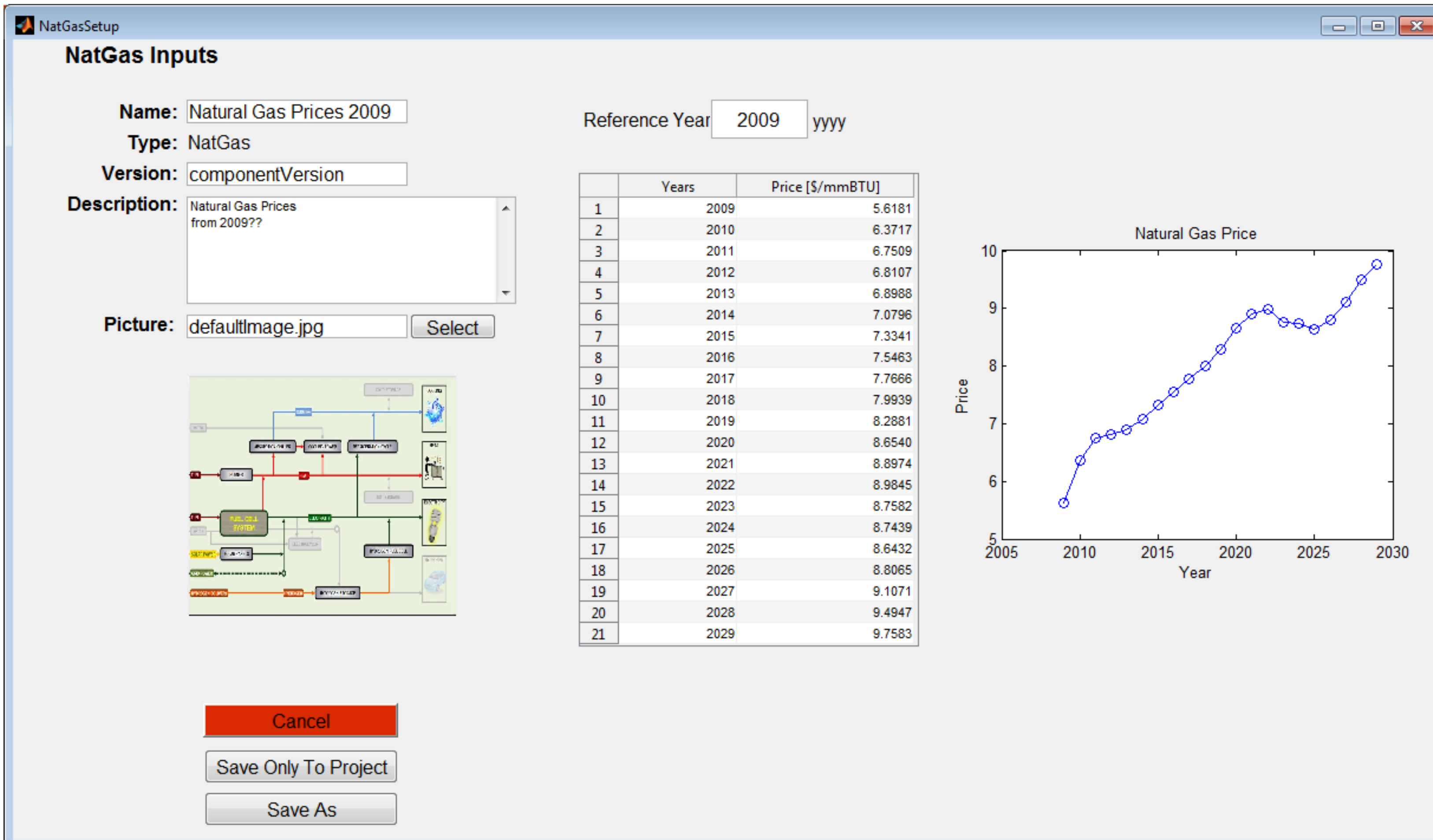
1. Off-Peak 0.08
2. Partial Peak 0.088
3. Peak 0.1

