Enlarging the Potential Market for Stationary Fuel Cells Through System Design Optimization

2011 Hydrogen & Fuel Cells Program Annual Merit Review

Darlene Steward
National Renewable Energy Laboratory

Washington DC
May 9-13, 2011

Project # FC083
Overview

Timeline
Start: January 2011
End: 10/2011*
Complete: 30%

Budget
Total Project Funding: $300k
– 100% DOE-funded
FY2011: $300k

*Project continuation and direction determined annually by DOE.

Barriers
Stove-piped/Siloed Analytical Capability [4.5.B]
Suite of Models and Tools [4.5.D]
Unplanned Studies and Analysis [4.5.E]

Reviewers/Partners
UC Irvine
Colorado School of Mines
DTI
Objective: **Answer the question:** What are optimum fuel cell types, sizes, and control strategies to meet economic and environmental goals?

Model fuel cells in realistic combined heat and power and combined cooling, heat and power applications to provide guidance for design and manufacturing of stationary fuel cells.

**Attributes of potential CHP applications**

- **Building stock characteristics**
  - Building use characteristics
  - Building age distribution
  - Existing versus new construction
- **Climate**
- **Fuel costs**

**Attributes of fuel cells**

- **Performance characteristics**
  - Efficiency and response time
  - Safety
  - Durability and maintenance
- **Manufacturing Economics**
  - Manufacturing methods versus type
  - Design for manufacturing
  - Economies of scale versus economies of number
Approach - Model Must Link Distinct Functions to Meet the Objective

The model must analyze the tradeoffs between manufacturing fuel cells that are perfectly matched to every application and fuel cells that are economical to manufacture.

Two sub-functions must be optimized together:

1. A model to analyze fuel cells’ interactions with various building types and occupancy patterns in various climates.

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building information (load profiles)</td>
<td>Fuel consumed</td>
</tr>
<tr>
<td>Regional fuel prices</td>
<td>Electricity and heat produced</td>
</tr>
<tr>
<td>Fuel cell size, performance and cost</td>
<td>Net cost of energy</td>
</tr>
<tr>
<td></td>
<td>Net environmental impact</td>
</tr>
</tbody>
</table>

2. A model to estimate the cost associated with manufacturing fuel cells of various types and sizes at various production rates
### Approach - FY 2011 Project Tasks

<table>
<thead>
<tr>
<th>TASK</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
<th>SEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature review</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collect building load and other input data</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUI proof-of-concept design</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstrate proof-of-concept tool</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. **Literature review** – Gather information about existing fuel cell and CHP models with the goal of:
   - Identifying useful modeling strategies
   - Identifying potential benchmarks for model validation

2. **Collect building load and other input data** – Initially, much of this effort will emphasize:
   - Identifying data gaps
   - Assessing data quality/needs

3. **GUI proof-of-concept design** – Initial emphasis will be on defining the output from the model to meet the overall objective

4. **Demonstrate proof-of-concept tool** – The goal is to have a working model that is capable of giving preliminary results that are reasonably accurate.
Literature review of existing models

- **Fuel cell models** (level of detail, control strategies)
- **Building models** (level of detail, potential for integration with FC CHP)
- **CHP models** (level of detail, technologies, strategies for integration with existing and new buildings)
- **Obtain models for benchmarking**

Approach - Collect Input Data

- Attributes of buildings, climate, fuel prices and emissions define the application topography for stationary fuel cells.
- Attributes of fuel cell manufacturing and performance define the topography of fuel cell costs and suitability for particular applications.
Approach - GUI Proof-of-Concept Design

- Defining the desired output up-front keeps the modeling effort on-track

Literature review
Collect building load and other input data
GUI proof-of-concept design

Build model components

Task 3
Approach - Demonstrate Proof-of-Concept Tool

- QC and validate sub-models
- Preview simple optimization scenarios
- Review model input and output
Approach - FY 2011 to FY 2013 Tasks and Plans

<table>
<thead>
<tr>
<th>TASK</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
<th>SEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature review</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collect input data</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUI design</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Demonstrate tool</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Milestones**

1. Review of initial layout and future functionality of proof-of-concept GUI
2. Demonstration of proof-of-concept tool using limited locations, fuel cell types, and building types. Review of included models and data

**FY 2012 and FY 2013 work plan**

<table>
<thead>
<tr>
<th>FY 2011</th>
<th>FY 2012</th>
<th>FY 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
</tr>
</tbody>
</table>

- Model validation
- GHG abatement analysis
- Fuel cell CHP system optimization analysis and additional modules
Accomplishments – GUI Main Screen Design

GUI facilitates adding and organizing data, setting up configurations to be analyzed, and viewing results in a meaningful format.

