NREL
NATIONAL RENEWABLE ENERGY LABORATORY
Innovation for Our Energy Future

Fuel Cell Power Model: Evaluation of CHP and CHHP Applications

2010 Annual Merit Review and Peer Evaluation Meeting

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June 8, 2010

AN015

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Project start date

January 2008

Project end date

Fuel Cell Power Model v1.0 Completed Sep. 08
Fuel Cell Power Model v1.1 Completed Sept. 09
(published November 2009)
Fuel Cell Power Model v1.2 to be completed Aug. 2010

Percent complete

Work on version 1.2 is 80% complete

Barriers

Section 4.5 of the Program's RD&D Plan

B: Stovepiped/siloed analytical capabilities

C: Lack of consistent data, assumptions, and guidelines

E: Unplanned studies and analysis

Budget

Total project funding

$530K to NREL

Funding received in FY08

$130K

Funding for FY09

$200K

Funding for FY2010

$200K

Partners

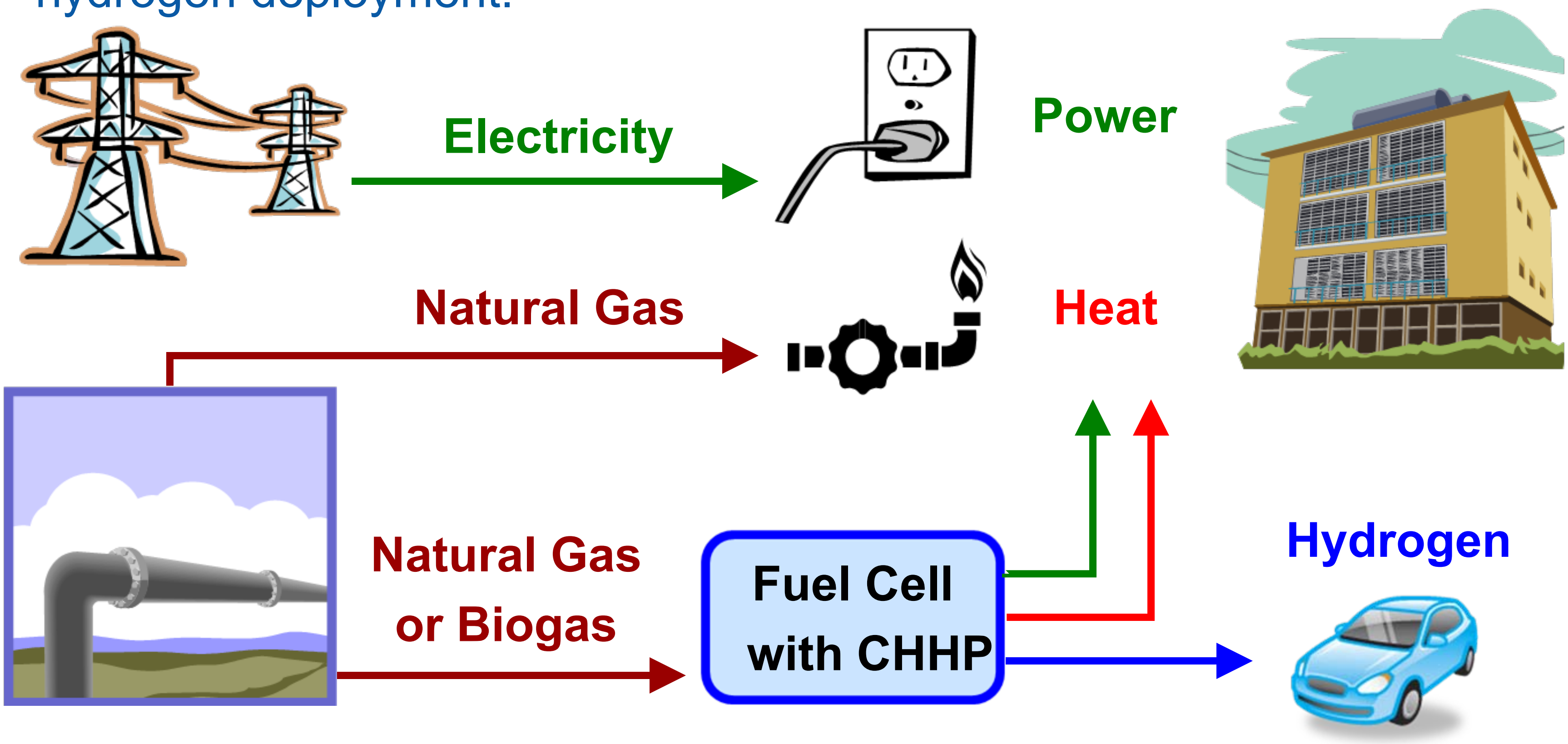
Peer reviewers from:

- Argonne National Laboratory
- Colorado School of Mines
- DTI
- Fuel Cell Energy
- Logan Energy
- Pacific Northwest Laboratory
- Rensselaer Polytechnic Institute
- Sandia National Laboratory
- UC Davis
- UC Irvine
- UCSD
- Versa-Power

Relevance – Fuel Cell Power Model Allows Analysis of New Transition Strategies

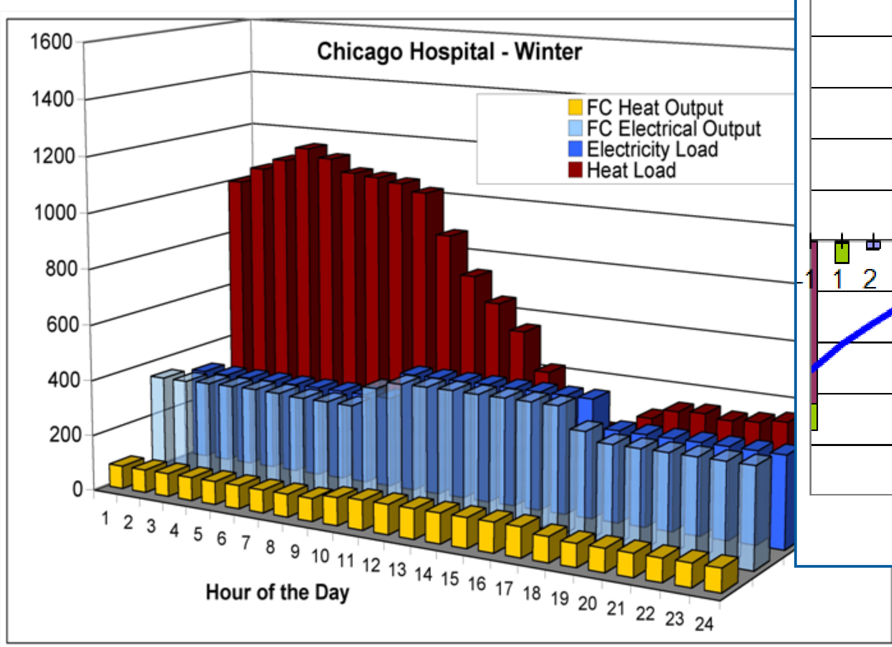
Hydrogen infrastructure costs for early transition phase are large, and are relatively high risk due to uncertainty of demand.

