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Fuel Cell Power Model for CHP and CHHP Economics and Performance Analysis

Darlene Steward

&

Mike Penev

National Renewable Energy Laboratory

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Outline

Fuel cell basics

Fuel Cell Power Model introduction

Dairy case study/tutorial

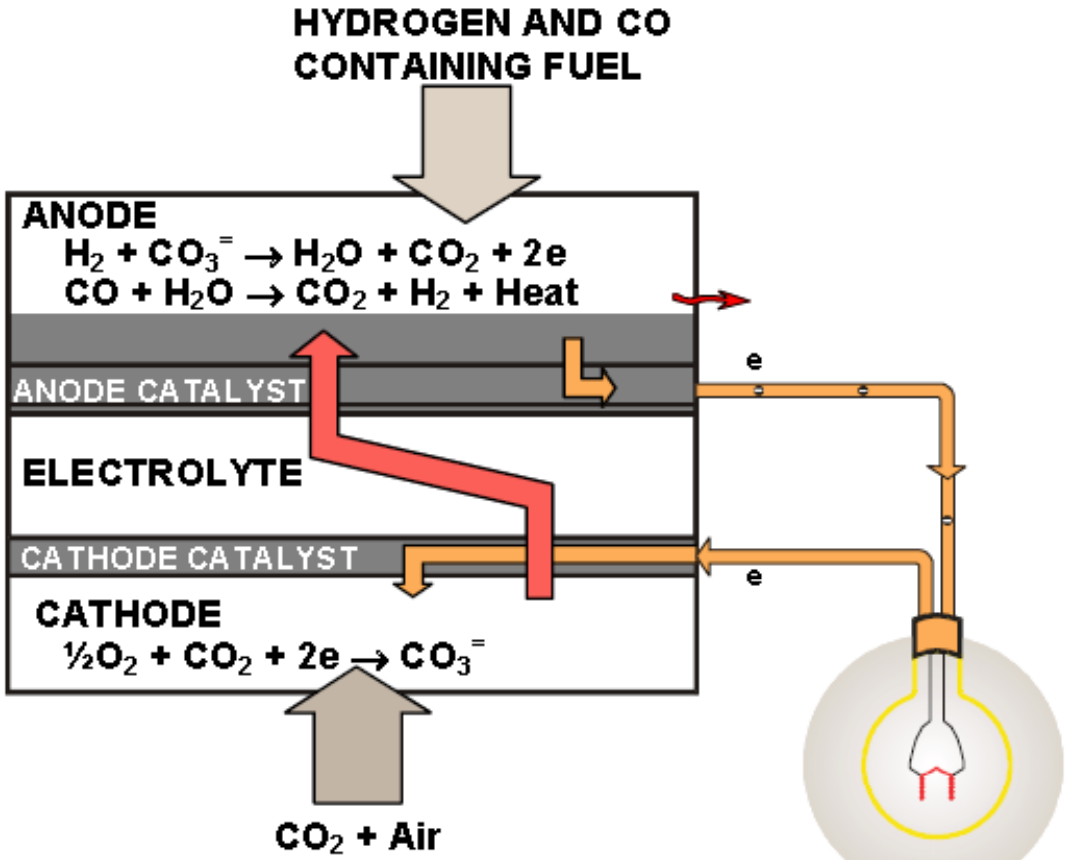
Costs and incentive values shown in this presentation were developed for demonstration purpose only.

Fuel Cell Basics

Fuel Cell General Types

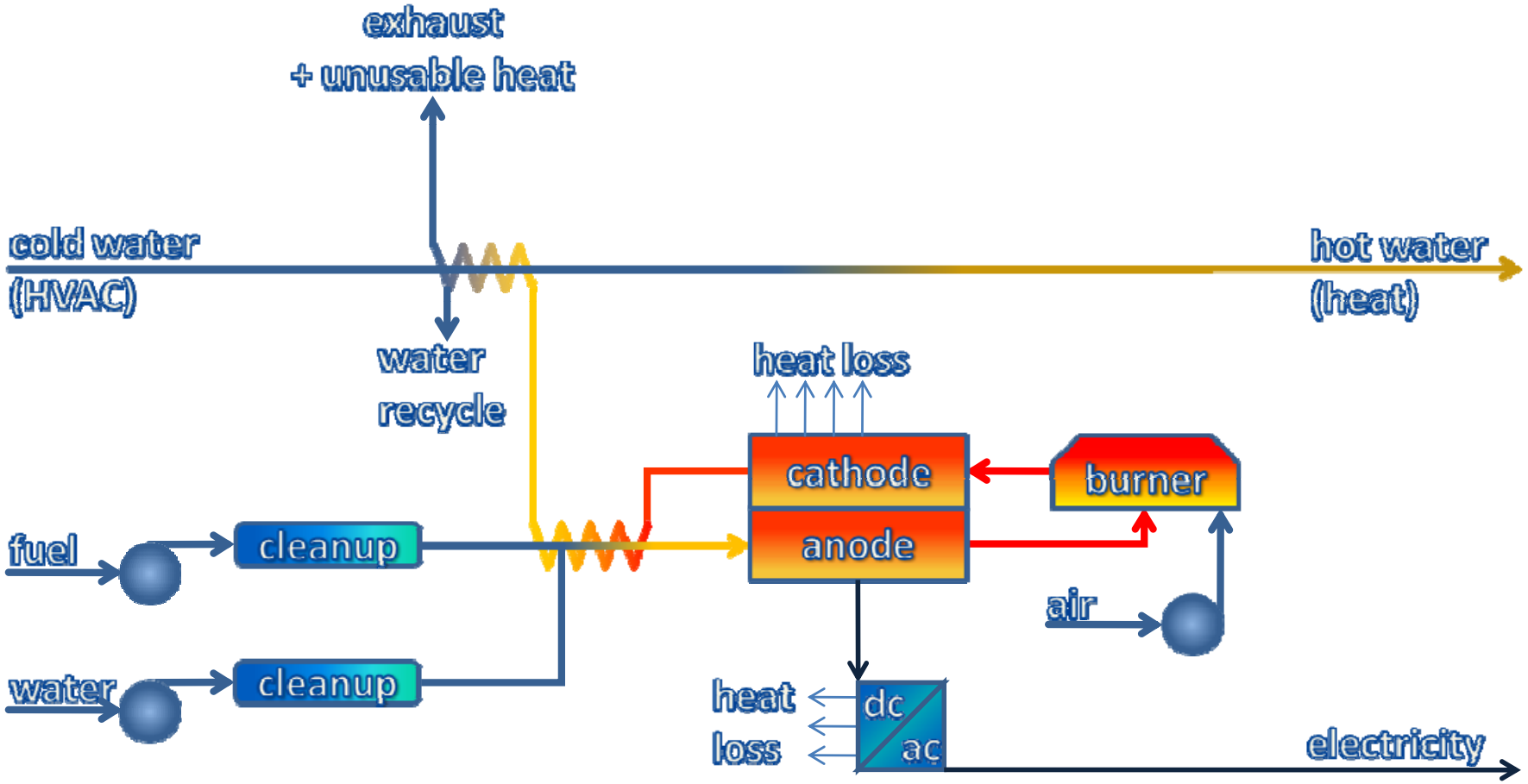
- **Proton Exchange (PEM)**
  - membrane fuel: H2
  - system fuel: hydrogen, low CO syngas
- **Phosphoric Acid (PAFC)**
  - membrane fuel: H2
  - system fuel: syngas
- **Solid Oxide (SOFC)**
  - membrane fuel: H_2, CO, CH_4
- **Molten Carbonate (MCFC)**
  - membrane fuel: H_2, CO, CH_4
- **Others:**
  - direct methanol (DMFC)
  - alkaline (AFC)

