NREL National Renewable Energy Laboratory
*Innovation for Our Energy Future*

# Fuel Cell Power Model for CHHP System Economics and Performance Analysis

**Delivering Renewable Hydrogen Workshop – A Focus on Near-Term Applications**

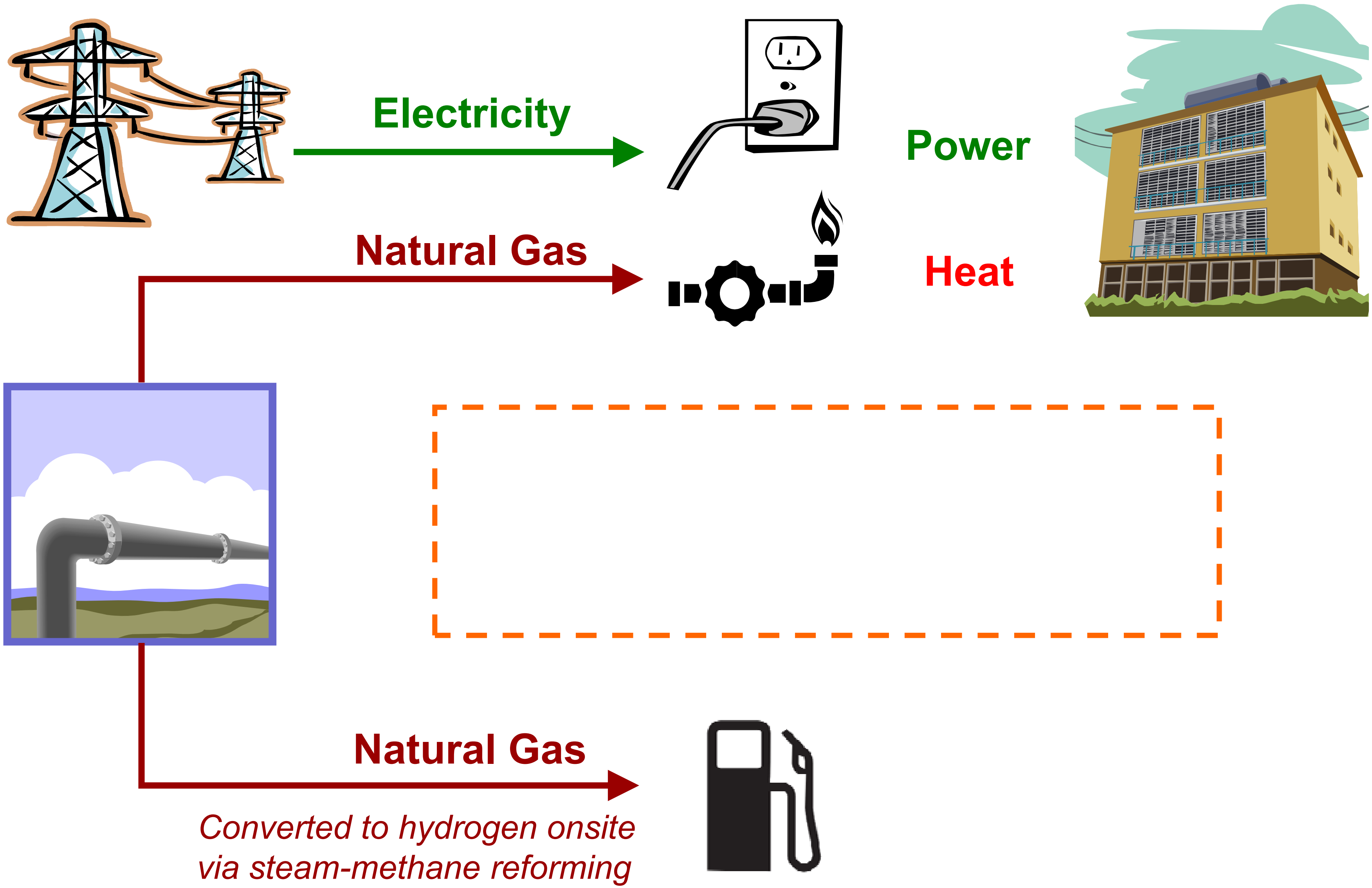

**Darlene Steward**


**November 16, 2009**

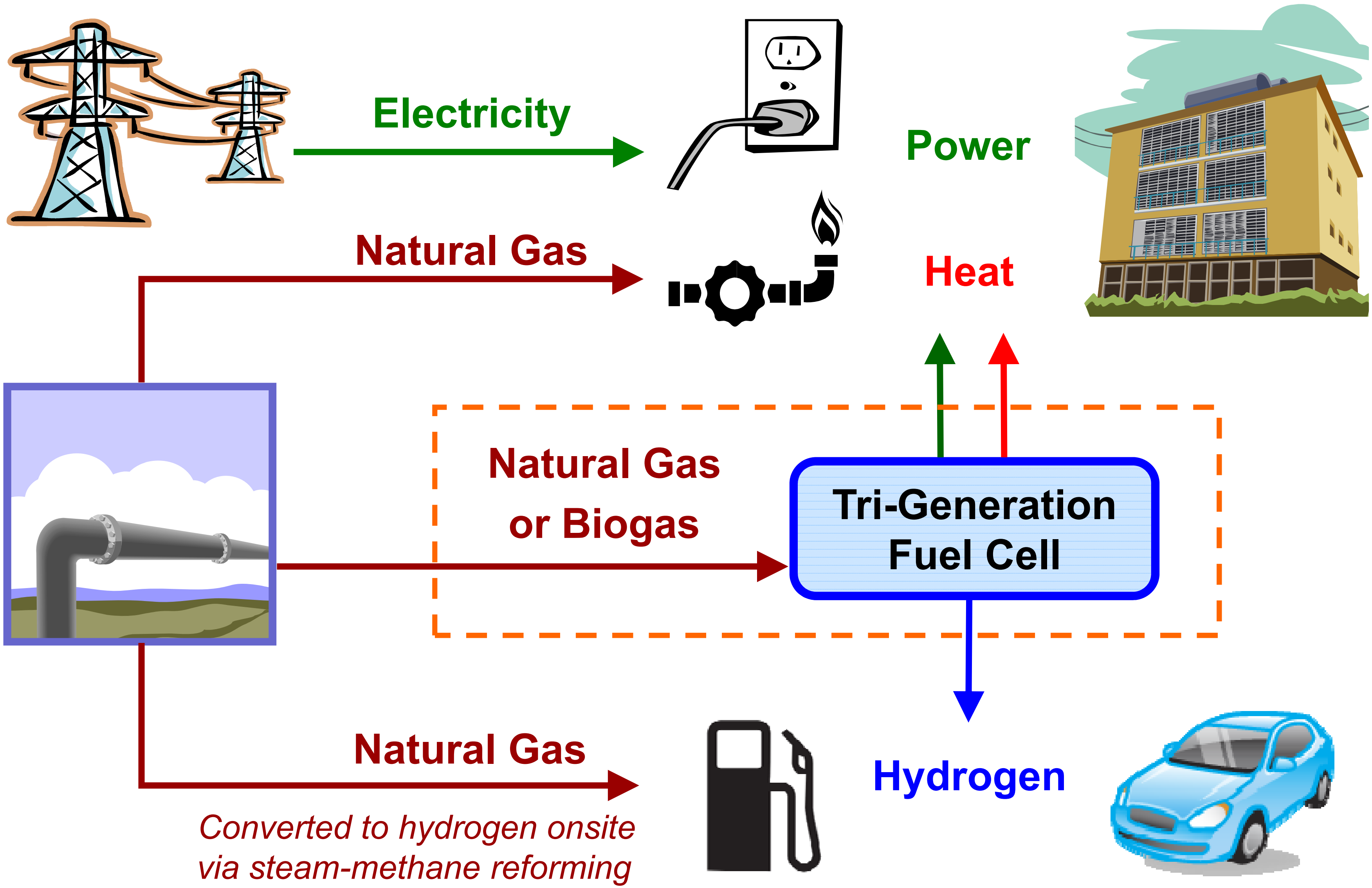

**NREL/PR-560-47123**


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

# Overview of the Tri-Generation Concept



# Overview of the Tri-Generation Concept



# FCPower Model Background

## Built on the "H2A" platform

**Need for "common ground" in economic analyses**

- Consensus on reasonable financial assumptions
- Common economic analysis methodology
- Common cost assumptions (technology maturity, common reference year for costs, etc.)

– **Allowed hydrogen researchers to talk to each other about technology costs**

## H2A Power Model – Use the same consistent economic analysis basis for a new CHP/CHHP model:

– Building Managers (first-pass estimates of fuel cell CHP system cost)
– Utilities (impacts of distributed generation)
– DOE/ systems analysts (scenarios for future energy mix)

