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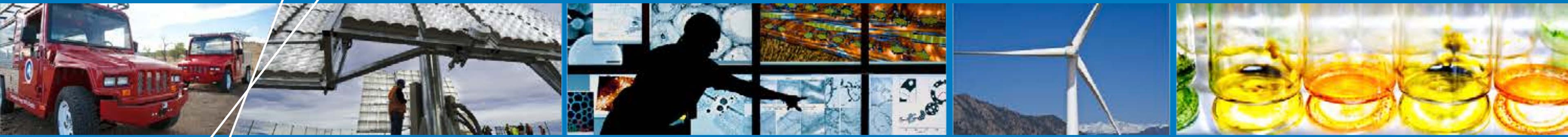
AN027

Cost, Energy Use, and Emissions of Tri-Generation Systems



2012 Annual Merit Review

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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

Model Development and Analysis Timeline & Budget

Start date: Dec 2010

Status: Completed Oct 2011

100% DOE funded

- $100K NREL
- $30K Sandia NL

Overall MSM Timeline & Budget

Start date: Feb 2005

Status: ongoing

Percent complete: 80%

100% DOE funded

FY11 funding

- $250K NREL/Systems Integration
- $100K Sandia NL

FY12 funding

- $150K NREL/SIO
- $100K Sandia NL

Barriers

- Stovepiped / siloed analytical capability (B)
- Inconsistent data, assumptions and guidelines (C)
- Suite of models and tools (D)

Partners

Sandia National Laboratories

- Computational development

NREL

- Fuel Cell Power Model

Argonne National Laboratory

- GREET

Fuel Cell Energy

- Information provided in development of the FC Power Model

SENTECH

- MSM User Guide

Project Overview

Approach

Cost, Energy Use, and Emissions of Tri-Generation Systems

Analysis Framework

- HyARC
- H2A Power design parameters
- H2A Power building load data
- Fuel Cell Energy – fuel cell operational data
- Hydra grid mix data
- GREET emissions data

Models & Tools

- H2A Power
- Hydra
- GREET
- Macro-System Model (MSM)

National Labs

ANL – GREET & HDSAM
NREL – H2A
SNL – MSM

Studies & Analysis

Potential for cost, energy use, and emission reduction, opportunities by using co-generation systems

Review by FPITT

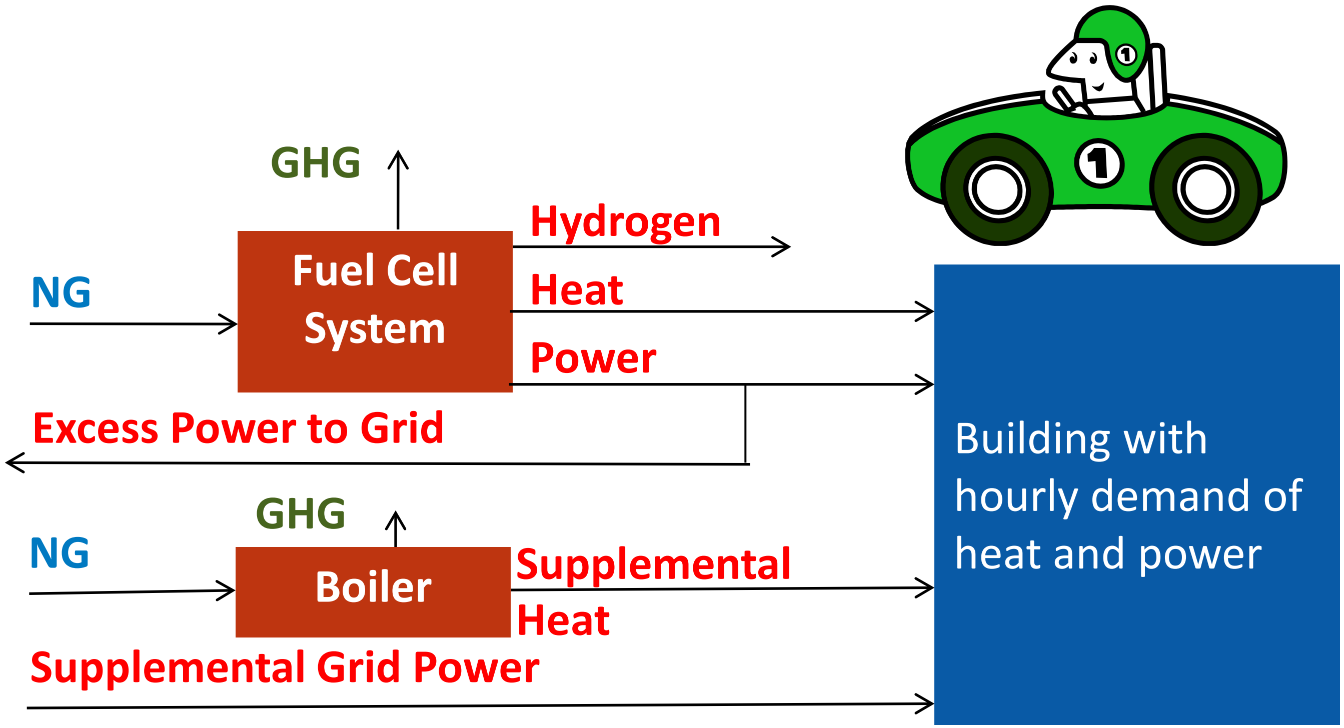
Outputs & Deliverables

Report

Improved understanding of potential niche opportunities for CHHP systems

NREL, FCT Program, & External Reviews

Tri-generation Concept



Hydrogen levelized cost and associated greenhouse gas (GHG) emissions might be reduced by combining with fuel cell combined heat and power (CHP) systems.