Hour of Day

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sunday	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Monday	1	1	1	1	1	1	1	1	2	2	3	2	3	3	3	3	3	3	2	2	1	1	1	1
Tuesday	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3	2	2	1	1	1	1
Wednesday	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3	2	2	1	1	1	1
Thursday	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3	2	2	1	1	1	1
Friday	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3	2	2	1	1	1	1
Saturday	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Approach: Natural Gas Pricing Module

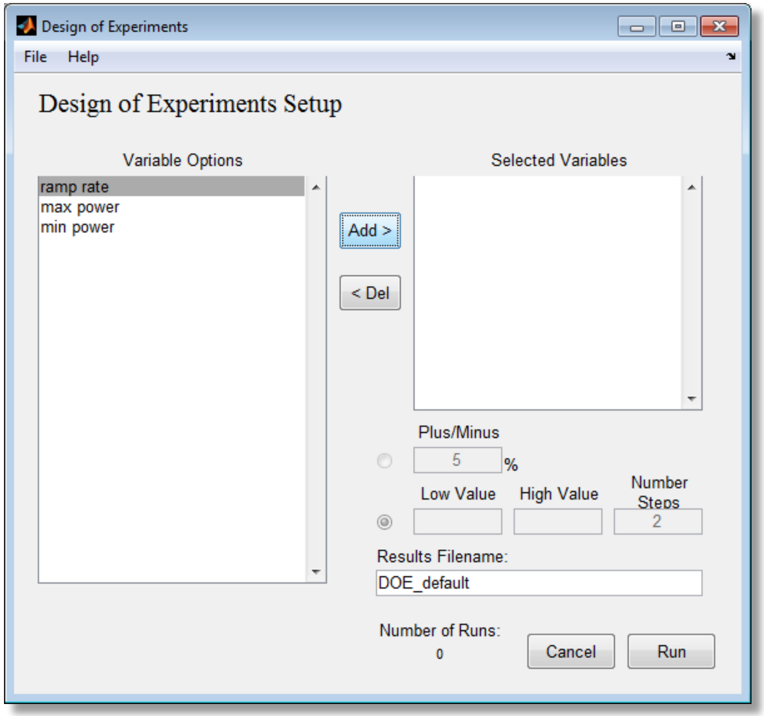
- **Gas pricing based on Energy Information Administration forecasts**



	Years	Price [$/mmBTU]
1	2009	5.6181
2	2010	6.3717
3	2011	6.7509
4	2012	6.8107
5	2013	6.8988
6	2014	7.0796
7	2015	7.3341
8	2016	7.5463
9	2017	7.7666
10	2018	7.9939
11	2019	8.2881
12	2020	8.6540
13	2021	8.8974
14	2022	8.9845
15	2023	8.7582
16	2024	8.7439
17	2025	8.6432
18	2026	8.8065
19	2027	9.1071
20	2028	9.4947
21	2029	9.7583