# FCPower Model Objective

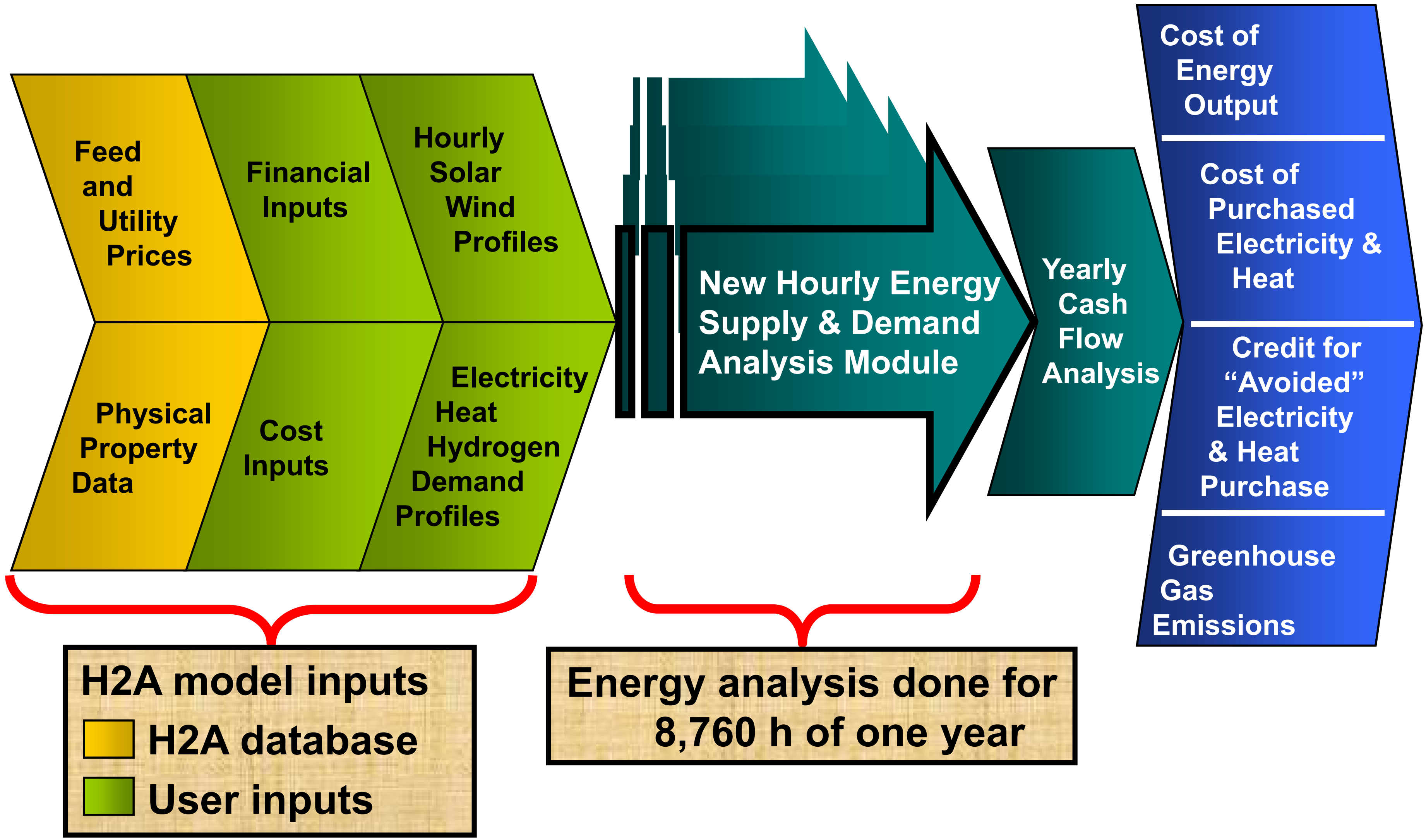
Develop a cost analysis tool that will be flexible and comprehensive enough to realistically analyze a wide variety of potential combined heat and power and hydrogen production scenarios

## Approach:

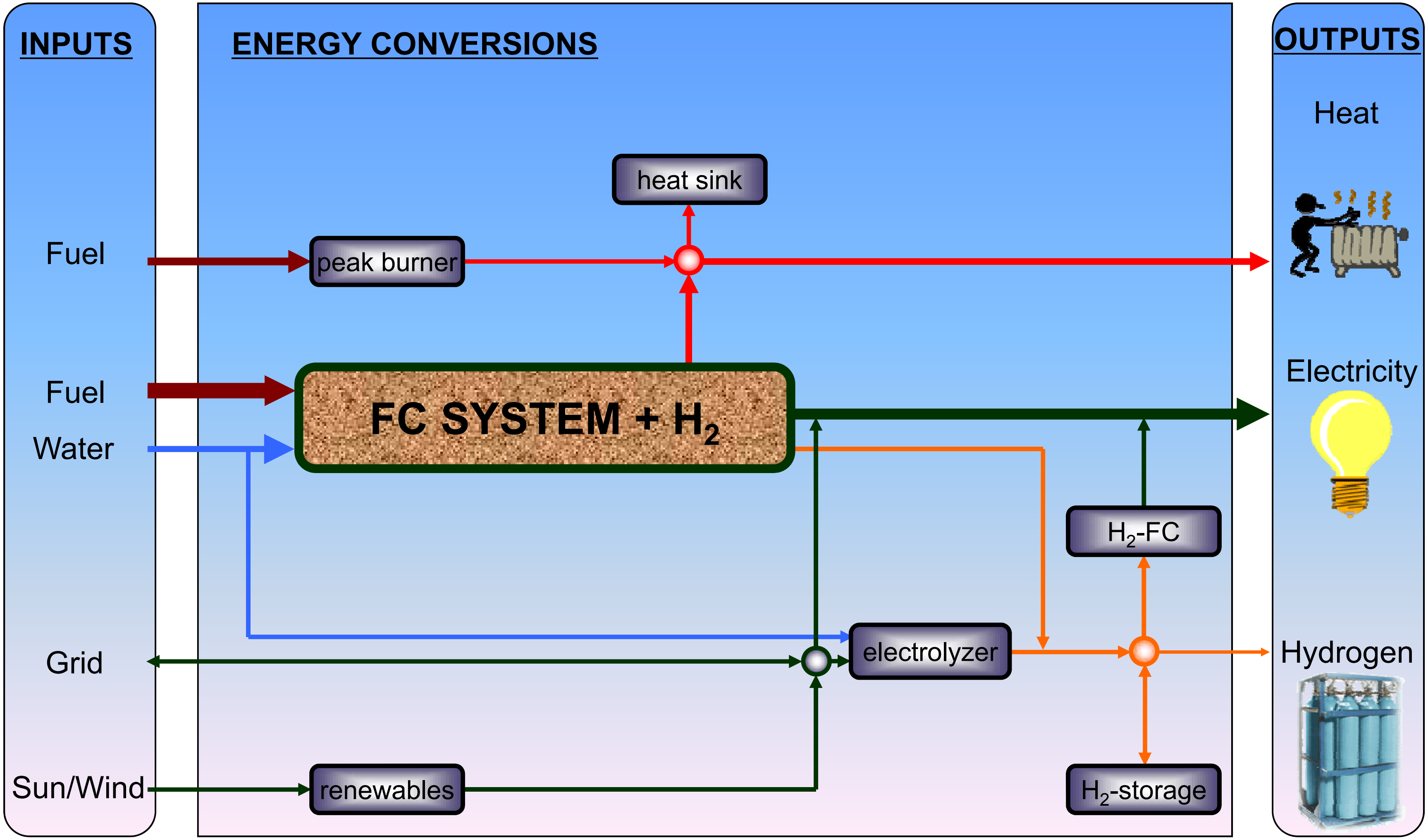
Develop an hour-by-hour energy analysis module that models the response of a stationary fuel cell to electricity, heat, and hydrogen demand profile