Analysis Objectives

Relevance

Quantify levelized cost and GHG emissions from tri-generation [combined heat, hydrogen, and power (CHHP)] systems for various:

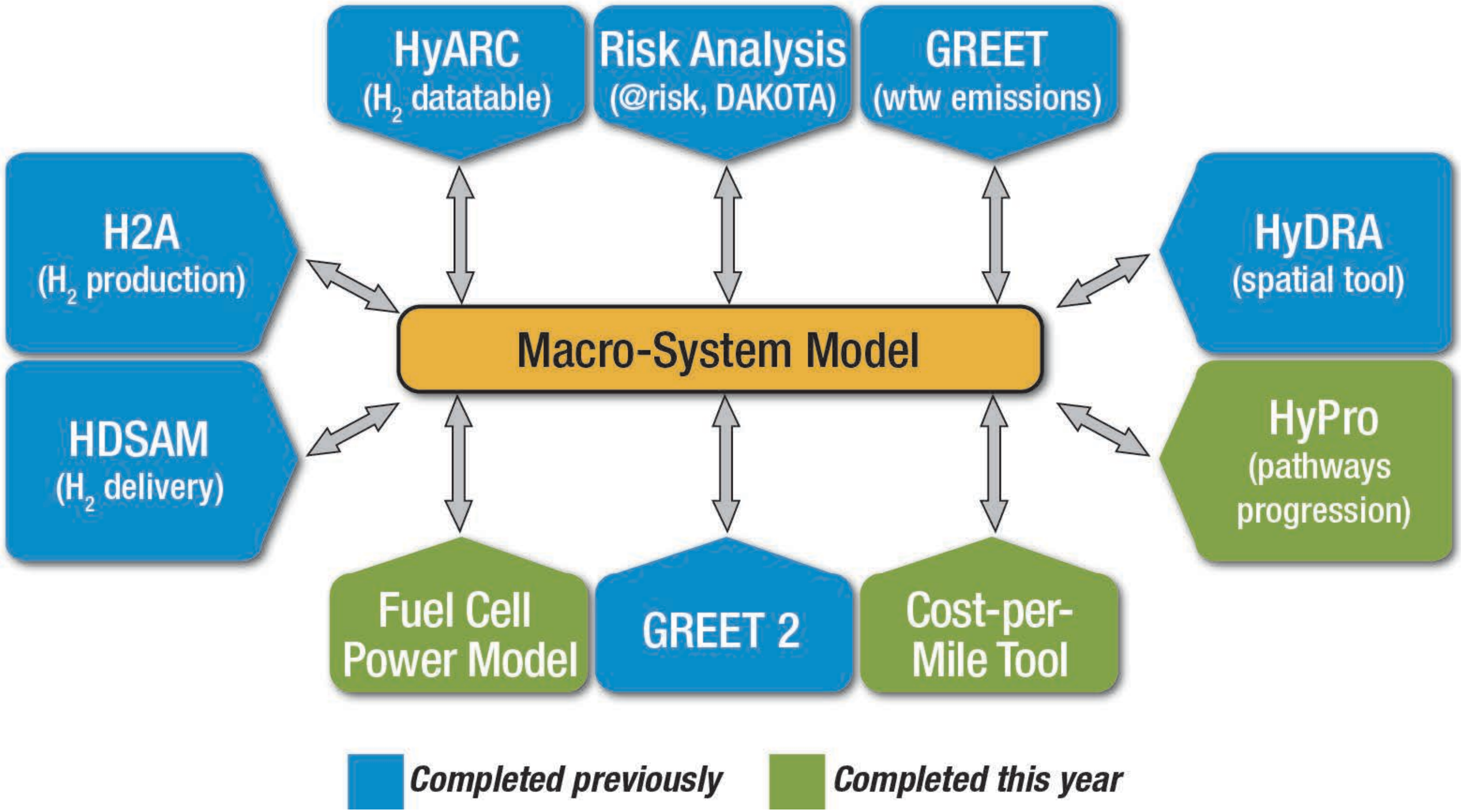
- **Fuel cell types**
- **Building types**
- **Building locations**

Develop a methodology for MSM users to create optimized CHHP scenarios easily

Primary Analytical Tool: MSM

Approach

The Macro-System Model (MSM) provides a ***central transfer station*** to simplify communication across models and guarantee consistency in simulations that involve multiple models. A graphical user interface (GUI) allows users to easily use the models.