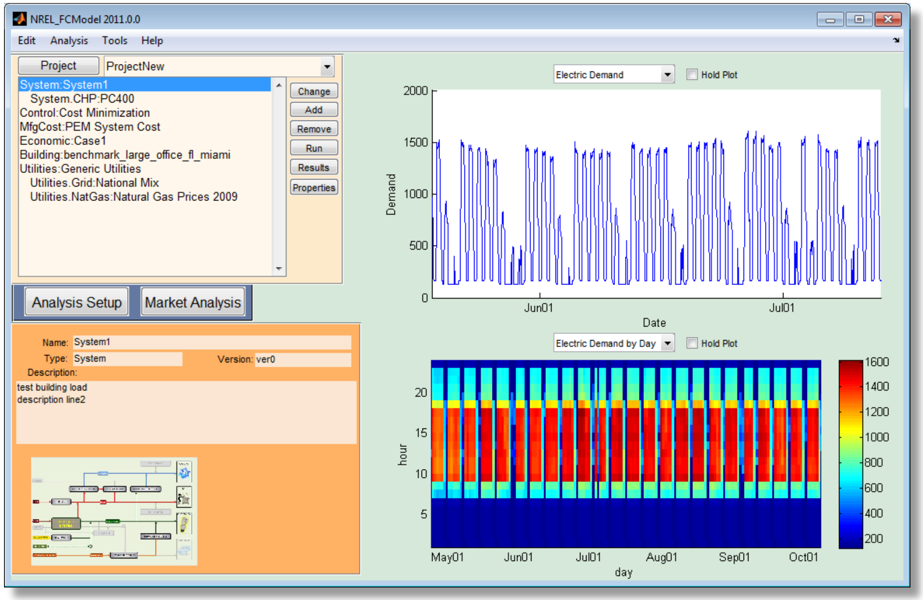
Approach: Optimization & DoE

- **Once the model can process one scenario, give it the ability to run multiple scenarios based on variations in the inputs, like a designed experiment.**
- **Add the ability to optimize a single parameter within a constrained solution space.**



Accomplishments: The Model

- Developed tool with a graphical interface capable of analyzing many different scenarios.
- It is important to build sufficient analysis depth for a single case before replicating to multivariate optimizations
- Incorporated 384 model buildings (50% completion)