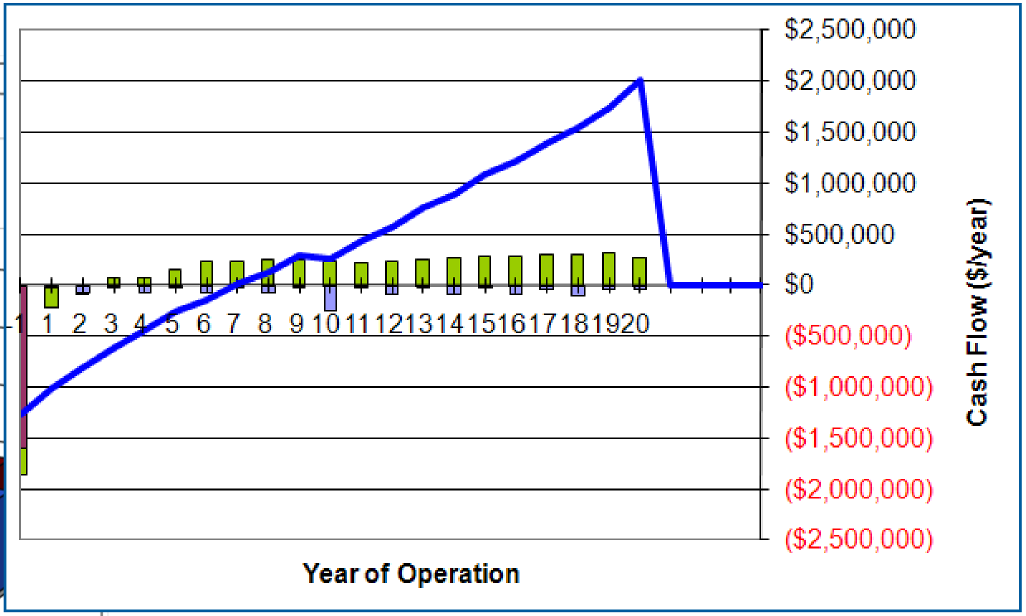
The Fuel Cell Power Model allows analysis of combined heat, hydrogen and power (CHHP) systems, which may improve hydrogen deployment.



Relevance – Objectives

- **Accurately model performance for stationary fuel cells** in combined heat and power (CHP) and combined heat, hydrogen and power (CHHP) applications
- **Combine detailed performance information with a comprehensive discounted cash flow methodology** to evaluate lifecycle costs





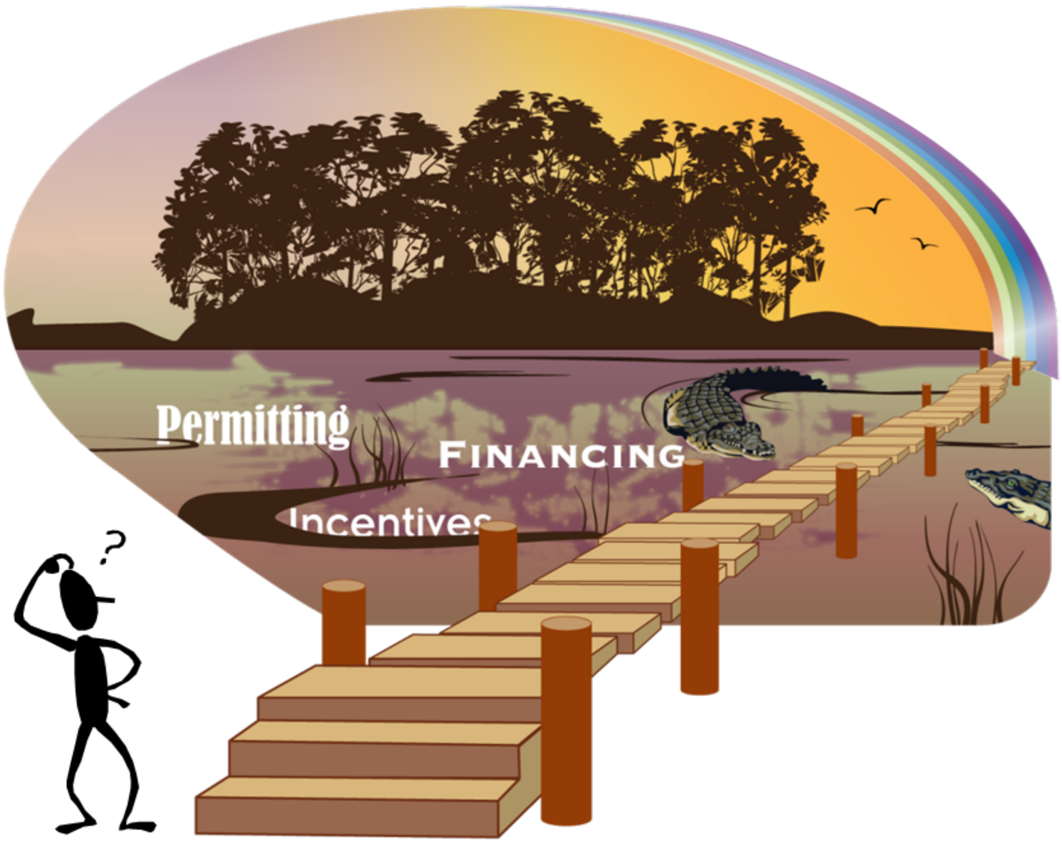
Energy profile and cash flow chart are not intended to depict the same installation

Relevance – Business Case Tab will Streamline Business Case Analysis

Help business decision-makers see whether "the view is worth the climb"

Decision-makers must navigate uncertainties & unknowns

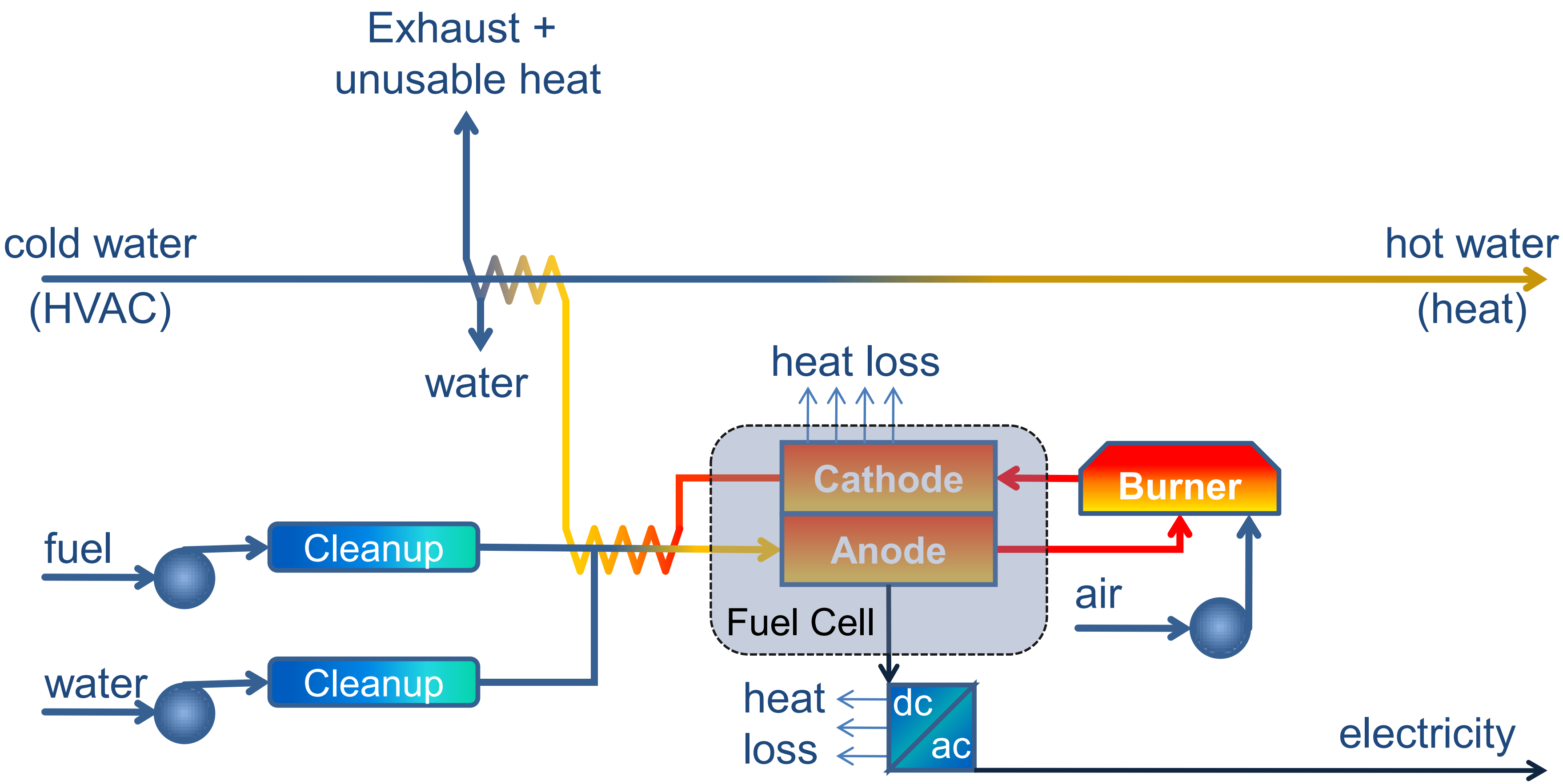
- Accurate assessments of costs and benefits
- Financing
- Permitting
- Regulations
- Satisfying requirements for incentives
- Utility interconnect agreements.