Fuel Cell Power Model

- Models tri-generation systems for buildings
- Built in Excel on H2A platform
- Includes user options of molten carbonate fuel cells (MCFC) or phosphoric acid fuel cells (PAFC)
- Allows for multiple inputs (natural gas; grid, solar, and wind-generated electricity), energy storage as hydrogen, and multiple outputs (electricity, heat, hydrogen)
- Utilizes hourly heat and building demand-profile databases
- Designed to follow building electricity demand, building heat demand, and then to produce hydrogen.
- Available at http://www.hydrogen.energy.gov/fc_power_analysis.html

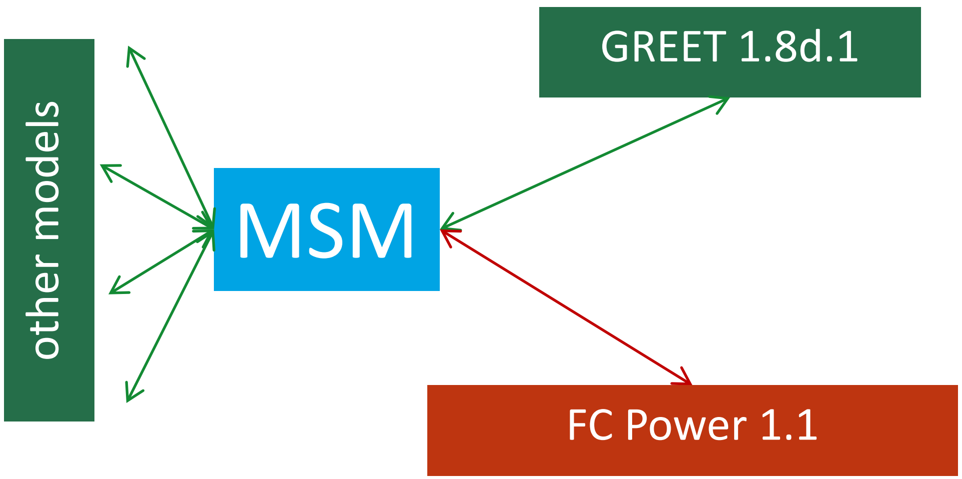
Tri-generation in the MSM

Approach

Adding the fuel cell power model to the MSM simplifies inclusion of regional costs, upstream energy use, and emissions in the FC Power model

User interface inputs:

- Unit capacity, cost
- Choice of power demand profile (office/hotel/mall; geographic location)
- Profile location so costs and grid mix can be imported from HyDRA



GREET calculates:

- annual average electricity fuel-cycle energy use & emissions
- annual average upstream natural gas (NG) energy use and total emissions

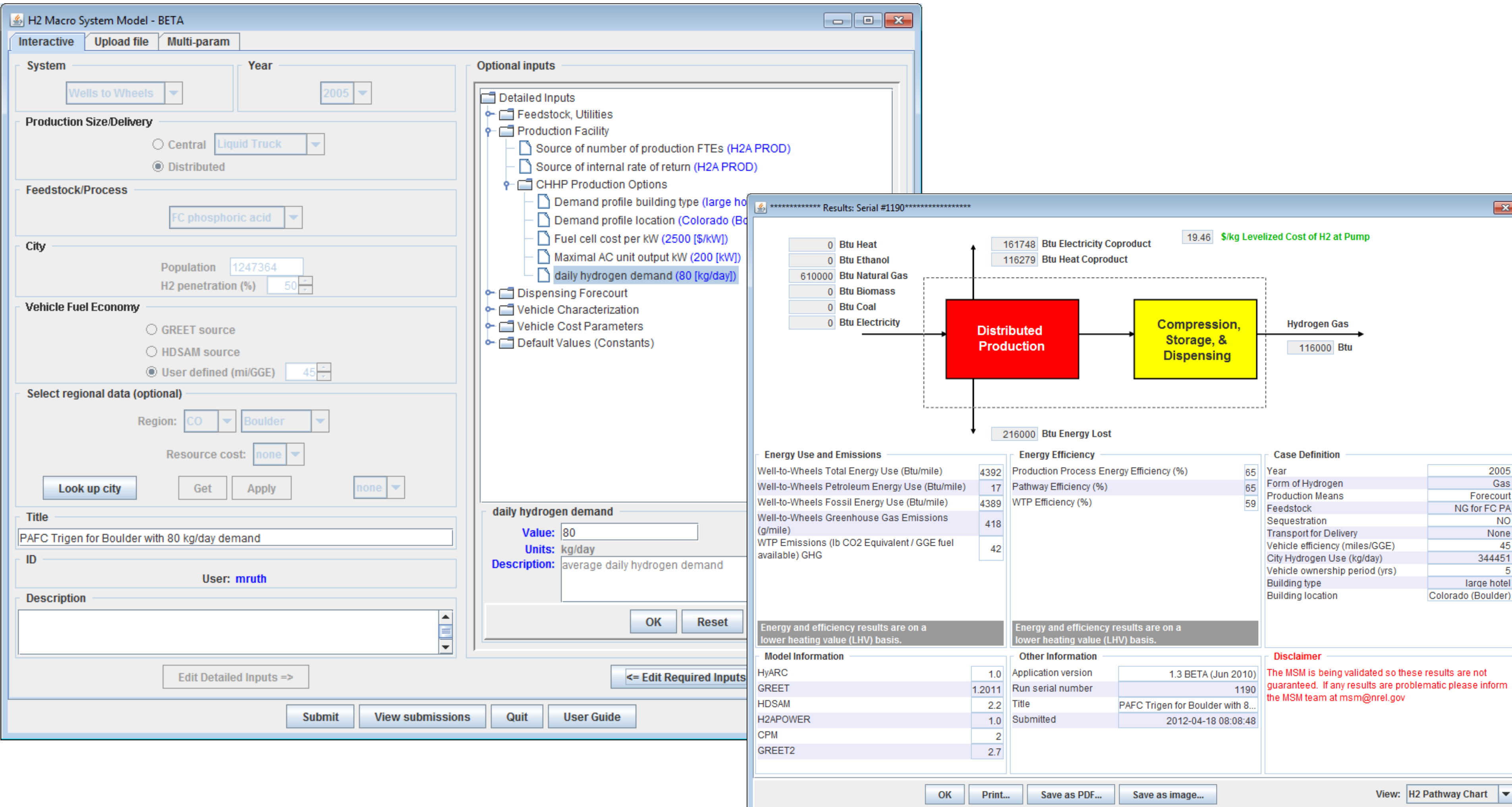
FC Power gets upstream energy & emissions entries for NG and electricity:

- total energy
- fossil fuels
- petroleum
- CO_2, N_2O, GHG

MSM Tri-Generation Simulations

Accomplishments

The MSM allows the user to easily provide desired inputs and easily see annual average quantities of energy products, levelized cost of hydrogen, well-to-wheels (WTW) energy use, and WTW emissions. Example screenshots are below.



Key Assumptions

Approach

Many assumptions are embedded in the models being linked but can be changed in sensitivity runs.

Buildings

- Types: Large hotel, large office, small hotel, small office, supermarket
- Locations: Seattle, Los Angeles, Chicago, Baltimore
- Electricity and heat load sources: NREL's Electricity, Resources, and Buildings Integration Center databases

Financial

- 10% IRR
- 20 year lifetime
- MACRS depreciation where appropriate
- 1.9% inflation
- Commercial electricity and natural gas prices from Hydra
- No incentive programs or costs of carbon

CHHP

- 320 and 1440 kW fuel cells used for this analysis
- Fuel cell cost: $3000/kW (purchased)
- Rent: $38,700/yr
- Compressor and dispenser replacement every 10 years
- PAFC catalyst and reformer replacement every 5 years and refurbishment every 10 years

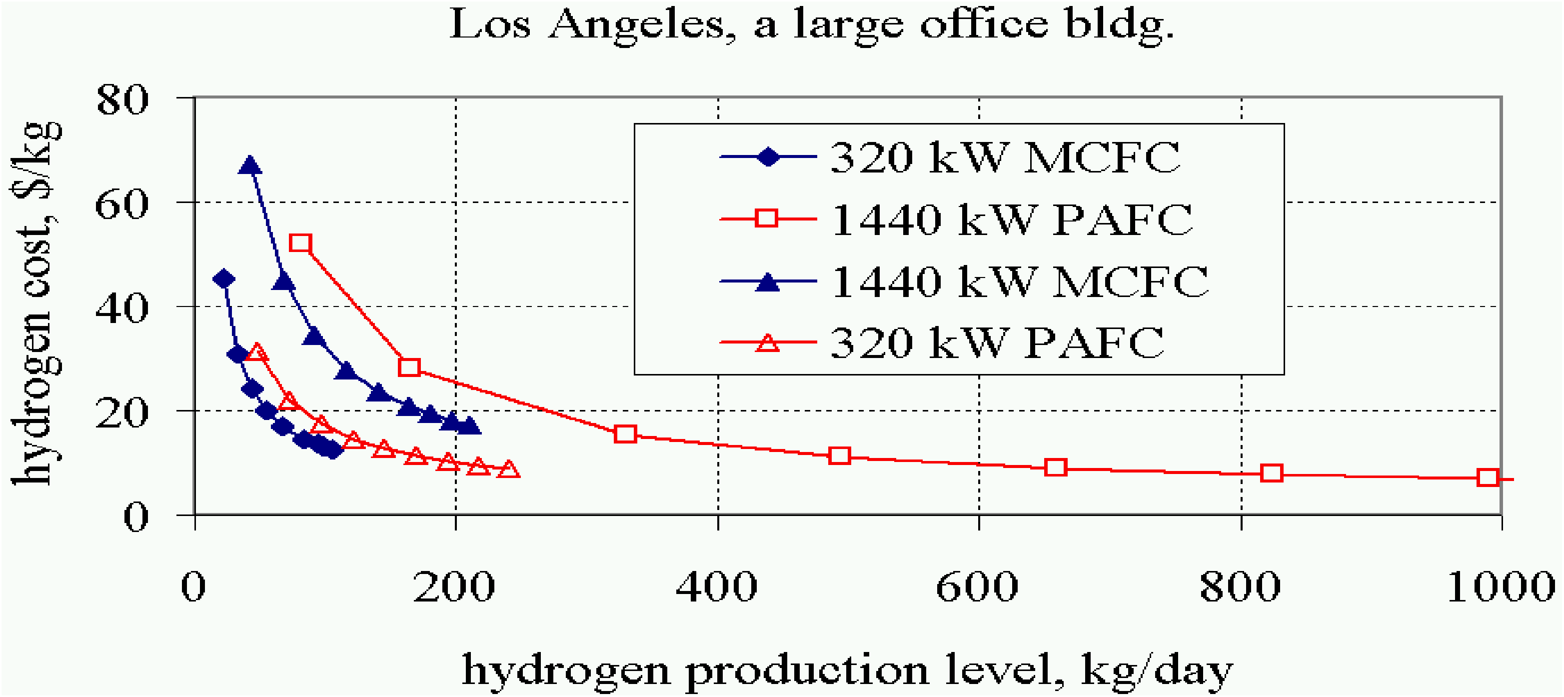
GREET

- Grid mixes from Hydra databases
- Upstream energy use, efficiencies and emissions from GREET databases

FC Size Selection & H_2 Production

Accomplishments

Minimum hydrogen levelized cost was used for this analysis. Maximizing hydrogen production minimizes the levelized cost of hydrogen for PAFCs and most MCFC scenarios.



- Hydrogen cost estimates for various fuel cell types (MCFC and PAFC) and sizes (320 and 1,440 kW maximum AC rating) for a large office building in Los Angeles are shown.
- The values of electricity and heat are set equivalent to market values of commercial grid electricity and cost to produce heat from NG using a commercial boiler.

Energy Comparisons

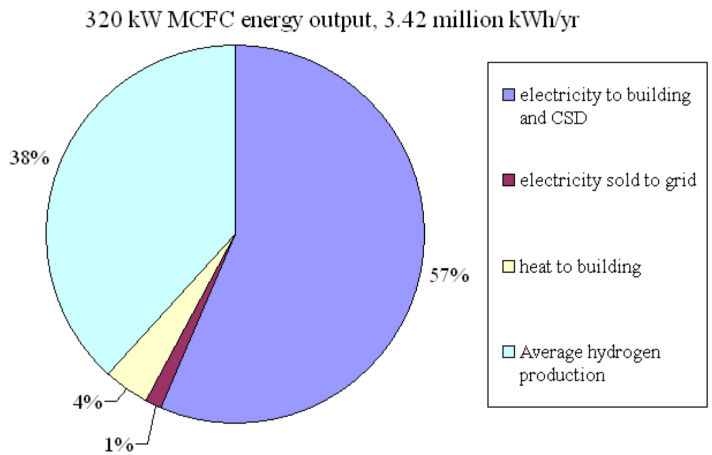
Accomplishments

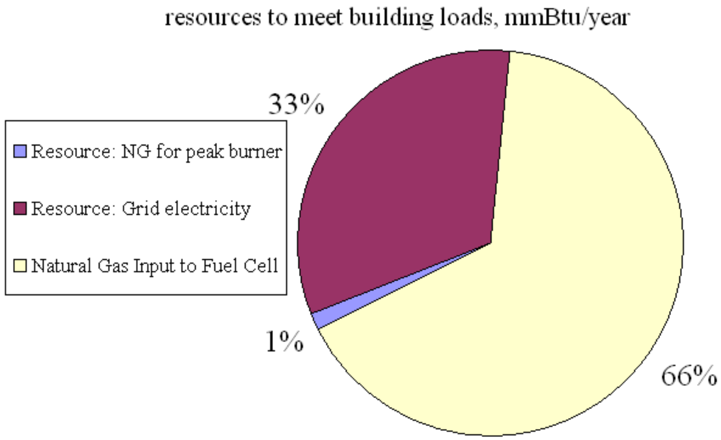
The smaller MCFC system mirrors building load needs while the larger PAFC is essentially a hydrogen and power generator for outside use.