Integrate the results of the energy analysis into the H2A discounted cash flow methodology to develop a new stationary systems model

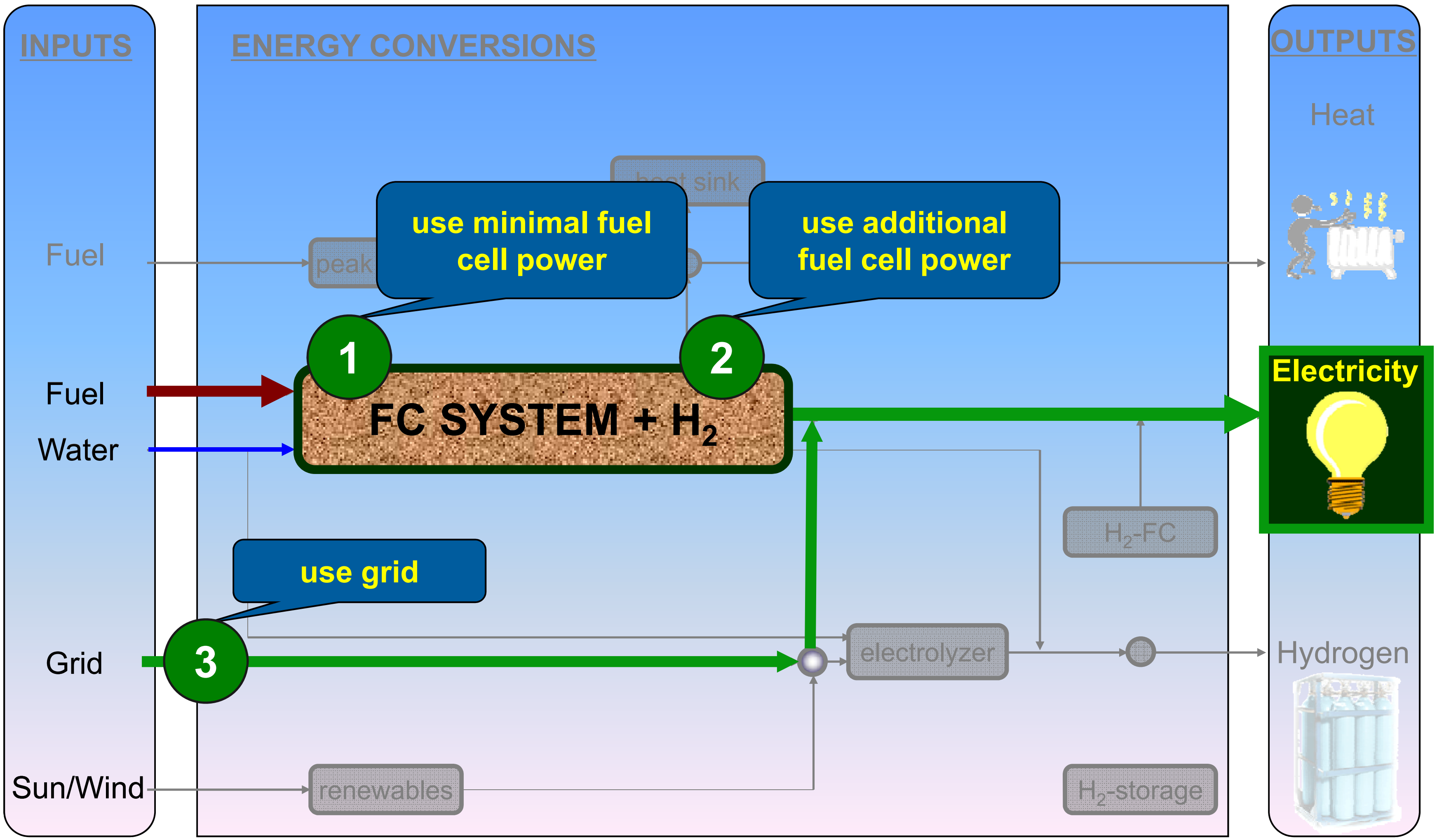
# FCPower Model Hourly Energy Analysis Module