MCFC Basics

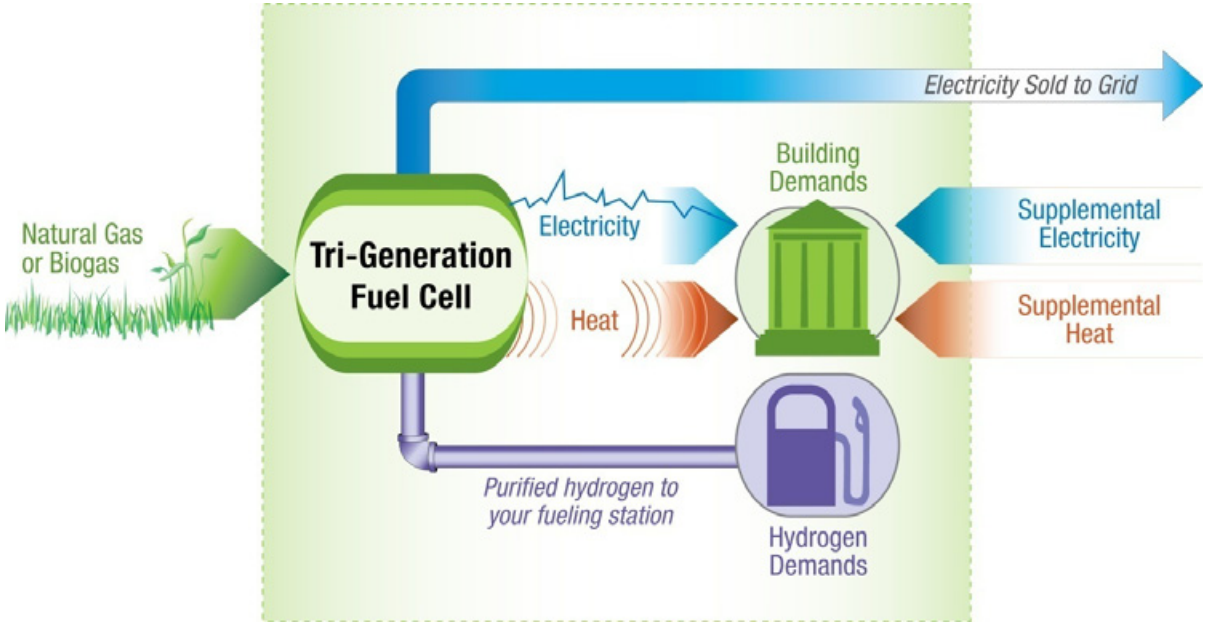


Schematic of MCFC operation (EG&G Technical Services 2004)