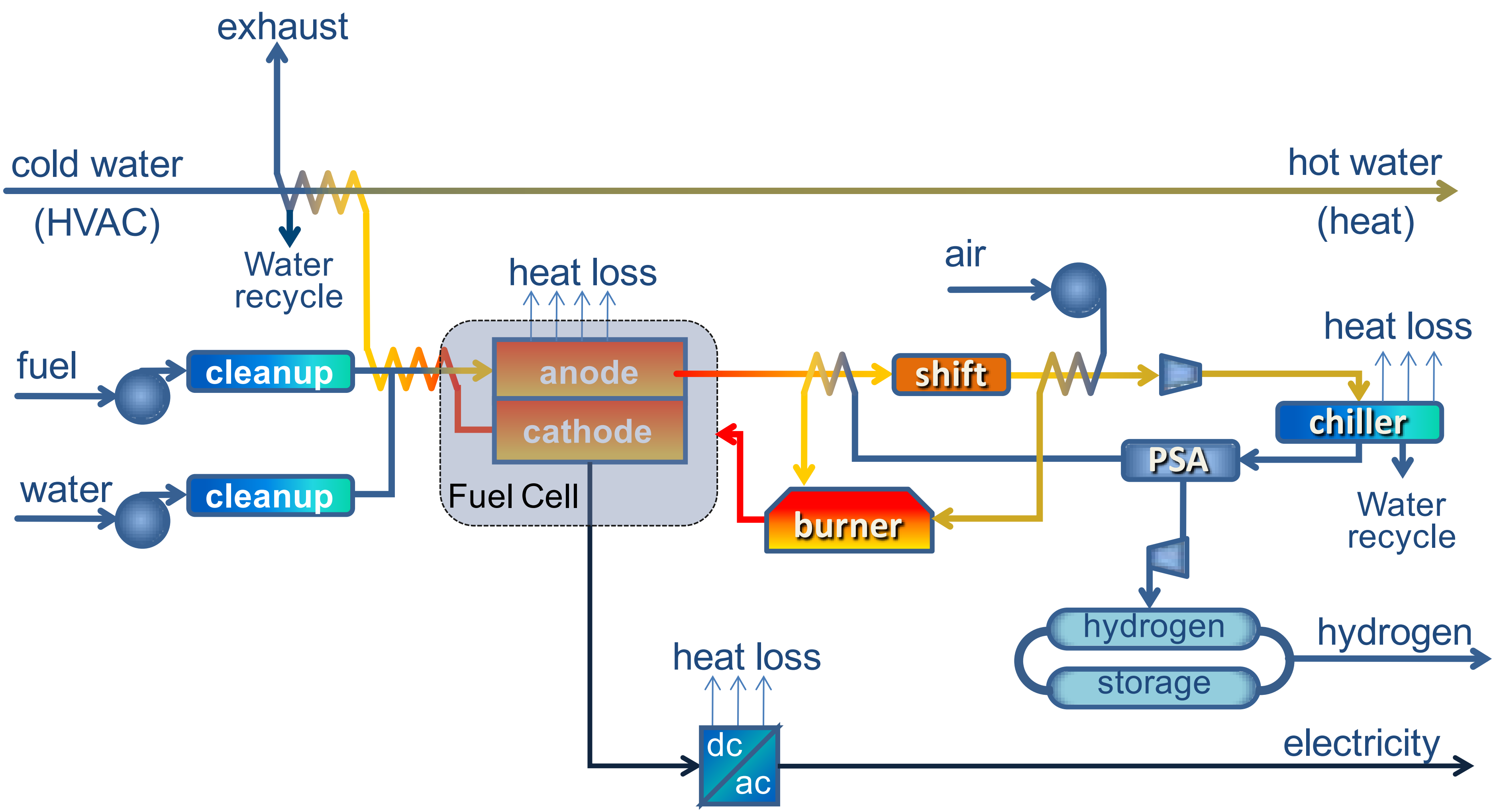
Relevance: Impact on Barriers

Barrier	*Impact*
Stovepiped/siloed analytical capabilities	• Model links distributed power and production of hydrogen for vehicle fuel • Combines fuel cell performance model with established cash flow analysis • H2A-based discounted cash flow model dovetails with other DOE tools (H2A, HDSAM, MSM, HyDRA, SERA)
Lack of consistent data, assumptions, and guidelines	• Built on the "H2A Platform" – a well established lifecycle cost analysis tool • Standard H2A financial assumptions ➢ Transparent and valid comparisons between FCPower model, H2A & HDSAM results
Unplanned studies and analysis	• Additional built-in capability for analysis of: ➢ Energy storage (wind > electrolysis > hydrogen > FC > electricity) ➢ Wind and solar integration in CHP, CHHP applications ➢ Backup power with a hydrogen (PEM) fuel cell