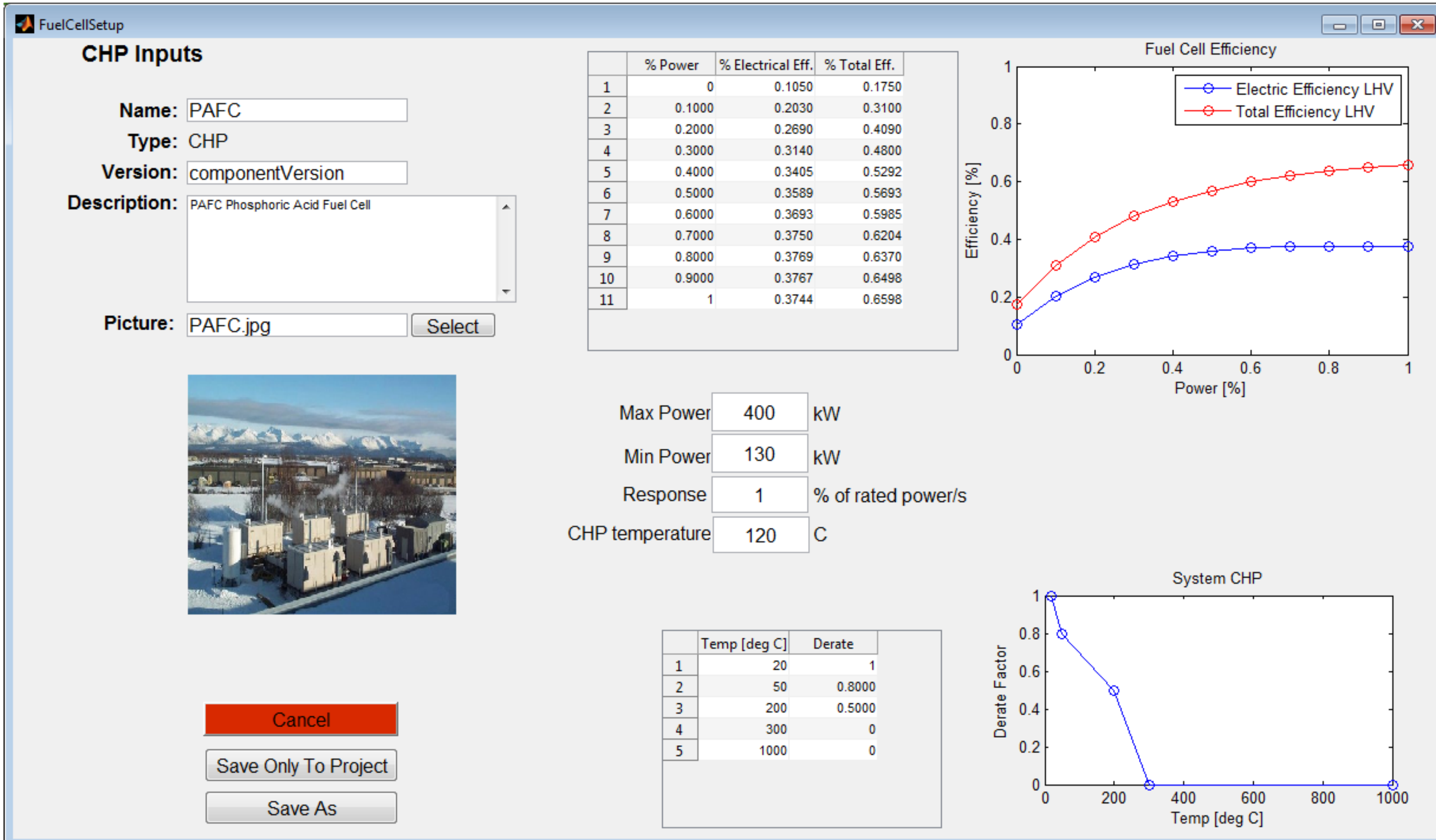


Accomplishments: Fuel Cell System Modules

- **Currently have models for**
  - PAFC – 400 kW
  - MCFC – 300 kW
  - Natural Gas Genset (as a control)
- **Developing models for**
  - PEM – 1, 5, 25, 100 kW
  - SOFC