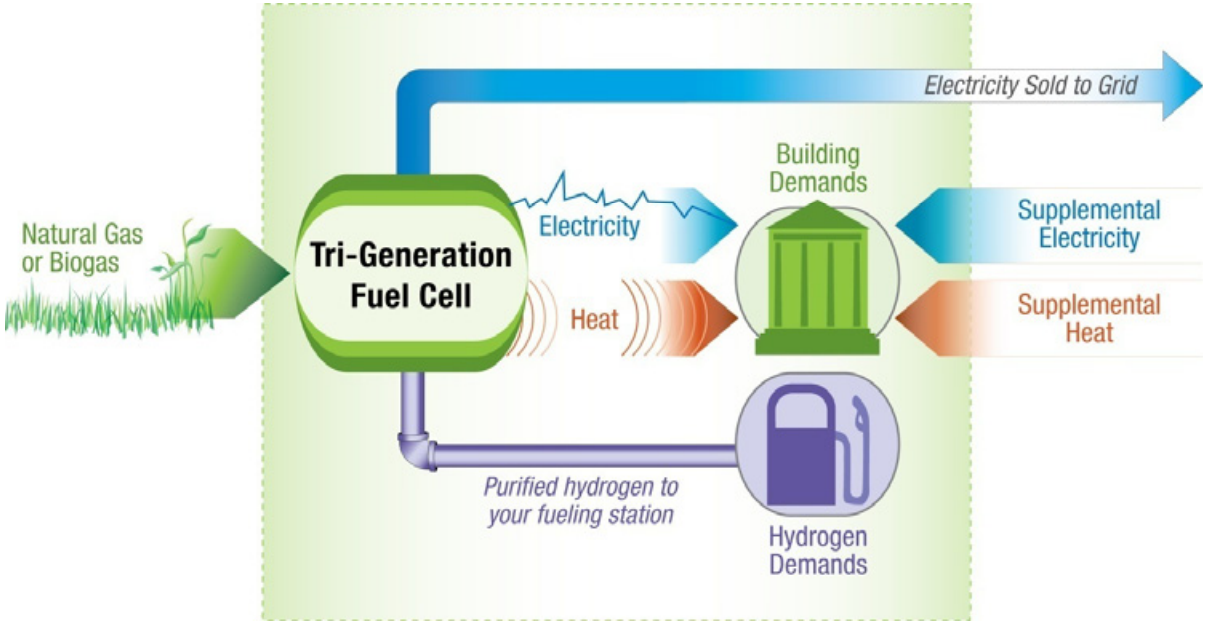
MCFC System Configuration



Fuel Cell Power Model Introduction

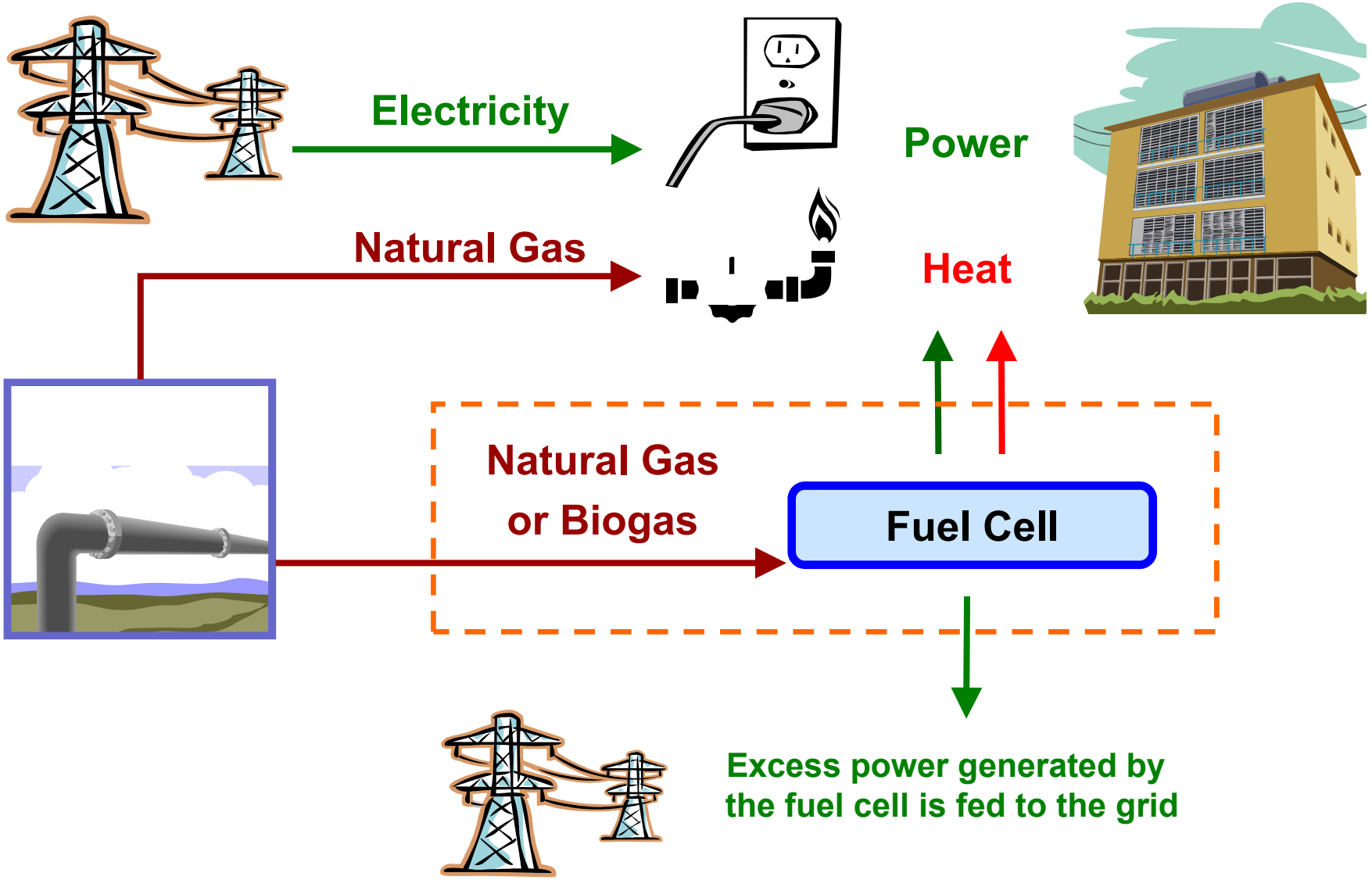


FCpower Model

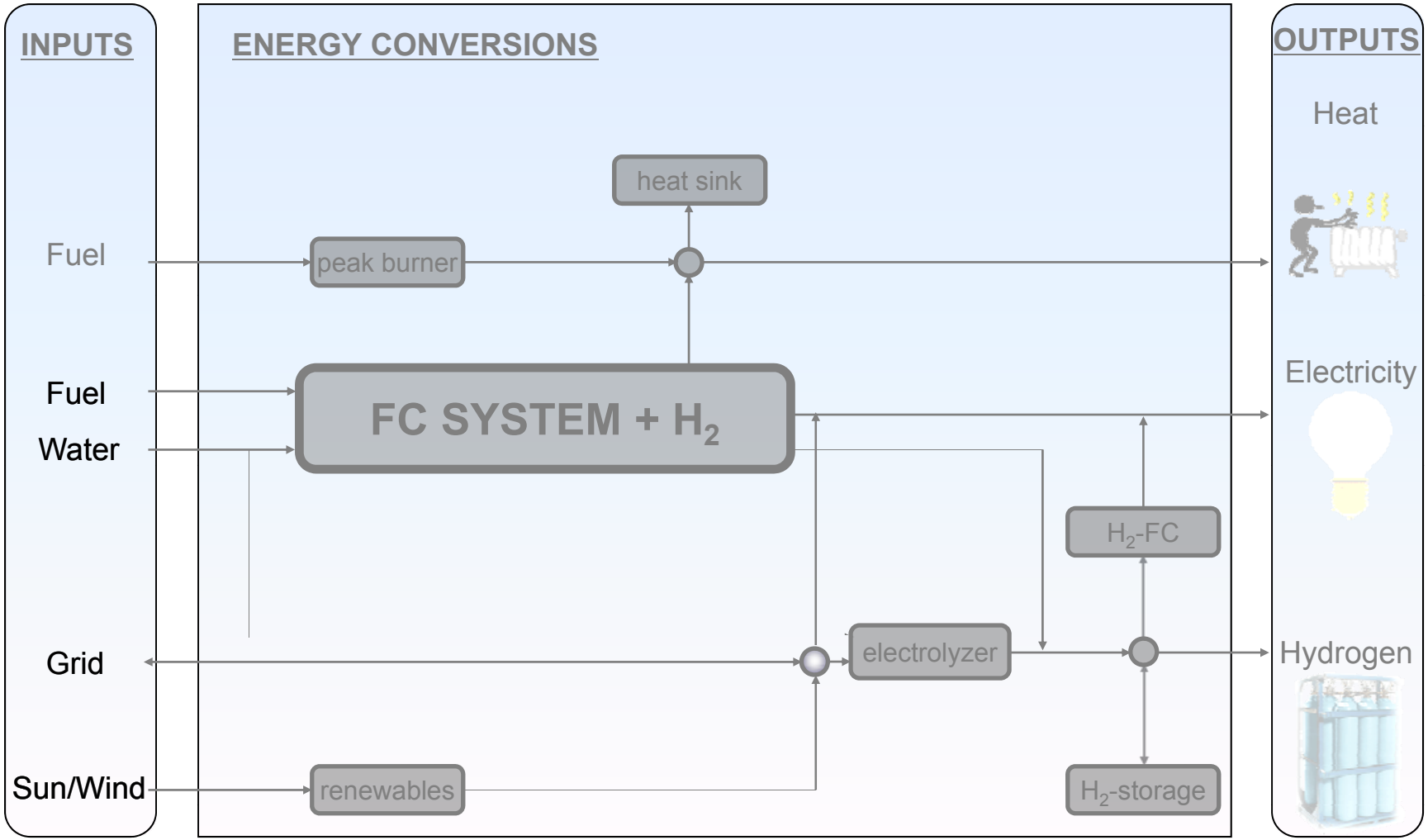