320 kW MCFC

Energy output: 11 MMkWh/yr

Building load: 16,000 MMBtu/yr

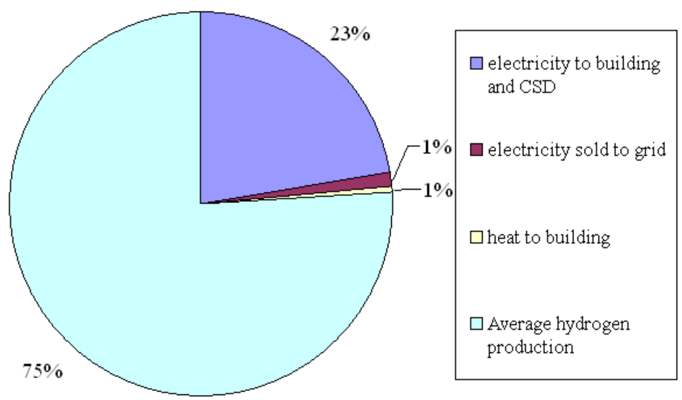


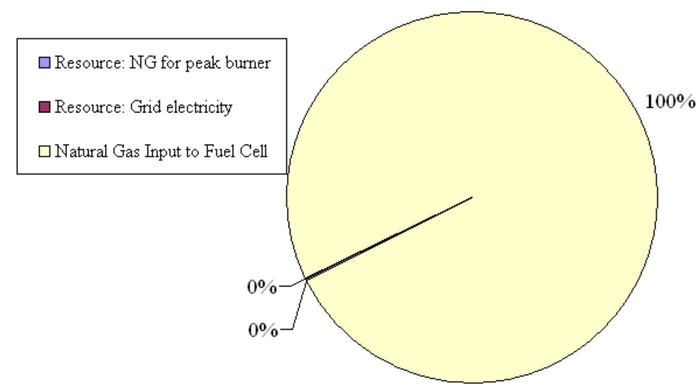


1,440 kW PAFC

Energy output: 27 MMkWh/yr

Building load: 16,000 MMBtu/yr





Large office building with Los Angeles climate, electricity cost & grid mix, and NG cost

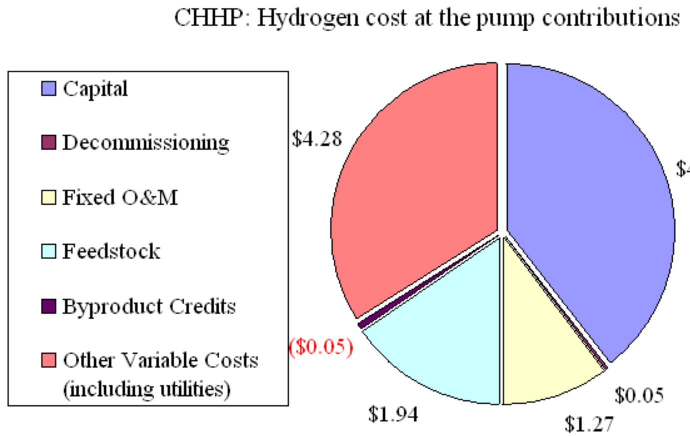
Cost Comparisons

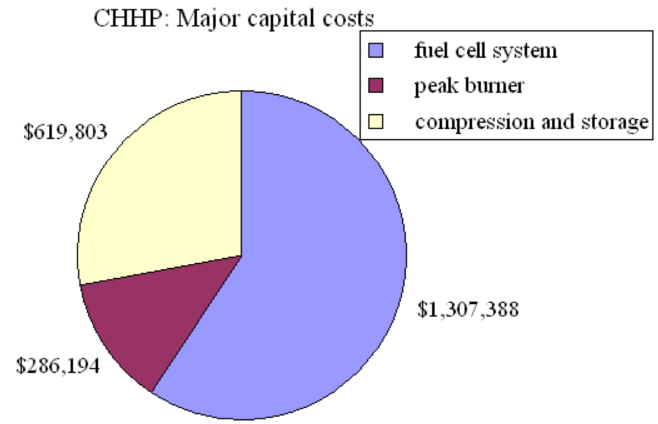
Accomplishments

Capital is the primary cost driver for all these systems; variable costs (rent and labor, primarily) are the secondary drivers for the smaller MCFC system.

320 kW MCFC

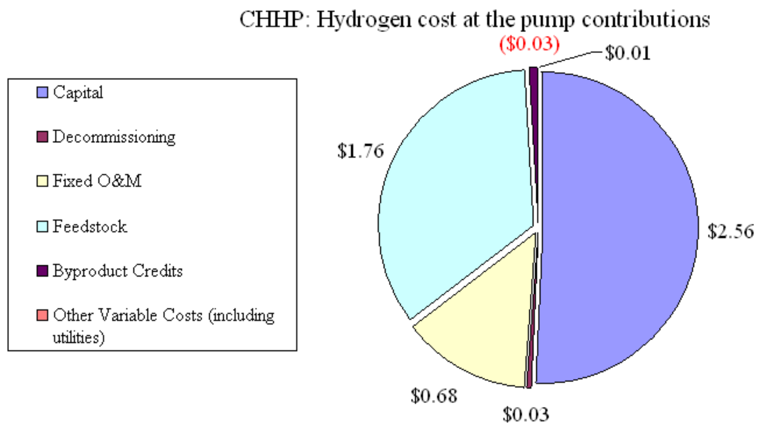
105 kg/day
Levelized Cost: $12.10 / kg
Capital Cost: $2,200,000