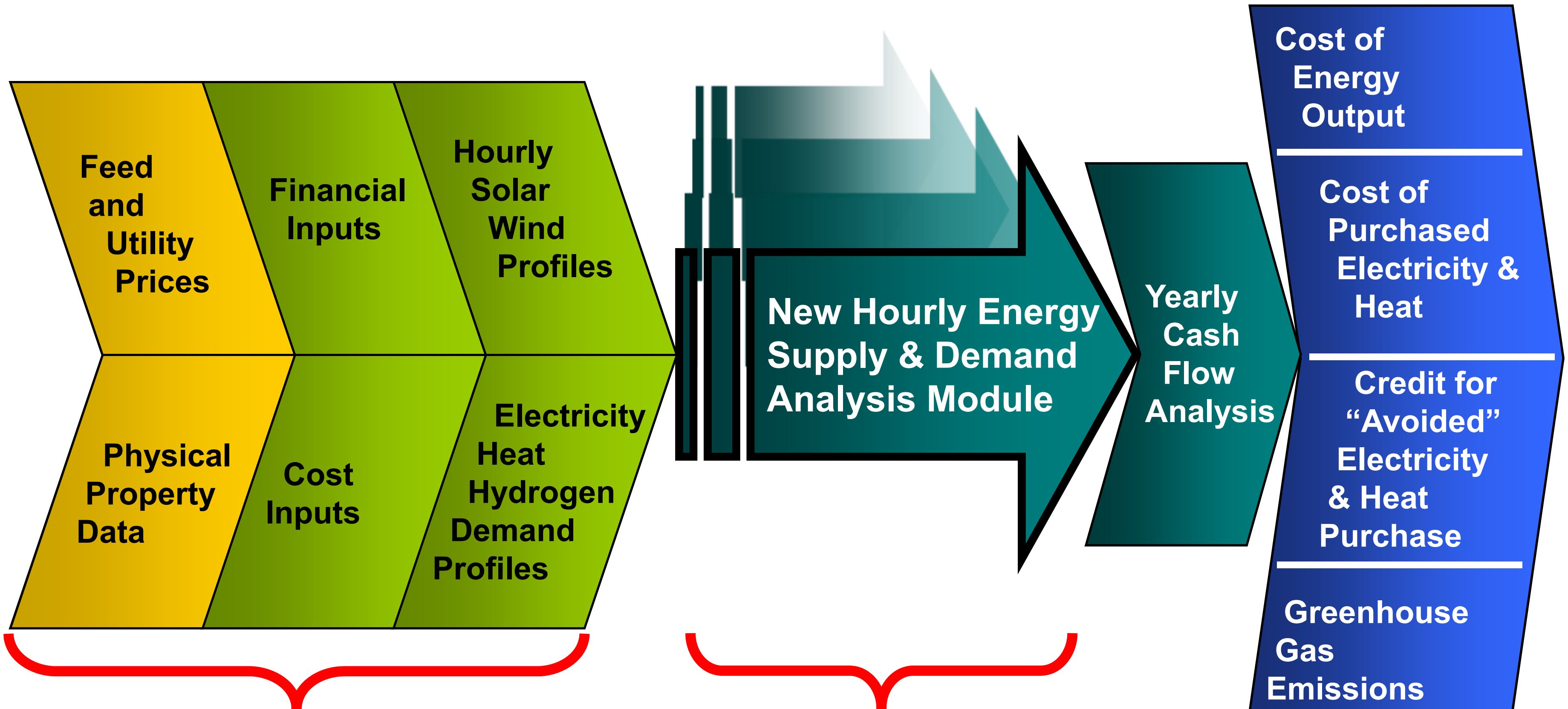
Technical Approach – MCFC System Simplified Model for CHP System



Technical Approach – MCFC System Simplified Model for CHHP System



Technical Approach – Fuel Cell Power Model
Hourly Energy Analysis Module Was Added



Model inputs
- Model database
- User inputs

Energy analysis done for 8,760 h of one year

Technical Approach – Business Case Tab

Provide a single simple-to-use home for "what-if" business case analysis

Costs have already been gathered & energy analysis is done – now what?

- Calculate cost without IRR
- Simple payback period calculation
- Solve for a different variable
  - Enter expected revenue and solve for IRR
  - Enter expected revenue and IRR; solve for NPV of after tax cash flow
- Calculate total lifecycle cost
- Calculate benefit-to-cost ratio [PV (all benefits) ÷ PV (all costs)]
- Calculate savings-to-investment ratio [PV (net savings) ÷ PV (principle investment costs)]

Under Construction

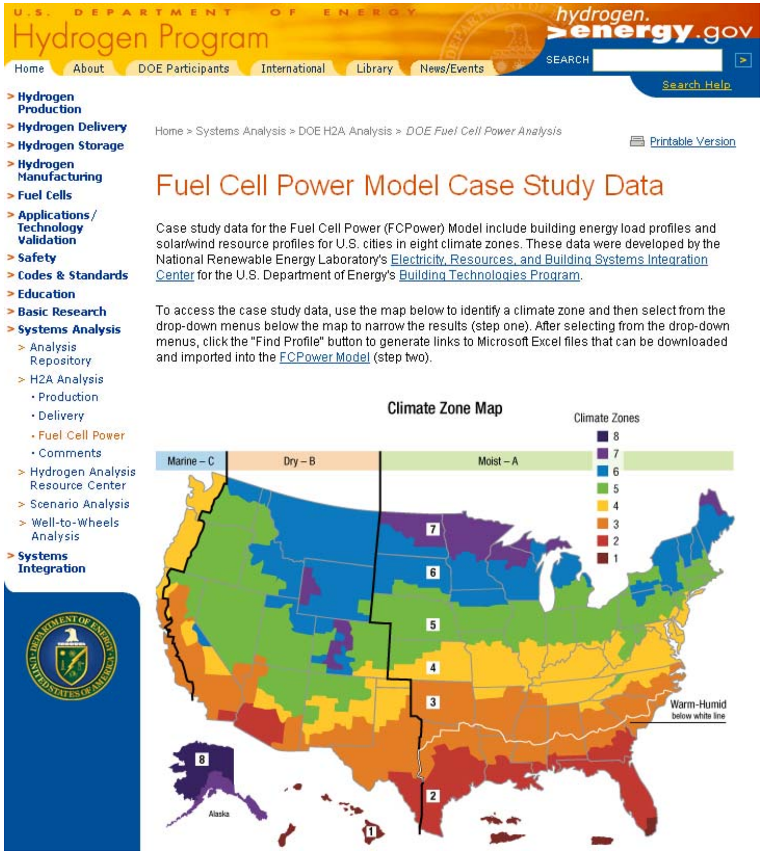
Technical Accomplishments – FCPower Model Public Outreach

Version 1.1 Published

- Molten Carbonate Fuel Cell and Phosphoric Acid Fuel Cell models
- Users guide
  - "How to" guide
  - Fuel cell performance models detailed
  - Case study descriptions

Presentations, webinars, one-on-one guidance

- Training and webinars for first users
- Electric Utility Consultants, Inc. (EUCI) webinar
- Market Transformation analysis were completed for several commercial and government entities