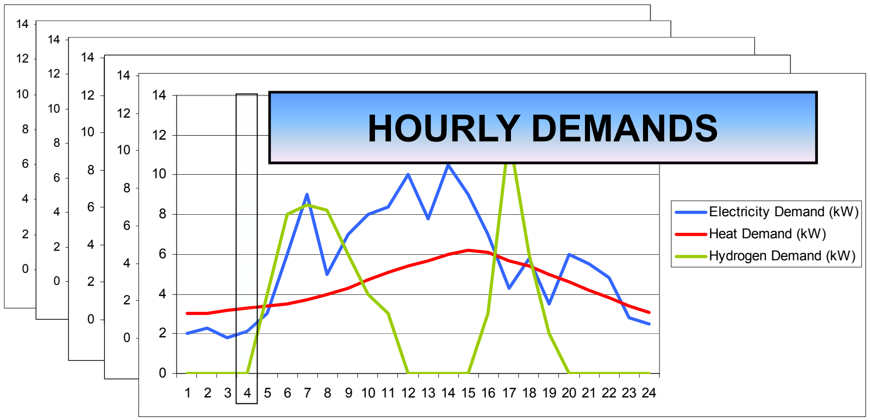
# Technology Selection for Hourly Energy Analysis



# Dispatch Sequence for Electricity Generation



# Integration of Demand Profiles, Renewables Availability, & Grid Cost Structure

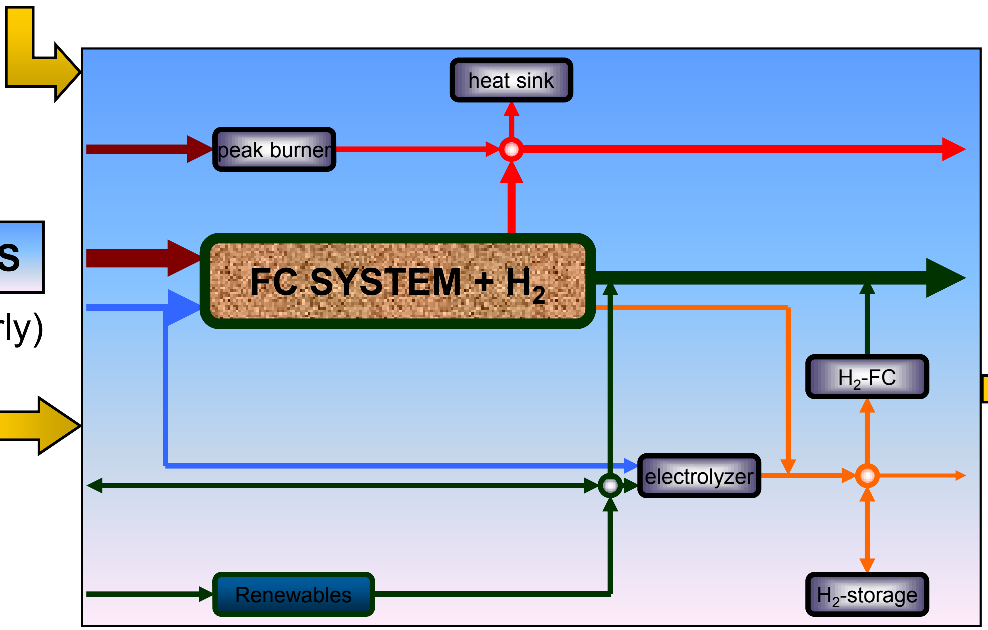



## Enter Process Specifications (default values will be provided)

Download or enter hourly demand profiles
Download or enter hourly renewable energy profiles
Enter grid electricity price profile (peaking price structure)
Enter equipment capital costs
Enter equipment capacity, operating parameters, and operating costs

## PRICE SCHEDULES

- Grid electricity (hourly)
- Fuel prices
- Water price




## ENERGY FLOWS ($)

- Delivered electricity
- Delivered heat
- Delivered hydrogen
- Used fuel
- Used grid electricity
- Sales to grid

# Model Features

- Automated import of load profiles
  - Profiles from building models (e.g., EnergyPlus)
  - Metered prior-year data for the building(s)
  - Estimated profiles from utility bills and similar building types
- Solar and wind resource data can be imported
  - Model algorithm estimates electrical output based on resource data and user input
- Detailed grid power purchase structure
- Net metering
- GHG tables from GREET 1.8 (onsite and upstream GHG emissions calculations)
- Financial summary sheet

# Model Features (cont.)

Comprehensive financial analysis for entire system life

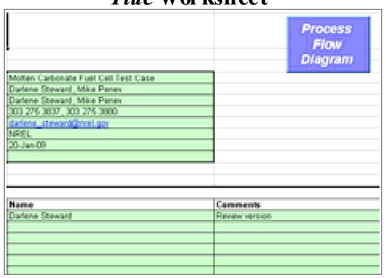
- Analysis of economic incentives
- Separate depreciation schedules for each subsystem
- Debt and equity financing
- Construction period and startup analysis
- Detailed fixed-operating-cost calculations
  - Labor
  - Overhead
  - Property taxes and insurance
  - Rent
  - Permitting and licensing
  - Maintenance costs
- Detailed variable-cost calculations
  - Waste treatment and disposal costs
  - Production based tax incentives
  - Operator profit and royalties