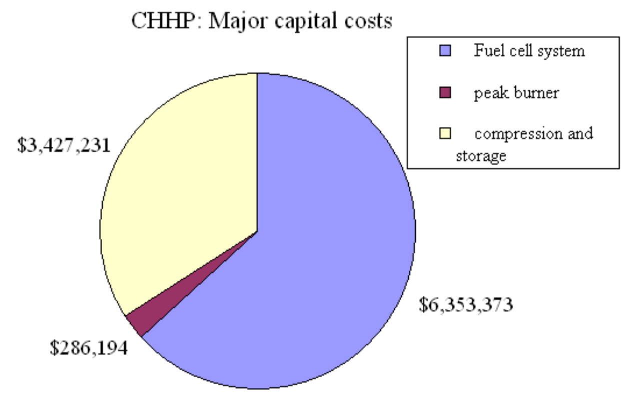




1,440 kW PAFC

1630 kg/day
Levelized Cost: $5.00 / kg
Capital Cost: $10,100,000





Large office building with Los Angeles climate, electricity cost & grid mix, and NG cost

Levelized Cost Results for Various Options

Minimizing the levelized cost of hydrogen results in costs higher than conventional systems.

320 kW MCFC: H_2 cost, $ / kg (and % change to the baseline system)				
	Large hotel	Large Office	Supermarket	Small hotel
Seattle, WA	$15.90 (+52%)	$14.30 (+66%)	$16.60 (+59%)	$27.70 (+79%)
Los Angeles, CA	$12.20 (+28%)	$12.10 (+38%)	$13.30 (+36%)	$23.50 (+61%)
Chicago, IL	$16.20 (+57%)	$14.50 (+71%)	$47.80(+231%)	$58.00(+198%)
Baltimore, MD	$14.70 (+41%)	$13.40 (+53%)	$15.70 (+49%)	$25.30 (+67%)
1440 kW PAFC: H_2 cost, $ / kg (and % change to the baseline system)				
	Large hotel	Large Office	Supermarket	Small hotel
Seattle, WA	$ 5.70 (+31%)	$ 5.40 (+51%)	$ 6.90 (+28%)	$ 9.70 (+30%)
Los Angeles, CA	$ 6.20 (+20%)	$ 5.00 (+40%)	$ 7.40 (+23%)	$10.90 (+29%)
Chicago, IL	$ 6.00 (+34%)	$ 5.60 (+55%)	$ 6.10 (+22%)	$ 8.70 (+23%)
Baltimore, MD	$ 6.20 (+30%)	$ 5.70 (+48%)	$ 7.40 (+28%)	$10.10 (+28%)

For consistency, hydrogen costs are compared for CHHP vs. conventional systems at equal production levels.

Levelized costs of hydrogen are reported in the table. The increases in cost over a baseline system [grid electricity, NG boiler for heat, and steam methane reforming (SMR) for hydrogen] are reported parenthetically.

GHG Emissions Results for Various Options

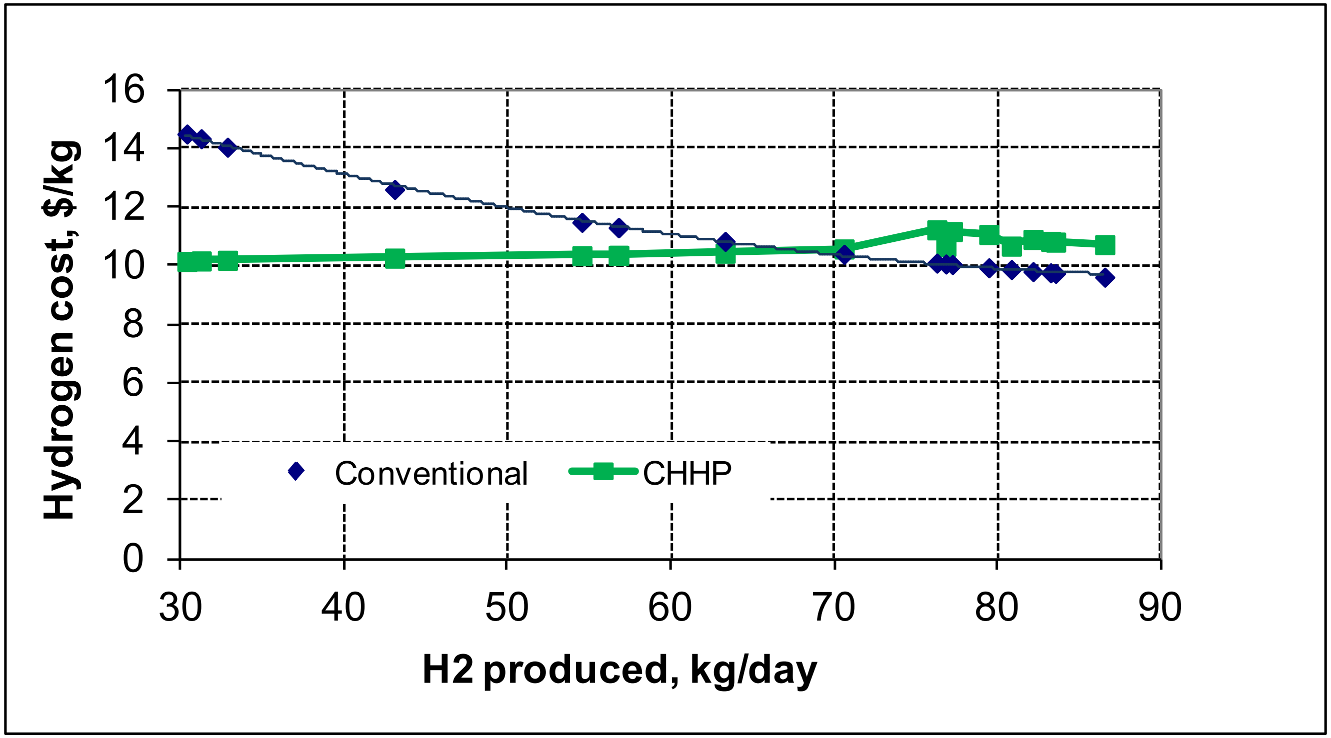
GHG emissions from tri-generation systems are lower than for the conventional option when the system size matches the building load.