Accomplishments: Fuel Cell System Modules

- **Users can input custom fuel cell characteristics to generate a new module.**

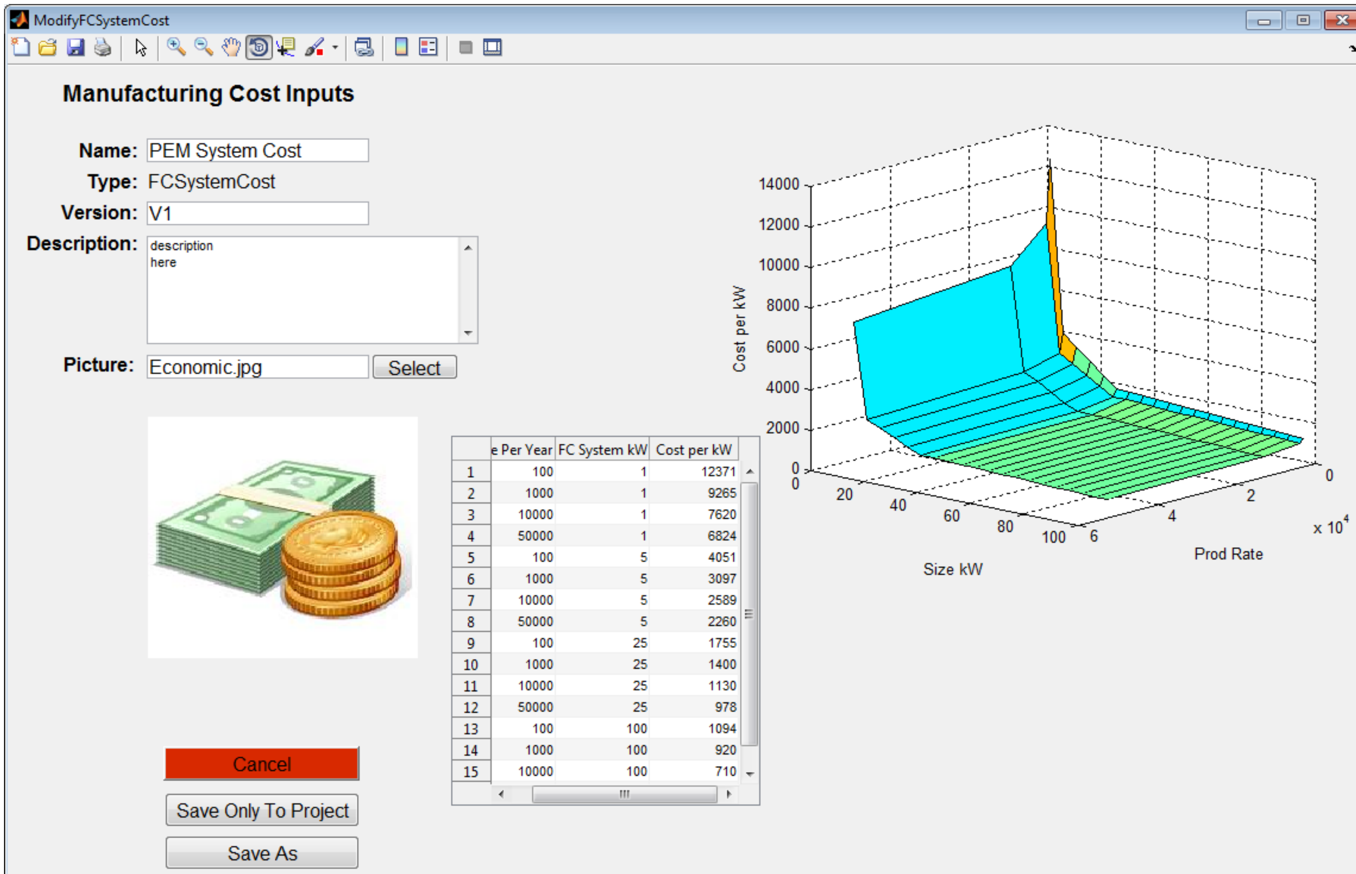


	% Power	% Electrical Eff.	% Total Eff.
1	0	0.1050	0.1750
2	0.1000	0.2030	0.3100
3	0.2000	0.2690	0.4090
4	0.3000	0.3140	0.4800
5	0.4000	0.3405	0.5292
6	0.5000	0.3589	0.5693
7	0.6000	0.3693	0.5985
8	0.7000	0.3750	0.6204
9	0.8000	0.3769	0.6370
10	0.9000	0.3767	0.6498
11	1	0.3744	0.6598