# Getting Started – PFD (Configuring the System)

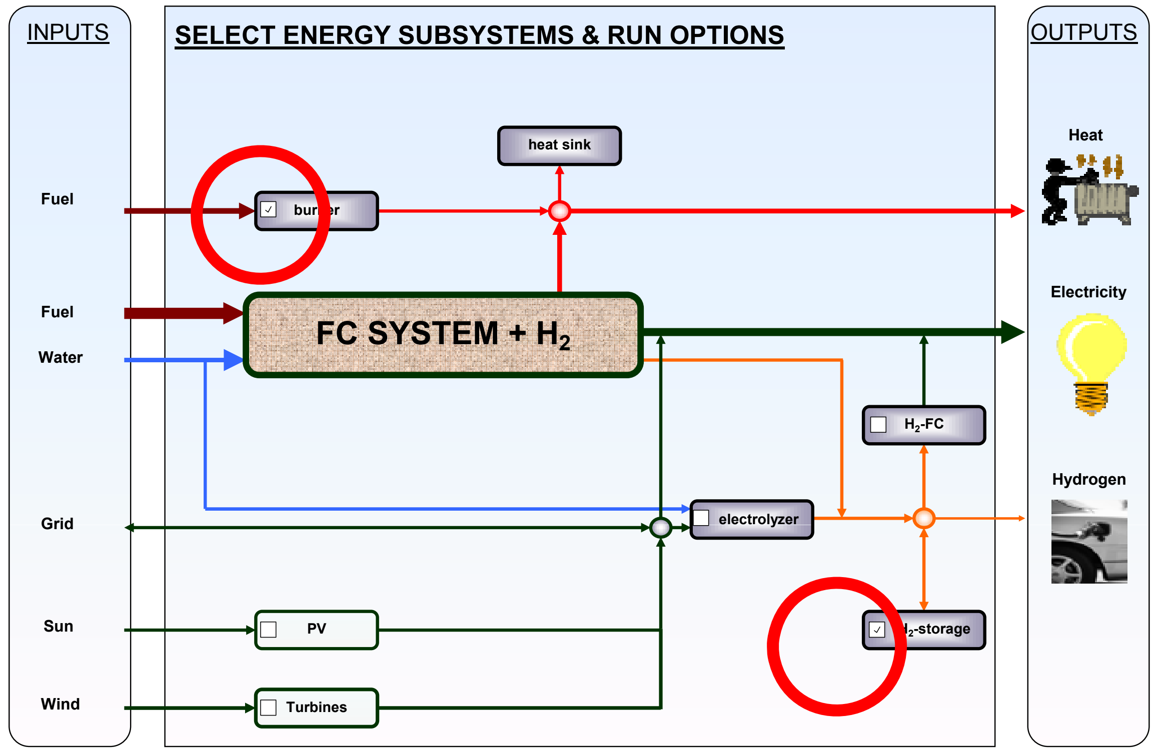
1

Click *Process Flow Diagram* button

*Title* worksheet




The model opens in the *Title* worksheet. Click the button to proceed to the *Process Flow Diagram* worksheet.