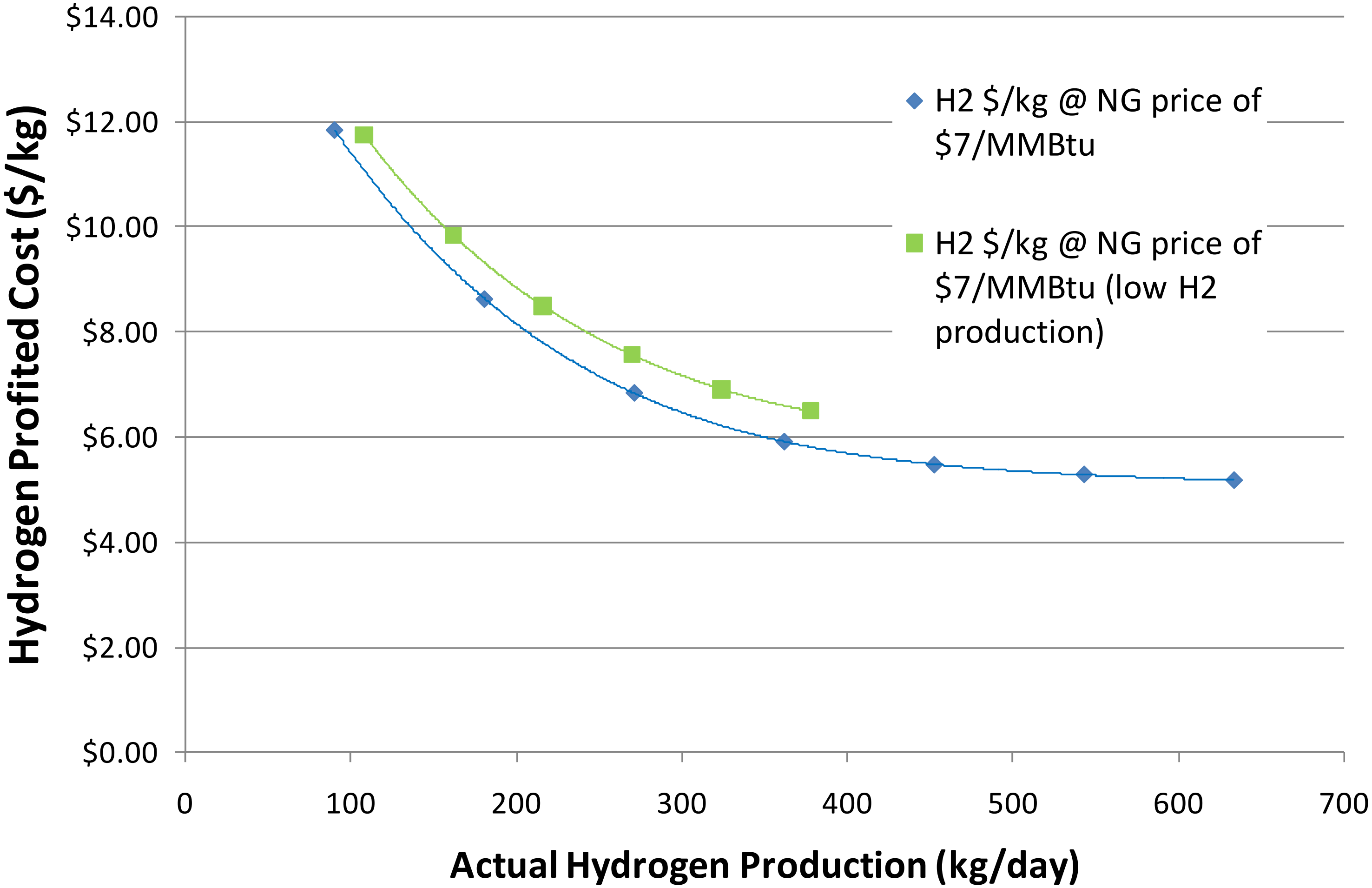
Technical Accomplishments – Support for Real World & Theoretical Applications

The FCPower model has been used to support a wide range of actual and proposed fuel cell installations, as well as theoretical research projects.

- NREL campus
- NASA AMES Research Center
- Los Alamitos Military base
- USPS Distribution Facility San Francisco
- MSRI
- Sandia / LLNL campus
- Three stores from a large grocery chain
- Five large food processing facilities
- DOE generic scenario studies
- Spatial model development for deployment (SERA)
- Biogas case studies

Technical Accomplishments – Effect of Additional Fuel for CHHP System Hydrogen Overproduction

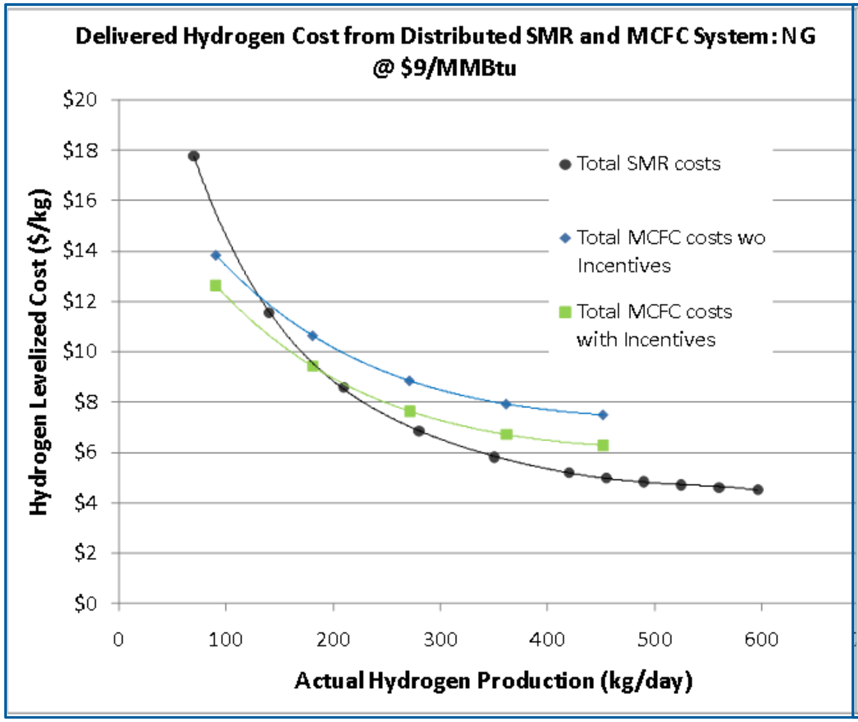
Use of additional fuel to boost hydrogen production reduces hydrogen cost

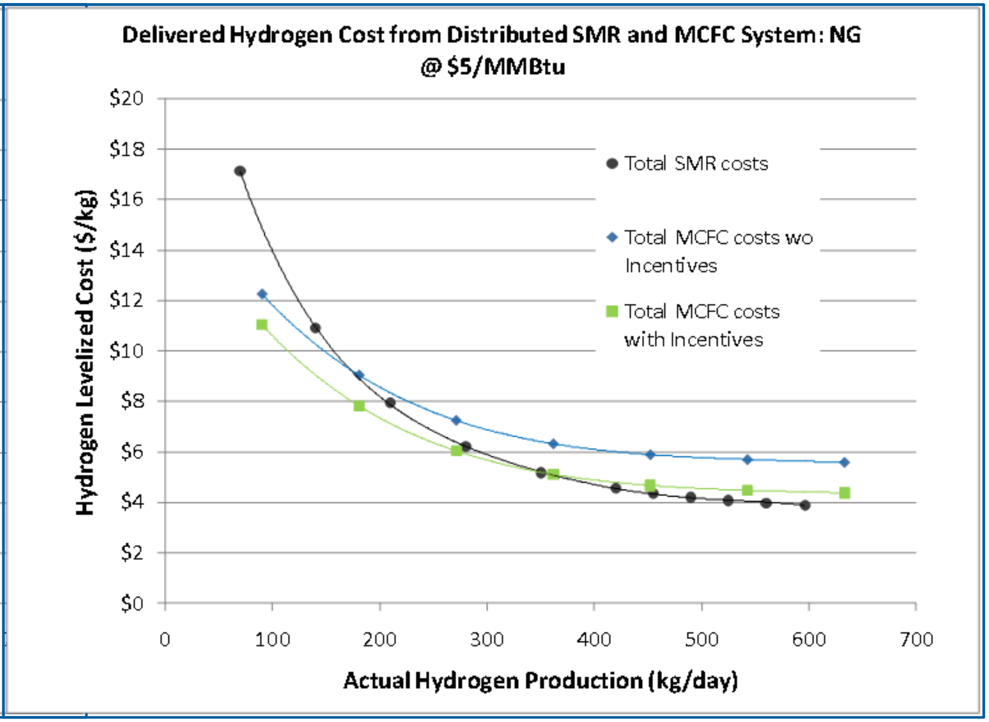


Source: FCPower Model, molten carbonate fuel cell, version 1.1

Technical Accomplishment - Comparison of Fuel Cell CHHP and SMR Hydrogen Production Strategies