	Temp [deg C]	Derate
1	20	1
2	50	0.8000
3	200	0.5000
4	300	0
5	1000	0

Accomplishments: Manufacturing Cost

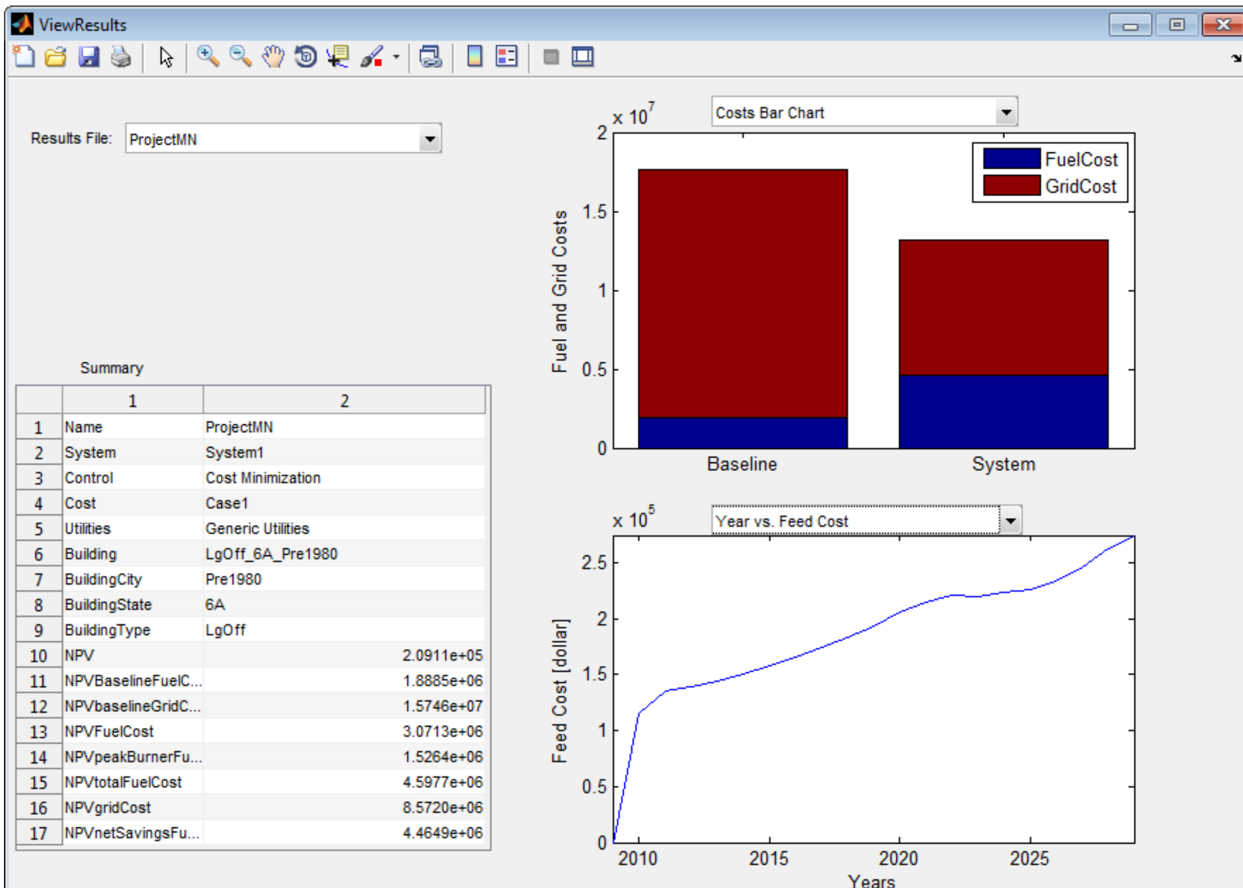
- **Model is built to receive cost surfaces (cost vs. power and production volume) developed by LBNL, Battelle and SA.**



	e Per Year	FC System kW	Cost per kW
1	100	1	12371
2	1000	1	9265
3	10000	1	7620
4	50000	1	6824
5	100	5	4051
6	1000	5	3097
7	10000	5	2589
8	50000	5	2260
9	100	25	1755
10	1000	25	1400
11	10000	25	1130
12	50000	25	978
13	100	100	1094
14	1000	100	920
15	10000	100	710

Model Results

- Results page shows a variety of economic indicators to help evaluate the viability of such a project.



Collaborations

- NREL Electricity, Resources, and Building Systems Integration Center.
- UCI – subcontracted for controls and integration work.
- LBNL– tie-in with their separate DOE project (FC098) for manufacturing cost surfaces.
- Strategic Analysis, Inc. and Battelle.
- Stationary Fuel Cell OEMs are providing product data sheets and supporting information.

Proposed Future Work

- **FY12**
  - Expand control strategies with UCI.
  - Develop a rough estimate for the range of FC sizes needed for the commercial building inventory to feed to the LBNL team, in order to focus their cost efforts.
  - Expand building types to include remaining 384.
  - Provide input to CBECS 2012.
- **FY13**
  - Expand fuel cell types.
  - Option to continue UCI work.
  - Implement Design of Experiments capability.
  - Implement speed improvements to dispatcher code.
  - Perform detailed optimizations.
  - Validate model against real-world data.
  - Provide input to CBECS 2012.

Summary

RELEVANCE Project addresses barriers of cost, market adoption, and electricity demand. Building integration sizes and shapes variability.

APPROACH Approach includes deep analysis that will be replicated to optimize stationary fuel cells for the U.S. commercial building inventory. Leveraging existing high value data sources.

ACCOMPLISHMENTS Have developed a detailed, scalable, multifaceted analysis tool that will allow for fast comparison of different options and sensitivities.

COLLABORATION Strong collaboration with academia, national labs (LBNL), and industry (Strategic Analysis, Fuel Cell OEMs).

FUTURE WORK Clear scope for future work.