http://www.hydrogen.energy.gov/fc_power_analysis.html

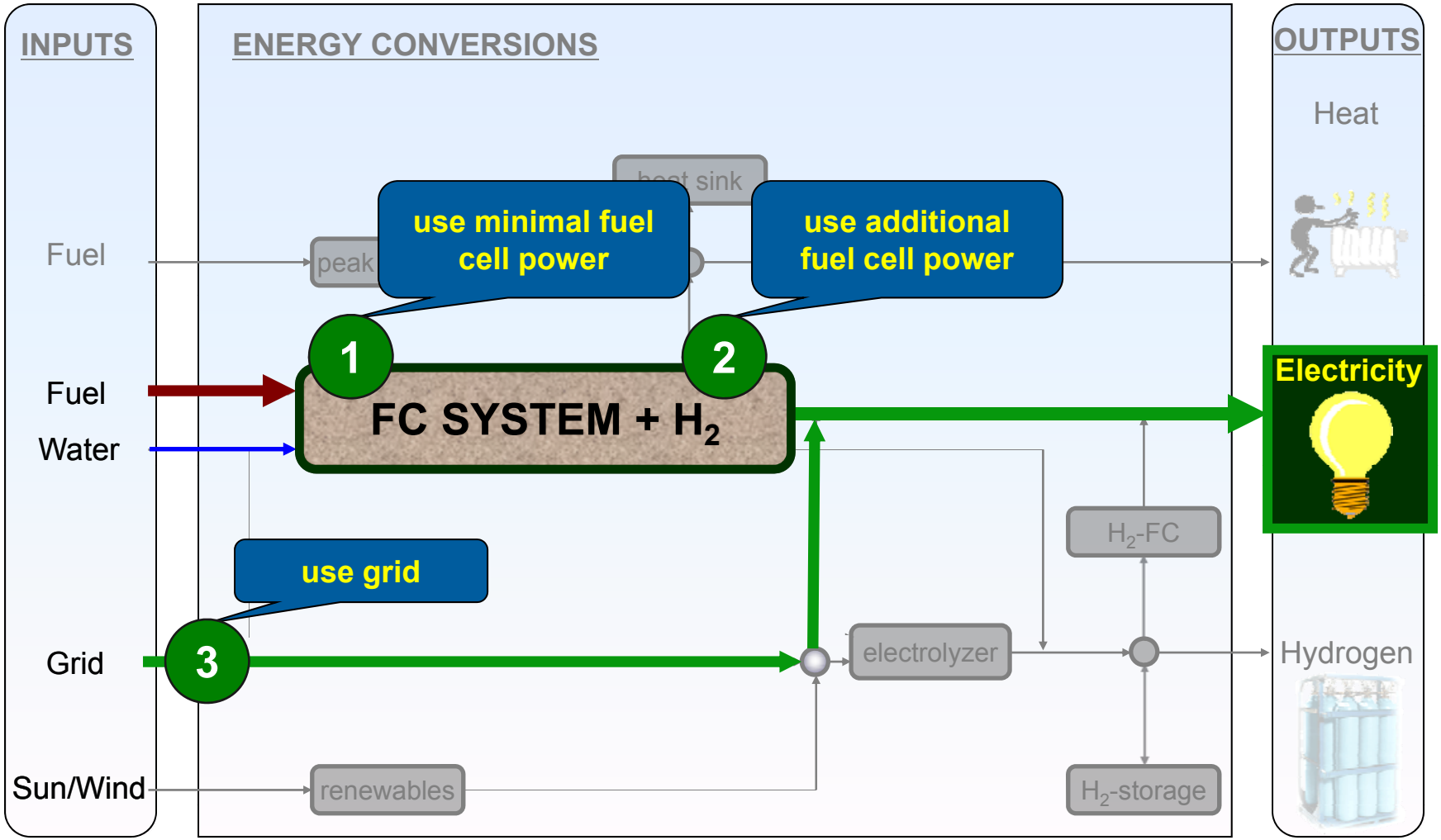
Overview of Combined Heat & Power Concept



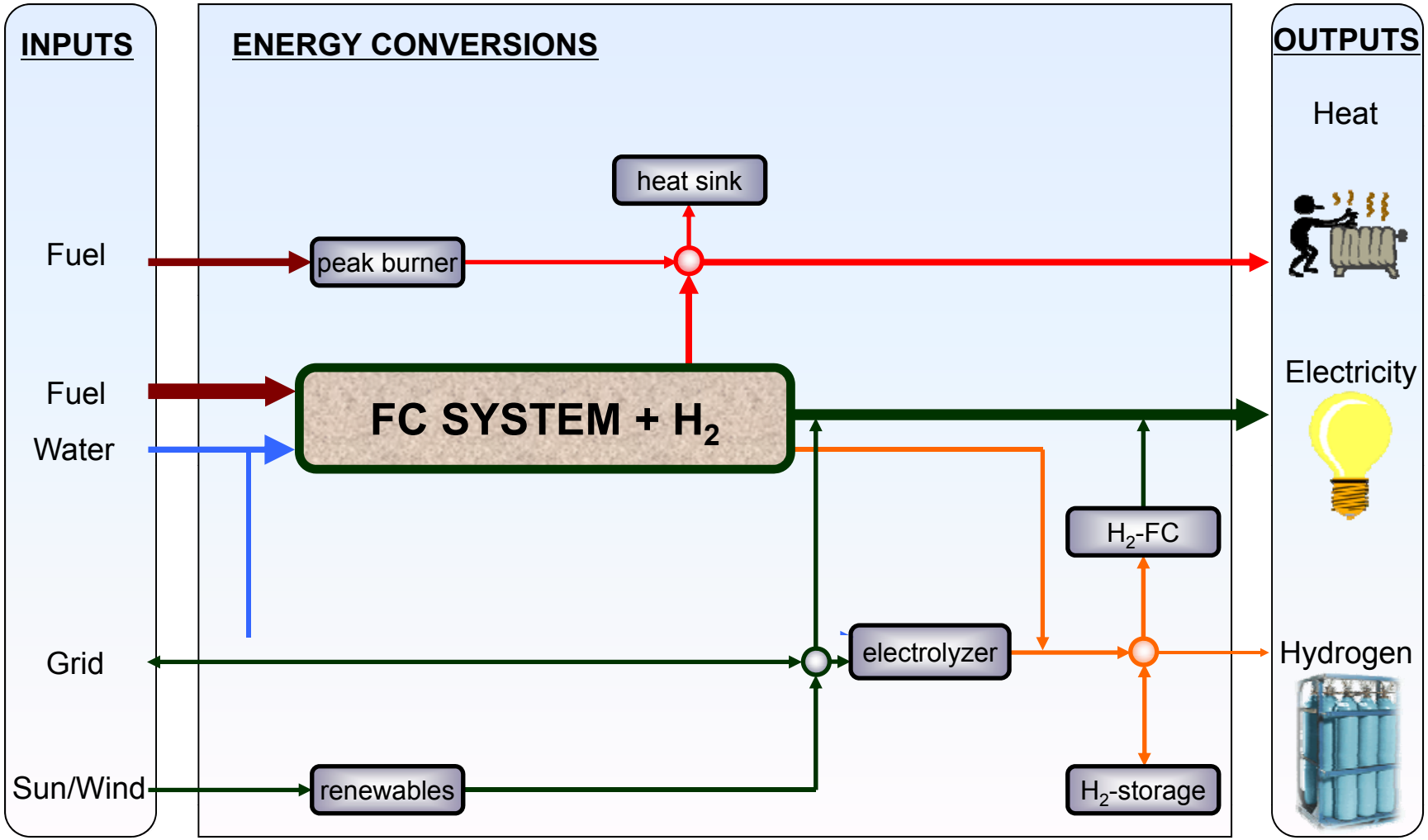
Dispatch Sequence for Electricity Generation