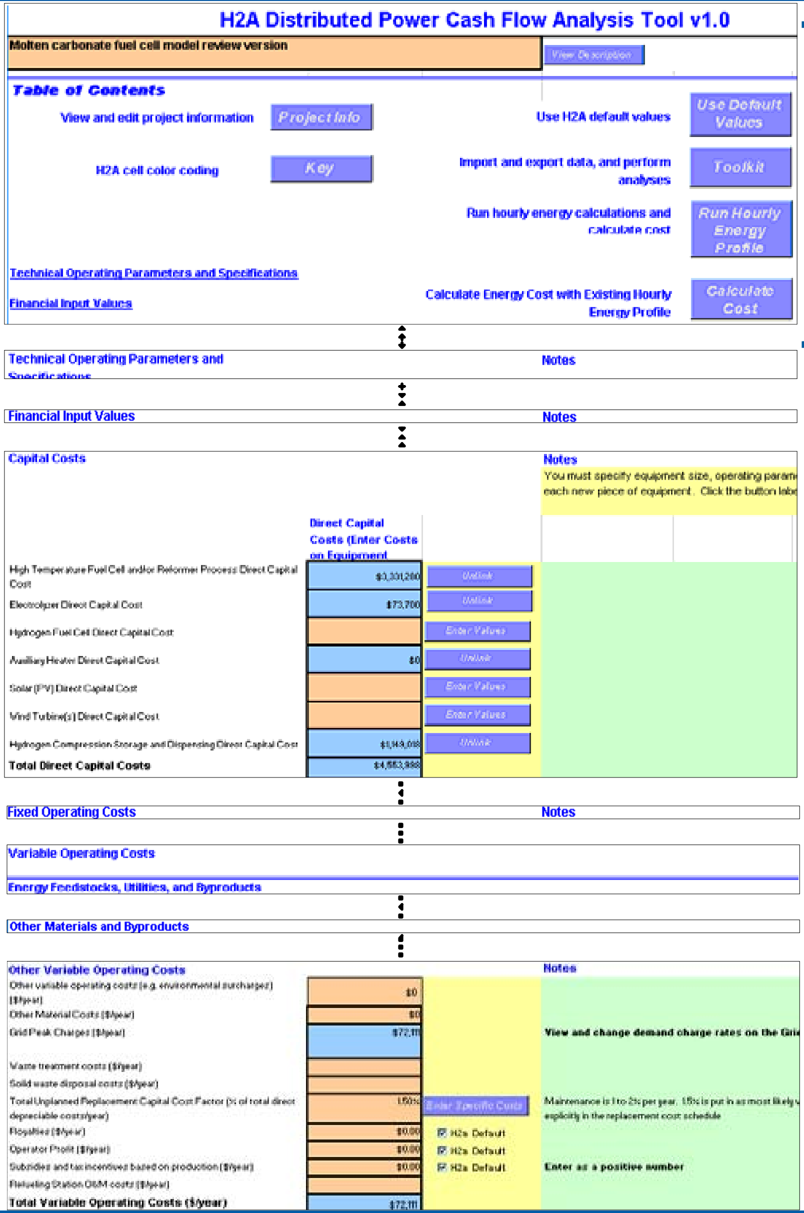



- Select *Subsystems* by clicking checkboxes on the “PFD” tab
- Select *$H_2$ Storage* if modeling a tri-generation system
- Note: *Fuel Cell System* is always selected.

2

- Configure system
- Click *Input Sheet* button

# FCPower Model Input Sheet – Central Location for Data Input and Navigation




Buttons that control import and export of data and calculations

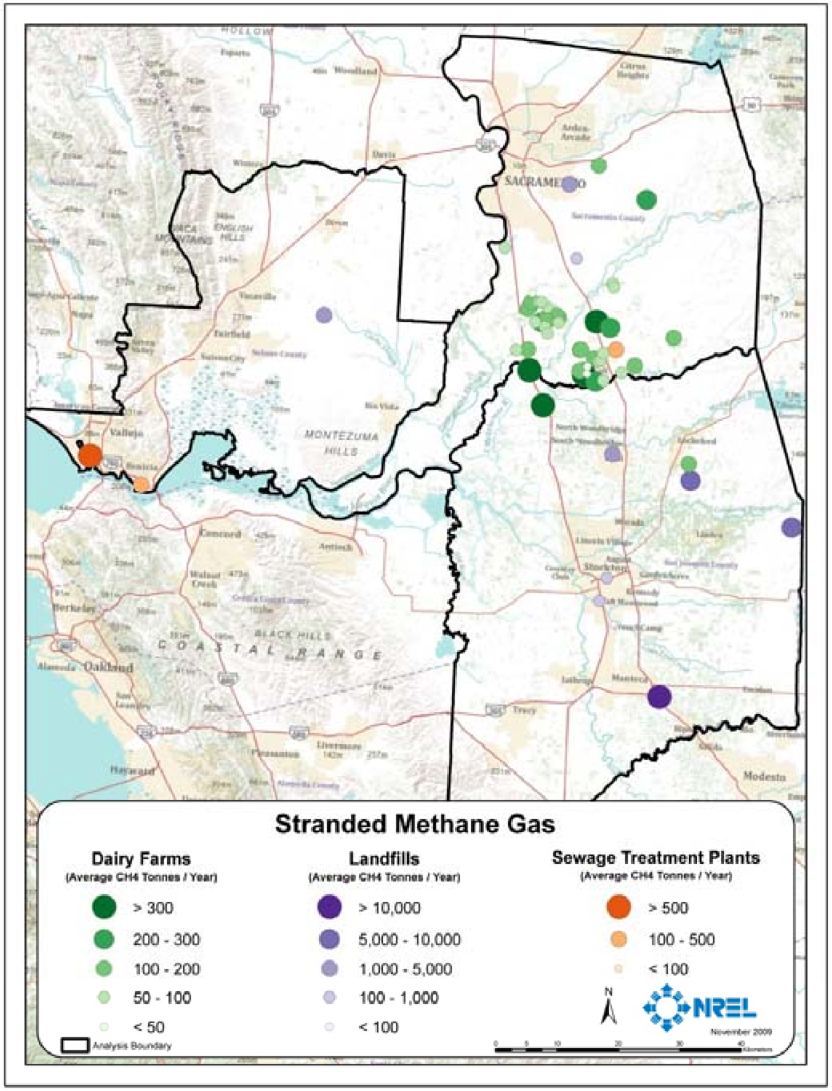
- Use the "Toolkit" button to import hourly load profiles

Links to capital cost and equipment specification sheets

Incentives, depreciation, and fixed operating costs

Variable operating costs including link to grid electricity price structure

# Methane Sources in the Sacramento Area




- About 5.5 MW of electricity could be generated from digester methane

# Economic Evaluation of Fuel Cell Installation at a Dairy

## Hypothetical facility profile:

1,000 cows housed in a free-stall barn

Biogas system:

- Manure collection
- Plug-flow anaerobic digester
- Biogas collection and purification
- Digester waste press separator
    - Windrow composting of solids
    - Field application of water
- Molten carbonate fuel cell for electricity and heat production
    - Electricity not used onsite is fed to the grid

# Energy & Material Values

| | Units | Value |
|---|---|---|
| Methane production | Btu CH4/day/ cow (kWh CH4/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.**

# 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.**

# Analysis Results for 1,000 Cow Dairy

| 1,000 cow dairy | Electricity (kWh/y) | Heat (kWh/y) |
|---|---|---|
| Used onsite | 367,920 | 367,920 |
| Sold | 1,810,190 | |
| Total | 2,178,110 | 367,920 |

Overall system efficiency is 54% based on heat used.
Utilization of available heat is only 26%.