Select from available fuel cell types (PEM, SOFC initially) and set up configuration.

Select from database of commercial building types (initial set):
• Hospitals
• Hotels
• Large office buildings
• Select climate zone(s)

Select from or add fuels and grid electricity mix and prices.
Initial set of modules:
- Electric generators: fuel cells, grid
- Heat generators: boilers, fuel cells
- Cooling: refrigeration cycle, absorption

Modules to be added after initial model validation:
- Electric generators: micro-turbines, genset
- Energy storage: hot and cold thermal storage
- Renewables: solar PV, solar thermal

New modules can be added and modules can be hooked together in different ways depending on the desired control strategy and optimization goal.
Accomplishments – Design of Fuel Cell CHP/CCHP Model

• Initial module design in Excel to facilitate testing and QC. Once validated, code is translated to Matlab®.
• Modular design allows maximum flexibility in system configuration and control strategy.

Flexible energy modules
- can be prioritized and controlled independently
- provide output to controller and input to other modules

Variable time step (ex: 1 second to 1 hour)
- can simulate fast transients
- can simulate grid outage
- can simulate backup power generators

Model is being designed for high speed operation
- optimization of fuel cell sizes
- sensitivity analysis
- analysis of large number of buildings

Initial set of modules and control algorithm to be completed by July 31, 2011
Accomplishments - Energy Control Strategy Developed

I can provide:
- 5 to 25 kW electricity
- 1 to 10 kW thermal
- 4¢/kWh-e*
- 925 lb GHG/MWhe

Each time step, energy controller collects bids from energy modules.
- Electric generators: fuel cells, turbines, gen sets, grid power
- Heat generators: boilers, fuel cells, turbines, gen sets
- Cooling: refrigeration cycle, absorption, evaporative
- Energy storage: heat, cooling (future capability)
- Renewables: solar PV, solar thermal (future capability)

*variable cost portion of power generator cost based on fuel price

Controller can be programmed to base prioritization on different optimization goals.
Accomplishments - Energy Control Strategy Continued

**Building demand during this time step**

- Electric asset actuation
  - Generator 1
  - Generator 2
  - Generator 4
  - Generator 5
  - Grid

- Thermal asset actuation
  - Generator 1
  - Generator 2
  - Boiler 1
  - Boiler 2
  - Storage 1

- Cooling asset actuation
  - Chiller 1
  - Chiller 2
  - Storage 1

**Actuation:**
- Hardware is actuated according to controller based on demand, control strategy and module capabilities
- Modules provide information to other modules
- Modules provide feedback to the controller

**Energy, Emissions, and Economic assessment:**
- Fuel usage and price
- Energy and emissions output

Variable cost, energy and emissions data collected in each time-step are aggregated and input into the economic model along with capital costs from the fuel cell manufacturing model.
Accomplishments – Optimization Strategy

Energy analysis model
Aggregated yearly:
- Variable operating costs
- Energy input and output for each module
- Emissions

Find the best applications for these fuel cells

Fuel cell manufacturing model
Provides cost and operating characteristics for fuel cells of various sizes at various manufacturing levels

The optimization strategy successively selects a fuel cell size and manufacturing rate then finds the best applications within the building dataset. The process is repeated to find the best fuel cell size and manufacturing rate.
Summary – A Detailed and Flexible Model Is Being Developed To Guide Research and Manufacturing of Stationary Fuel Cells

Tasks 1 and 2
• Existing models for benchmarking, partners, and reviewers have been identified.
• Attributes for an initial set of buildings, climate, fuel prices, and emissions have been collected and entered into an extensible database.
• Attributes of fuel cell manufacturing and performance have been collected or estimated for an initial set of fuel cells (PEM and SOFC).

Tasks 3 and 4
• The layout and primary functional screens of the user interface have been developed.
• Sub-modules have been developed for the initial set of equipment.
• A flexible control strategy has been developed.
### Planned Future Work

<table>
<thead>
<tr>
<th>FY 2011</th>
<th>FY 2012</th>
<th>FY 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2</td>
<td>Q1</td>
<td>Q1</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>Q2</td>
</tr>
<tr>
<td></td>
<td>Q3</td>
<td>Q3</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>Q4</td>
</tr>
<tr>
<td>Model validation</td>
<td>GHG abatement analysis</td>
<td>Fuel cell CHP system optimization analysis</td>
</tr>
</tbody>
</table>

**Additional model capabilities**

- Interface with building models/or incorporate simple building modeling capability
- Enhanced environmental analysis capabilities
- Built-in comparison to other CHP technologies
- Batteries and/or thermal storage
- Multi-building/district heating scenarios
- Hydrogen production for vehicles