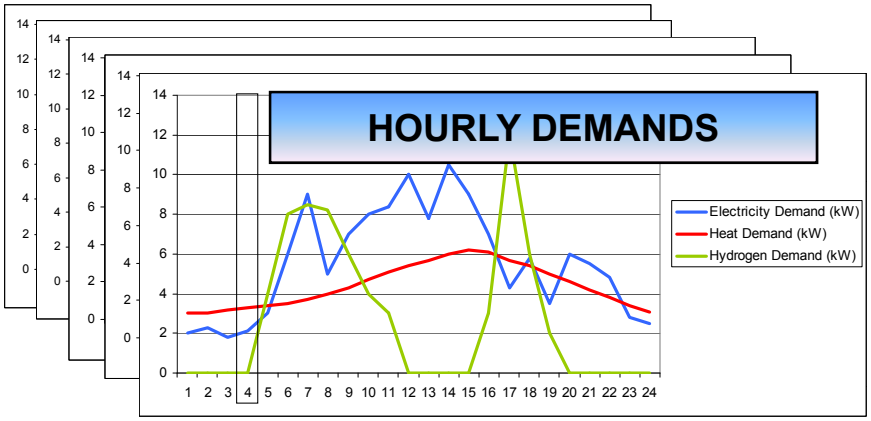
Dispatch Sequence for Electricity Generation



Technology Selection for Hourly Energy Analysis



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

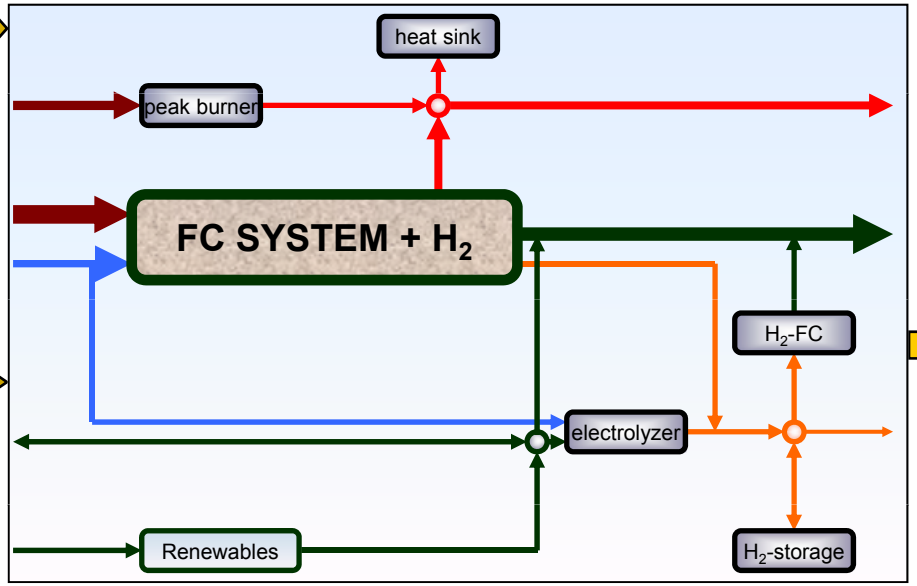


Enter Process Specifications (default values will be provided)

- 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

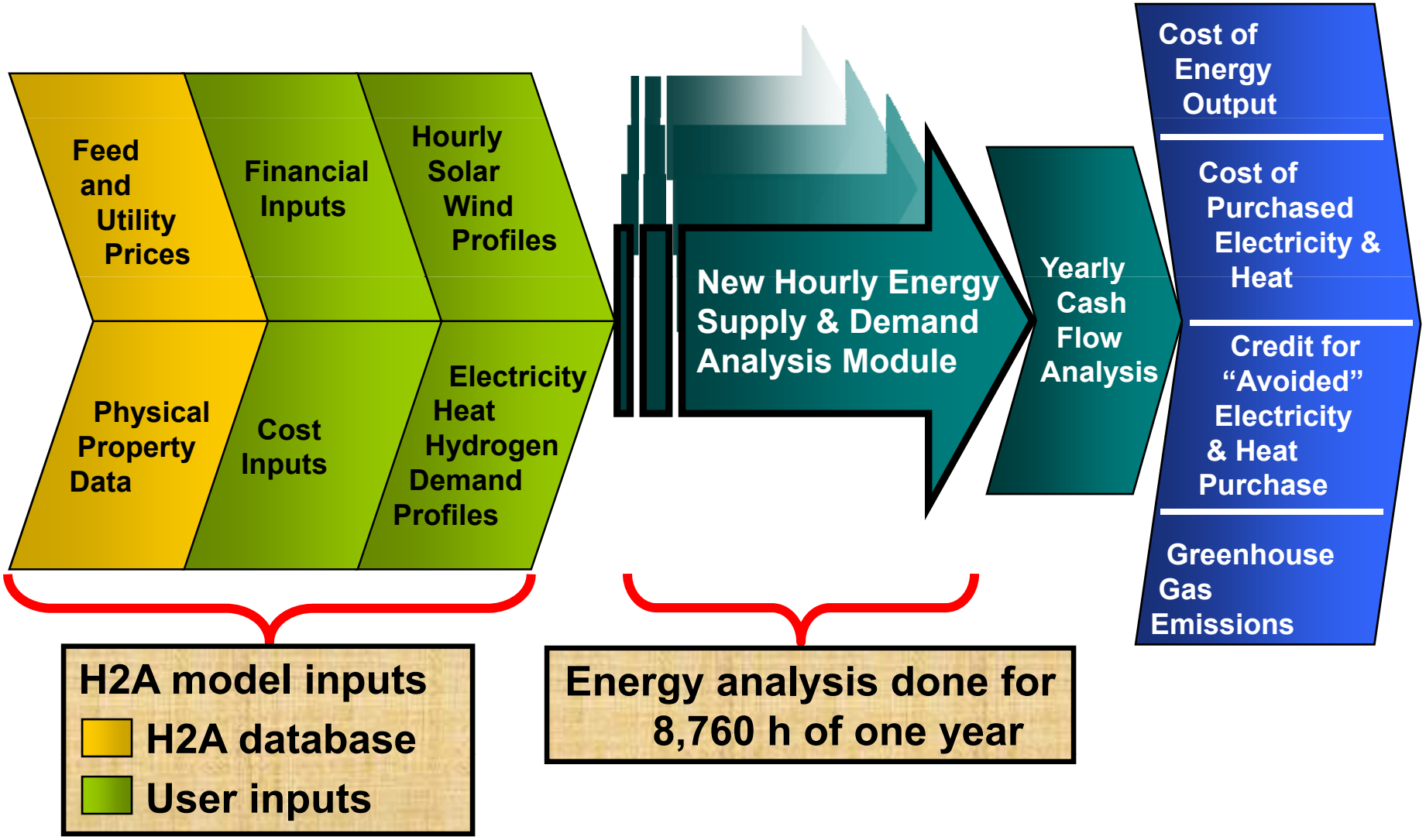
- Grid electricity (hourly)
- Fuel prices
- Water price