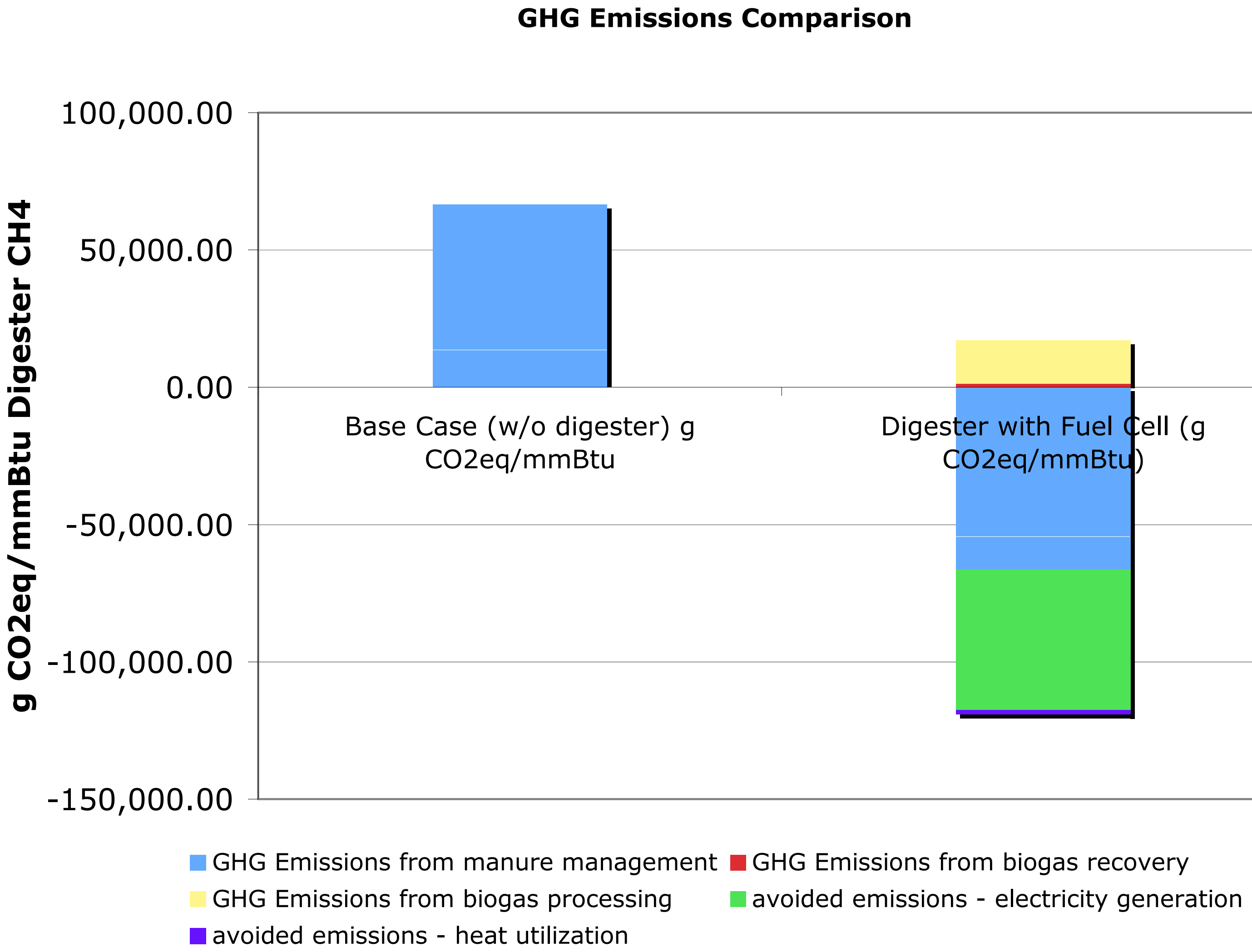
# Analysis Results for 1,000 Cow Dairy

**CHHP System Annualized Costs**

| **Annualized costs** | |
|---|---|
| Capital costs | $55,461 |
| Decommissioning costs | $3,227 |
| Fixed O&M | $26,371 |
| Feedstock costs | $0 |
| Other raw material costs | $0 |
| Byproduct credits | -$49,090 |
| Other variable costs (including utilities) | $9 |
| **Total** | $35,978 |

For comparison, purchase of natural gas for chillers would be $13,444/year.

# GHG Emissions Comparison




**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.**

# Thank You

## Contact Information:
Darlene.steward@nrel.gov