320 kW MCFC: GHG emissions reduction, %				
	Large hotel	Large Office	Supermarket	Small hotel
Seattle, WA	21%	24%	21%	18%
Los Angeles, CA	20%	8%	11%	4%
Chicago, IL	40%	39%	-3%	12%
Baltimore, MD	32%	25%	34%	33%
% = (emissions change / baseline emissions); negative = increase in emissions				
1440 kW PAFC: GHG emissions reduction, %				
	Large hotel	Large Office	Supermarket	Small hotel
Seattle, WA	-2%	-9%	-4%	-6%
Los Angeles, CA	-2%	-15%	-13%	-17%
Chicago, IL	11%	7%	-8%	-2%
Baltimore, MD	4%	-2%	3%	1%

System-wide WTW GHG emissions are reported in the table . The increases in emissions over a baseline system (grid electricity, NG boiler for heat, and SMR for hydrogen) are reported parenthetically.

Levelized Costs Compared to SMR

At hydrogen production less than 70 kg/day, the levelized cost of hydrogen produced by MCFC tri-generation system for a small office in Los Angeles is less than that of a similarly sized SMR providing costs for rent are scaled.



Conclusions

- Hydrogen cost is minimized at the highest hydrogen production rate due to economies of scale for the costs of dispensing.
- But those resulting levelized costs may not be the most competitive with conventional technologies
- Levelized costs of hydrogen can compete with SMR at low production capacities (<70 kg/day) providing the cost of rent scales.
- GHG emissions from tri-generation systems are lower than the conventional option when the system size matches the building load.

Proposed Future Work

No additional funding is planned for this analysis and the only future work is finalizing the report. If we had additional funding, we would like to:

- **Test other options for setting CHHP parameters in the MSM**
- **Update GREET & H2A FC Power models**
- **Analyze tri-generation systems to balance the grid where variable generation (intermittent) is in place.**
- **Additional review of parameters and gap analysis**

As ongoing projects, the MSM is being updated and an analysis of the parameters used in estimating levelized cost and energy use and emissions is underway.

Collaborations

- NREL - FC Power Model & Hydra
- Fuel Cell Energy – Fuel cell operational data
- Argonne National Laboratory - GREET
- Fuel Pathway Integration Tech Team (FPITT) - Review and discussion

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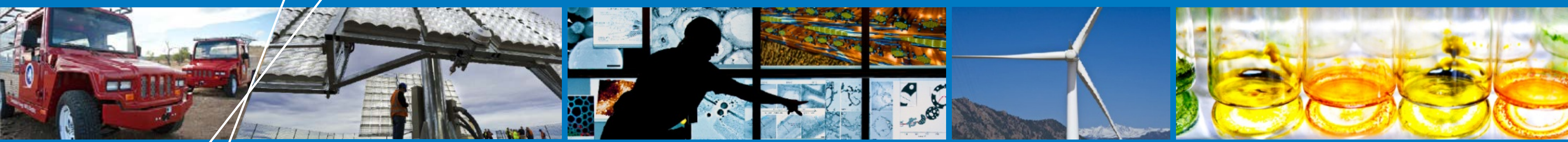
Technical Backup Slides



Approach: Model Validation

- Model inputs and results were reviewed by the Fuel Pathway Integration Tech Team (FPITT), others in the H_2 analysis community and industry experts
- One major MSM output – Pathway Report(s) – undergoes thorough reviews by FPITT. The data reported in that report were used for this analysis.
- The H2A Production models and HDSAM are built in a transparent way and undergo their own validation prior to being published; these models are reviewed by the Production Tech team and by the Delivery Tech team
- GREET is widely used and is being constantly reviewed and updated

Validating models at both integrated and component levels