ENERGY FLOWS ($)

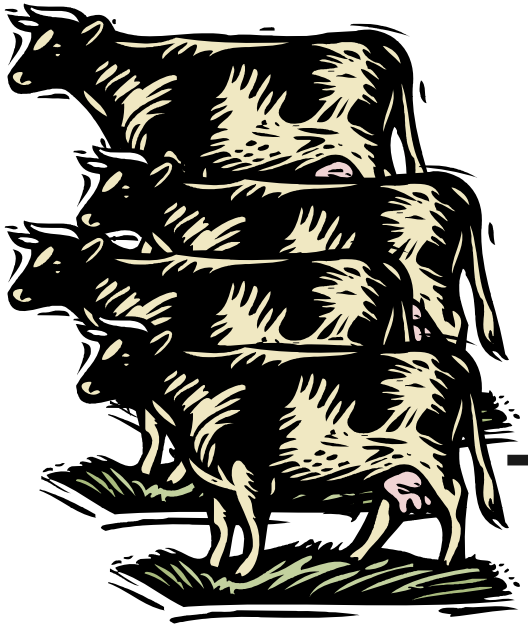
- Delivered electricity
- Delivered heat
- Delivered hydrogen
- Used fuel
- Used grid electricity
- Sales to grid

FCPower Model Hourly Energy Analysis Module



Biogas Case Study

System Being Considered



1,000 cows

Plug-flow anaerobic digester

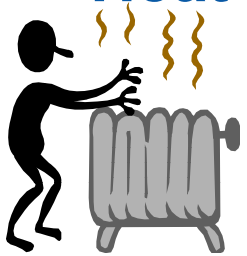
Solids Separation (bedding + fertilizer)

Gas Cleanup

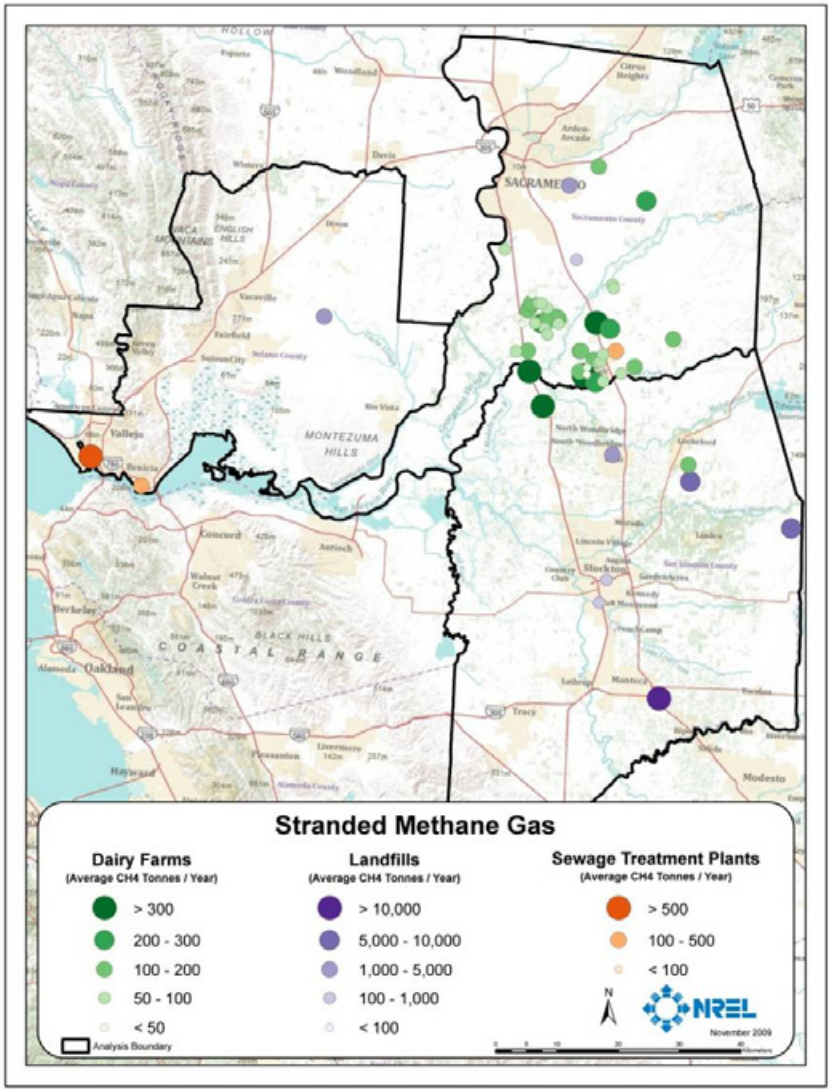
Fuel Cell

Electricity

Heat



Methane Sources in the Sacramento Area



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

- Rule of thumb:

  1 cow = 200 W electricity

Quick Start – 4 steps

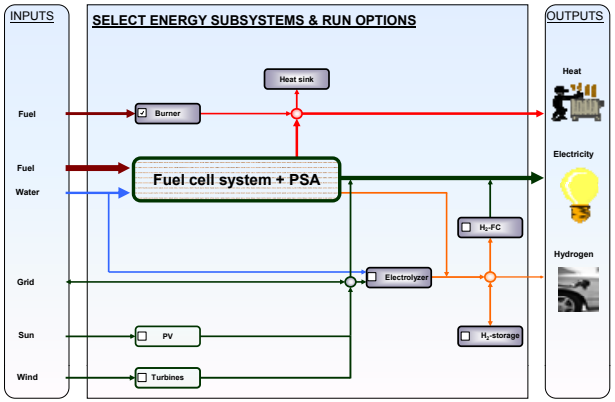
1 Click Process Flow Diagram

Process Flow Diagram

Title

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

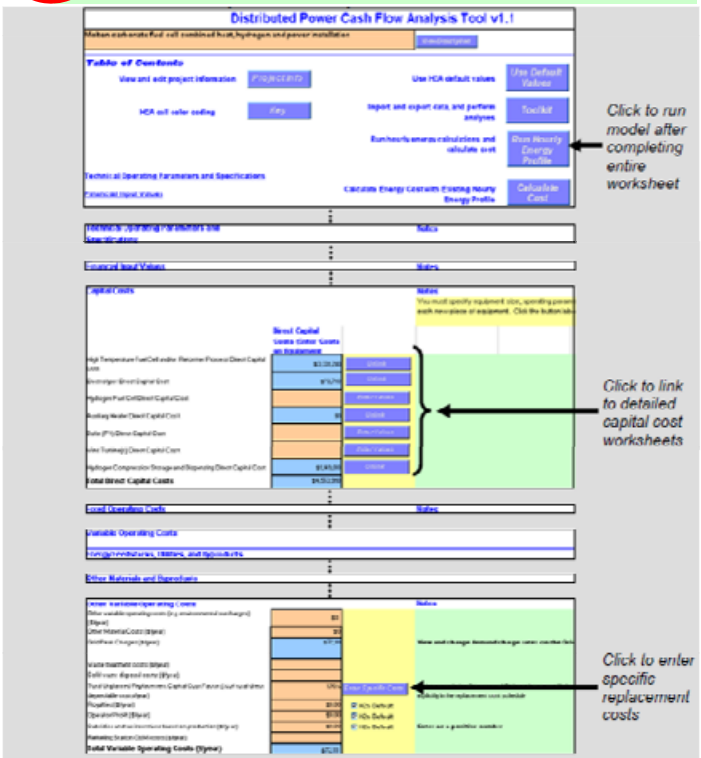


System Component Selection

Peak Burner	TRUE
Fuel Cell System	TRUE
Electrolyzer	FALSE

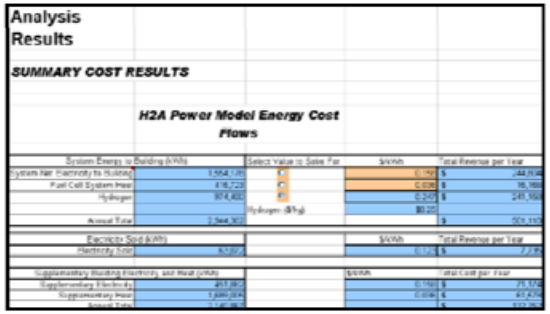
Input Sheet

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.

Economic Evaluation of a Fuel Cell 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

Fuel cell system:

- Molten carbonate fuel cell (MCFC) produces electricity and heat
- Electricity not used on site is fed to the grid

Information Needed

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$_{di}$ gester)

Energy costs

- Electricity ¢/kWh
- Heat $/MMBTU

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.

Step 1

1 Click Process Flow Diagram

Title

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Authors:	Darlene Steward, Mike Penev
Contact:	Darlene Steward
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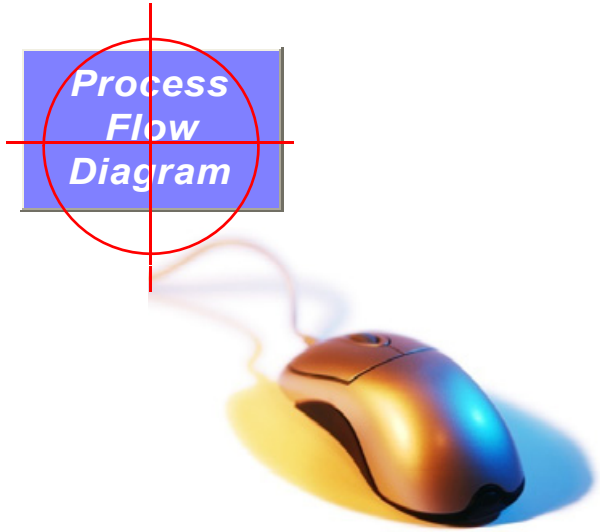
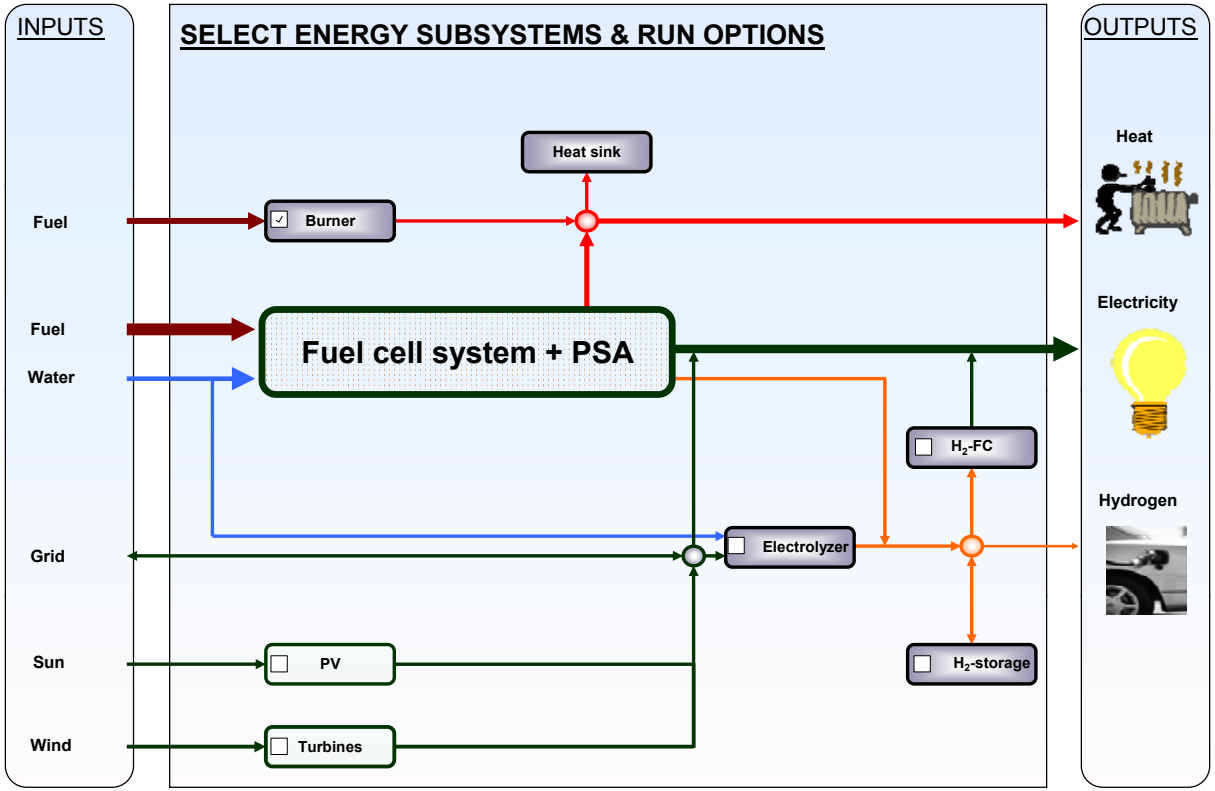


Simple: *just click!*

Model users are first directed to this screen.