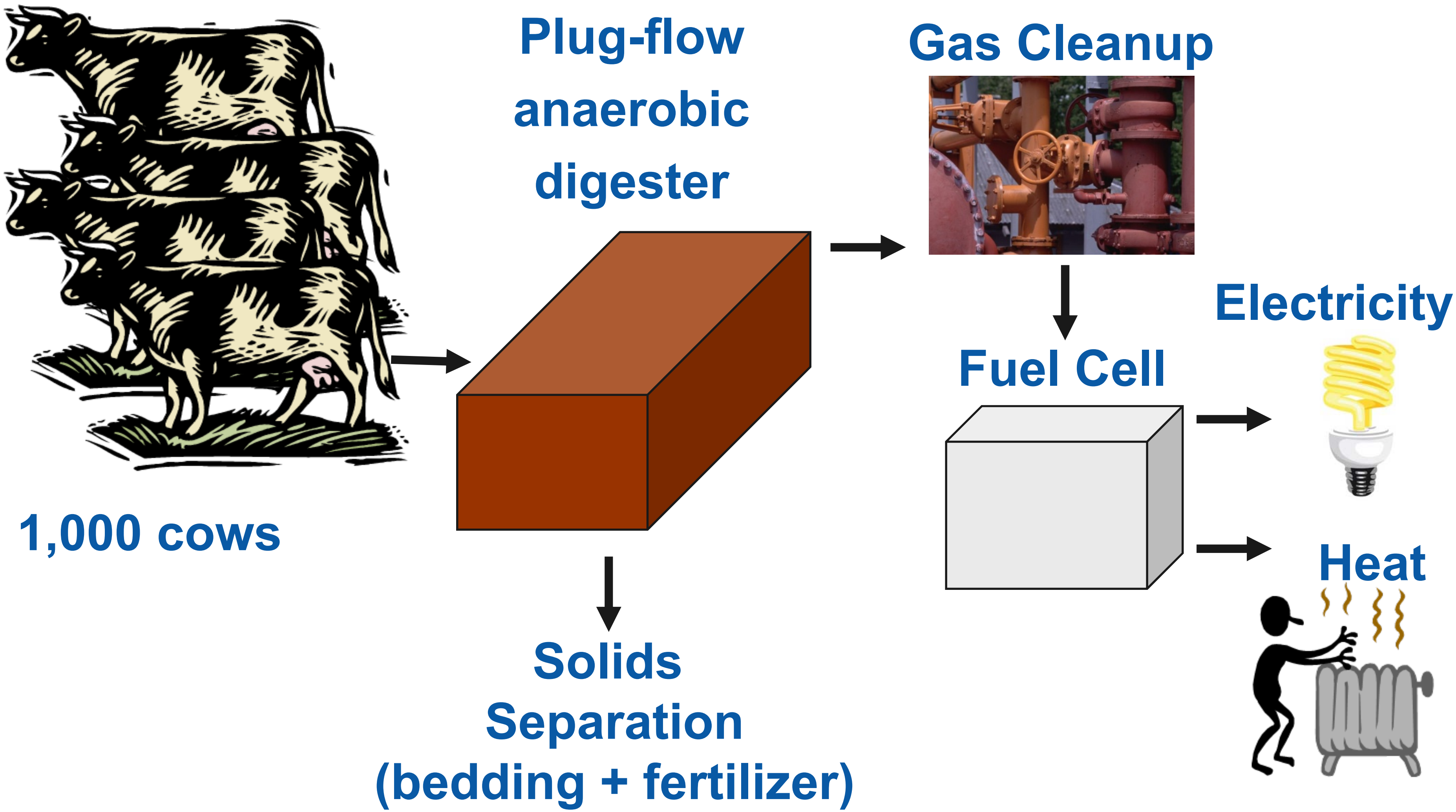
Hydrogen production from the fuel cell CHHP system is less expensive than SMR for small-scale systems.





Source: FCPower Model, molten carbonate fuel cell, version 1.1 and Current Forecourt Hydrogen Production from Natural Gas (1,500 kg per day) version 2.1.2

Technical Accomplishments – Example CHP Case; Dairy Farm Digester Gas



Technical Accomplishments – Dairy CHP Case – Data Gathering

Capital cost, O&M, Life, Performance

- Digester
- Gas cleanup
- Fuel cell system

Incentives

- Federal incentives
- State incentives

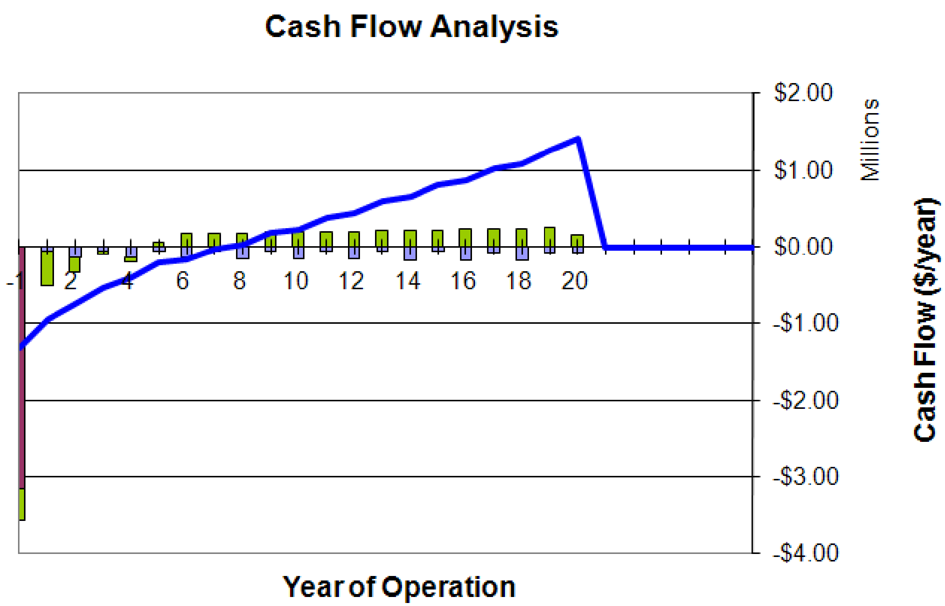
On-site energy demands

- Electricity hourly
- Heat hourly (including digester)

Energy costs

- Electricity ¢/kWh
- Heat $/MMBTU

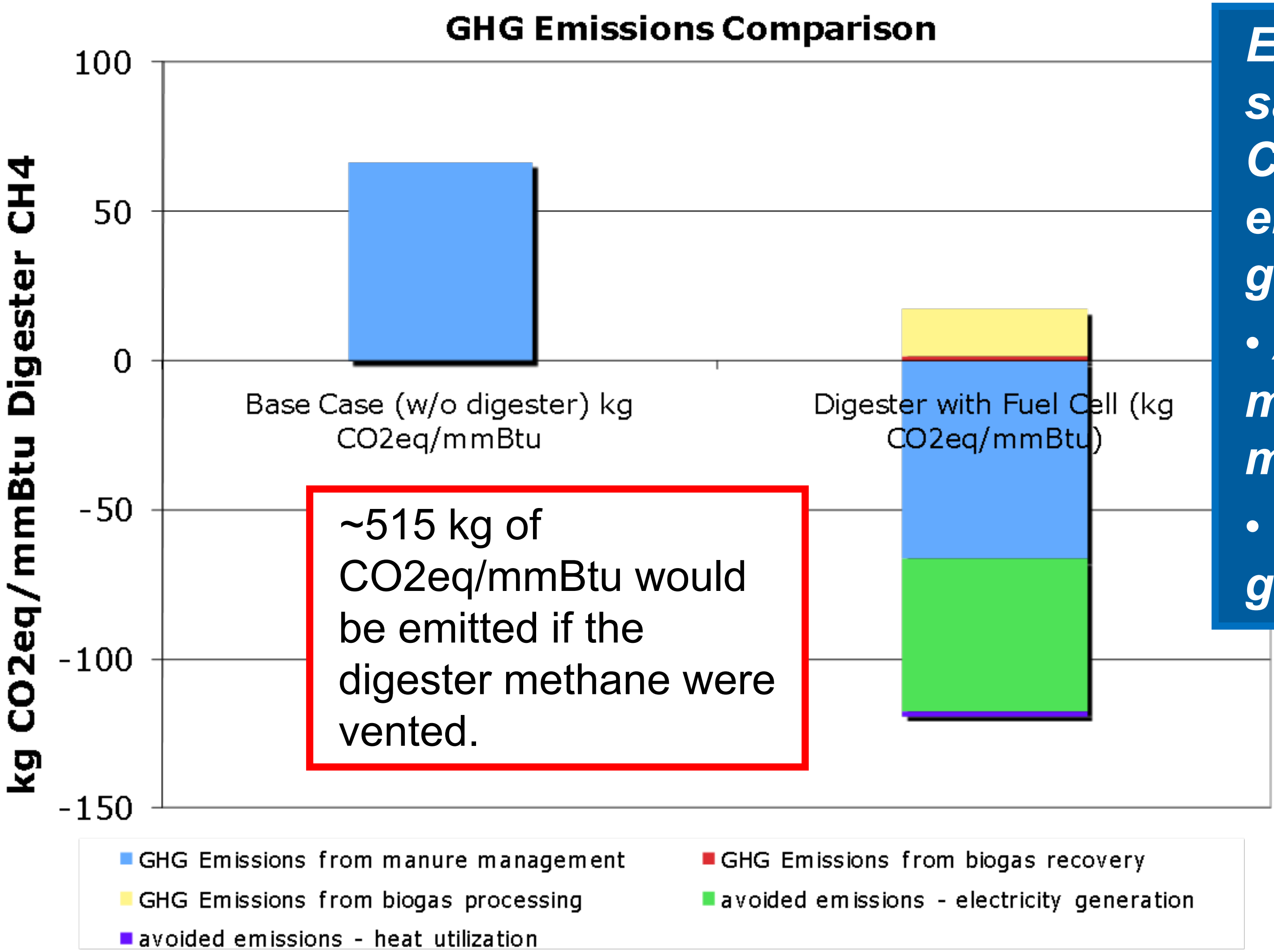
Technical Accomplishments – Dairy Case Results



Digester/fuel cell system would break even after ~7 years and give an 8.5% IRR assuming equivalent value for grid electricity and fuel cell electricity (~14¢/kWh)

CHHP System Annualized Costs	
Annualized costs	
Capital costs	$92,806
Decommissioning costs	$1,176
Fixed O&M	$14,422
Feedstock costs	$0
Other raw material costs	$0
Byproduct credits	-$43,590
Other variable costs	$8
Supplementary electricity	$2,702
Supplementary heat	$0
Total	$67,525

Technical Accomplishments – Emissions Projections



Emissions savings ~750 g CO2eq/kWh electricity generated:

- ***Alternative manure management***
- ***Displacing grid electricity***

Data Source: CARB, *Detailed California-Modified GREET Pathway for Liquefied Natural Gas (NG) from Dairy Digester BioGas,* CARB Stationary Source Division, Version 2.0, September 23, 2009.

Proposed Future Work

- The business case tab will be modified and enhanced as experience is gained from the business community.
- Additional specific case studies will be developed. When available, data from actual fuel cell installations will be used for comparison.
- The model will be used by NREL and other researchers to evaluate early transition scenarios and evaluate the potential impact on electricity systems and greenhouse gas emissions.
- SOFC fuel cells & residential sized systems will be added.
- The model will be enhanced in response to requests and needs identified through its use.
- The model will be integrated with the MSM and SERA models.

Summary

Relevance	• Model links distributed power and production of hydrogen for vehicle fuel • H2A-based discounted cash flow model dovetails with other DOE tools (H2A, HDSAM, MSM, HyDRA, SERA)
Approach	• Application combines fuel cell performance model with established cash flow analysis methodology • Excel-based tool is transparent and adaptable
Accomplishments	• Version 1.1 published • Presentations, webinars & one-on-one assistance for users • Custom analyses • Research, collaboration, & planning for version 1.2
Collaborations	• NREL H2 analysis team, business development & financial experts • Business research subcontractor
Proposed Future Work	• Addition of SOFC fuel cell • Addition of “business case” tab

Thank You

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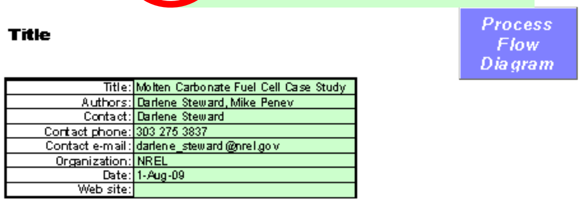
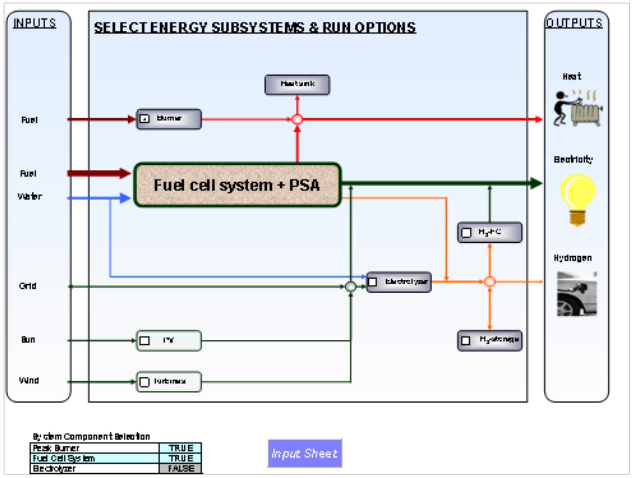
Technical Approach – Excel Based Tool is Transparent and Easy to Use

1 Click Process Flow Diagram

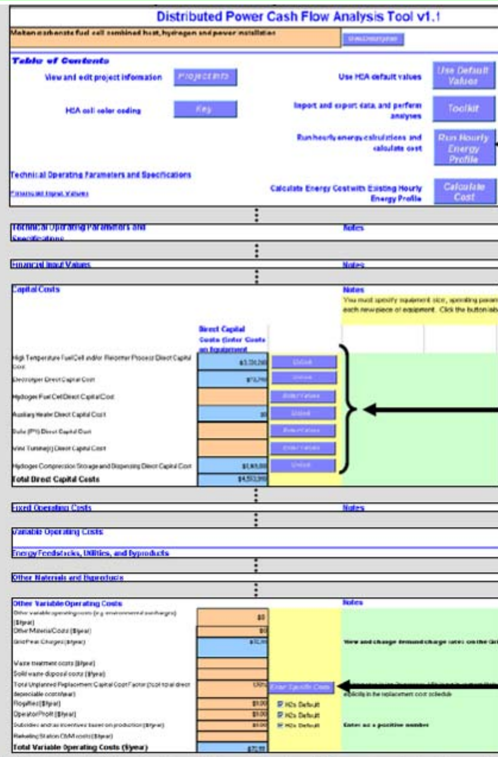


Title:	Molten Carbonate Fuel Cell Case Study
Authors:	Darlene Steward, Mike Penev
Contact:	Darlene Steward
Contact phone:	303 275 3837
Contact e-mail:	darlene_steward@nrel.gov
Organization:	NREL
Date:	1-Aug-09
Web site:	

2
- Configure system
- Click *Input sheet* button

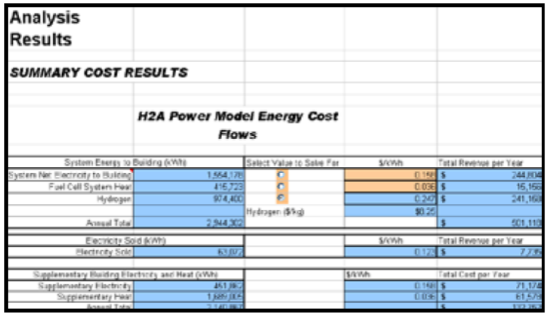


3
- Fill out *Input Sheet* completely
- Click *Run Hourly Energy Profile* button



Complete the *Input_Sheet_Template* worksheet from top to bottom. Some values in the *Capital Costs* and *Variable Operating Costs* sections can link to other worksheets; after entering values on those worksheets, click the *Input Sheet* button to return to the *Input_Sheet_Template* worksheet. In the *Other Materials and Byproducts* section, you must click the *Add* button to add materials.

4 View Results



After clicking the *Run Hourly Energy Profile* button in the *Input_Sheet_Template* worksheet, the model runs energy and cost calculations, and you are sent to the *Results* worksheet, where you can view the cost, energy, and emissions results of your system. Also see the *Financial Summary* and *Key Figures* worksheets, the tabs for which are adjacent to the *Results* tab.

Technical Accomplishments - Objective and Modeling Strategy for CHHP SMR Comparison

The purpose of the analysis is to compare hydrogen production costs for stand-alone SMR station and a MCFC CHHP application

- The SMR forecourt station was scaled to near 600 kg/day actual hydrogen production capacity to match maximum hydrogen output from 1.4MW(electric) MCFC operating at 95% utilization
- Hydrogen production is reduced below 600 kg/day by curtailing operation of the reformer.
- To model lower hydrogen production from the fuel cell, the fuel cell was scaled from 1.4 MW to 200kW maximum electrical output. This strategy is based on the assumption that the fuel cell size will be determined by the electricity demand and that the hydrogen purification equipment is integrated with the fuel cell and operates whenever the fuel cell is operating.

Technical Accomplishments - MCFC Hydrogen Production Cost (Varying Fuel Cell Size) - Assumptions

- Total storage volume set at 1,800 kg H2, but costs for CSD in FCPower model = 0 (cost correlation from SMR used for CSD costs in this analysis)
- AC demand (building + auxiliaries) at 95% fuel cell utilization
- Heat demand set at 100% of FC output
- FC electricity price set at grid price
- FC heat price set at NG price and assuming 80% efficient device

- For cases with incentives, federal incentive only is used
- Fuel cell uninstalled cost = $2,500/kW for all sizes of fuel cell
- Hydrogen purification equipment (PSA, PSA compressor, shift reactor, auxiliaries) scaled with hydrogen production rate using FCPower model equations.
- Replacement of fuel cell stack at 30% of FC uninstalled cost every 5 years (distributed annually)
- PSA compressor replaced at 10 years
- Shift catalyst replaced every 5 years at 15% of shift reactor uninstalled cost.
- Indirect capital costs set to the same percentages as forecourt SMR (assumed same level of maturity would result in comparable costs for items such as engineering and one-time permitting)
- Unplanned replacement cost factor = 0 (match SMR)

Technical Accomplishments – Dairy Case Energy & Material Values

	Units	Value
Methane production	Btu CH_4/day/ cow (kWh CH_4/day/cow)	45,218 (13.25)
Electricity production (assuming 45% average electrical efficiency for fuel cell)	kWh/day/cow	~6
Usable heat production (assuming 75% total efficiency for fuel cell)	kWh/day/cow	~4
Finished compost	Cubic yards/year/ cow	3.32
Electricity required for digester operation	kWh/cow/day	~1
Heat required for operation of chillers (for milk) and heating of the digester	kWh/cow/day	~1*
*0.014 tons chilling per cow per day per hour of milking		

Sources: Martin, John H. Jr. *A Comparison of Dairy Cattle Manure Management With and Without Anaerobic Digestion and Biogas Utilization*, EPA AgSTAR Program, June 2004.

EPA AgSTAR Handbook, Second Edition.

Technical Accomplishments – Dairy Case Cost Values

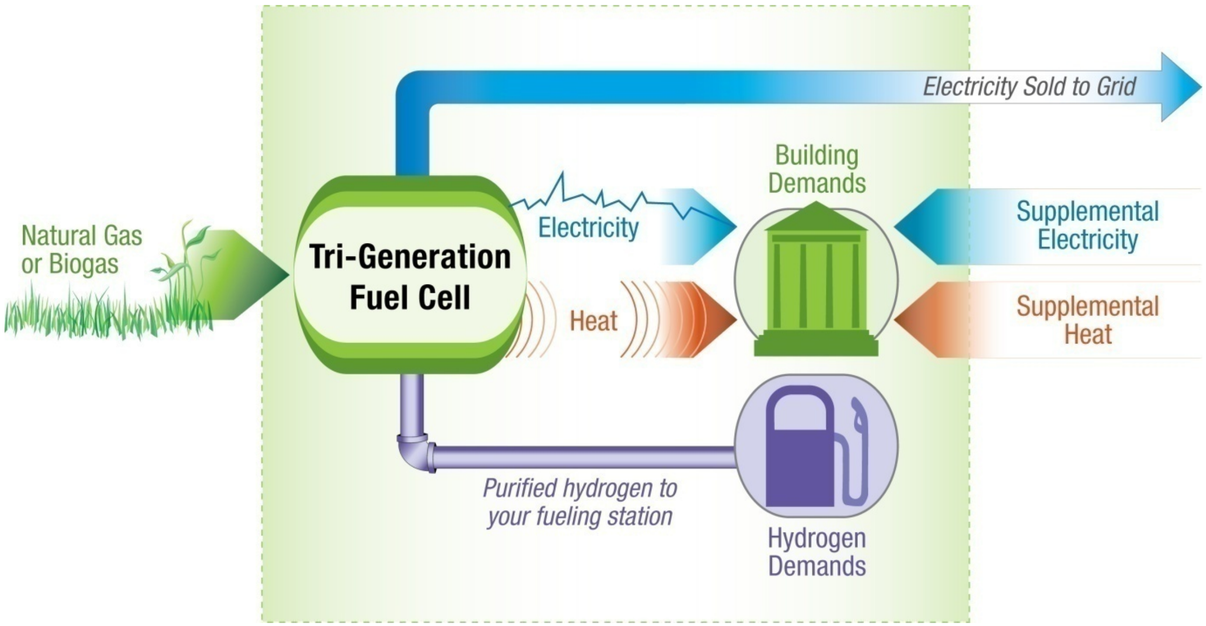
	Units	Value for 1,000 cow farm
Digester system installed cost	$K = [563*(number of cows) + 678,064]/10^3	1,170
Post-digestion solids separation system	% of total project capital cost ($K)	6.9 (98)
Hydrogen sulfide removal	% of total project capital cost ($K)	4.5* (64)
Utility hookup	% of total project capital cost ($K)	7.9 (112)
MCFC uninstalled cost	$/kW ($K), 300 kW system**	2,500 (750)
Federal tax incentive	$K	324
CA SGIP using renewable fuel	$K, $4.50/W for FC > 30kW using renewable fuel	1,350

*High end of cost range assumed for fuel cell purity requirements.
** 250 kW system would be required for 6kWh/day/cow average production.

Sources: Martin, John H. Jr. *A Comparison of Dairy Cattle Manure Management With and Without Anaerobic Digestion and Biogas Utilization*, EPA AgSTAR Program, June 2004.

EPA AgSTAR Handbook, Second Edition.

FCPower Model Website



http://www.hydrogen.energy.gov/fc_power_analysis.html