Step 2: Selecting Hardware

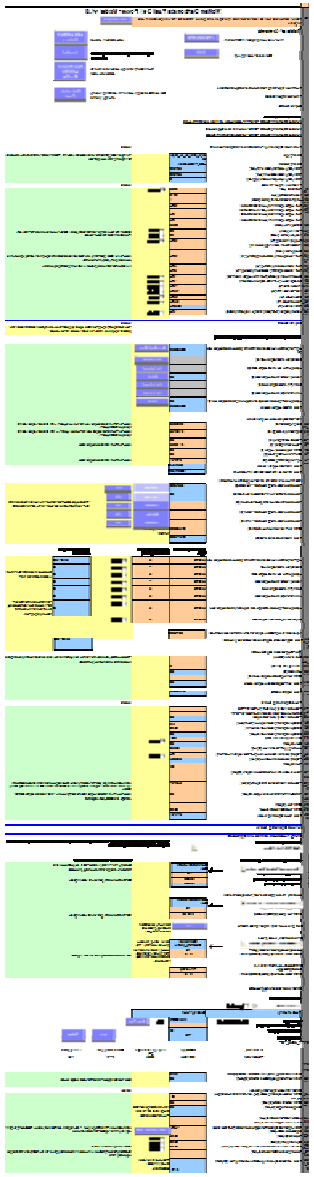
2 • Configure system
• Click *Input sheet* button



System Component Selection	
Peak Burner	TRUE
Fuel Cell System	TRUE
Electrolyzer	FALSE

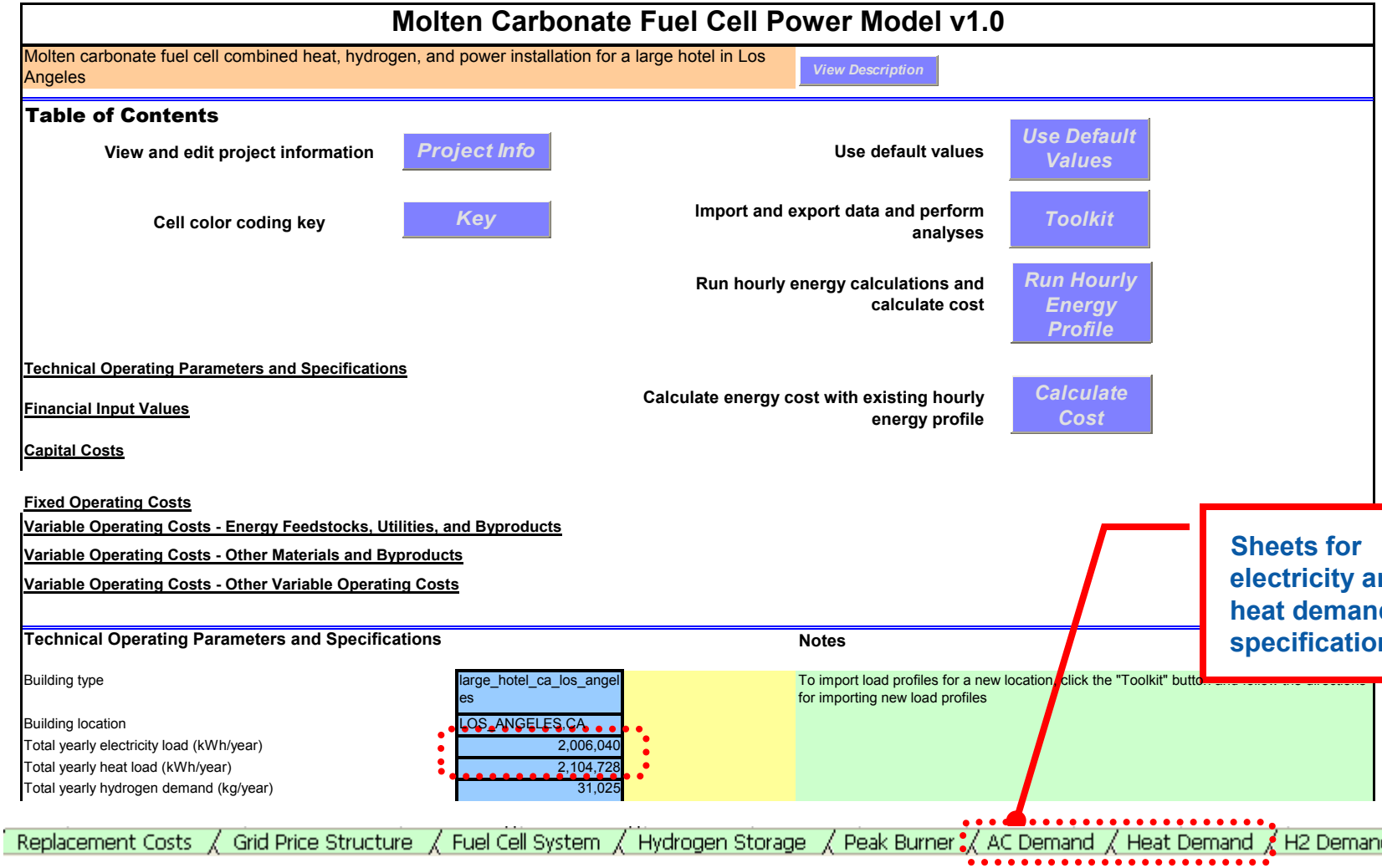
- The Fuel Cell System analysis is active by default
- Burner evaluation should also be selected

Step 3: Entering Detailed Specifications



- The “Input_Sheet_Template” sheet is the main model interface
- The subsequent slides will describe each section of the interface
- Tools and defaults are available for most values
- A lot of customization is possible for special case evaluations

Step 3A: Entering Specifications



- First input is specifying electricity and heat demands.
- Estimates call for 1 kWh /cow-day = 42 kW for heat and electricity

Step 3B: Input Electric and Heat Demands

AC Demand

(hourly electric demand)

benchmark_large_hotel_ca_los_angeles.csv
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0

Year	2008
Jan 1, day of week	Tuesday
Demand maximum (kW)	42.0
Demand minimum (kW)	42.0
Demand average (kW)	42.0
Demand Stdev (kW)	0.0
Demand total (kWh/year)	367920

Heat Demand

(hourly heat demand)

benchmark_large_hotel_ca_los_angeles.csv
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0
42.0

Demand maximum (kW)	42.0
Demand minimum (kW)	42.0
Demand average (kW)	42.0
Demand Stdev (kW)	0.0
Demand total (kWh/y)	367920.0

- Input 42 kW for each hour for both the electricity and heat demands
- Go back to the **Input_Sheet_Template** sheet

Step 3C: Economic criteria specification

Financial Input Values		
Reference year	2005	☑ Default
Assumed startup year	2010	
Length of construction period (years)	1	
% of capital spent in 1st year of construction	100%	
% of capital spent in 2nd year of construction		
% of capital spent in 3rd year of construction	0%	
% of capital spent in 4th year of construction	0%	
Startup time (years)	0.038	
Plant life (years)	20	☑ Default
Analysis period (years)	20	☑ Default
% equity financing (%)	100%	☑ Default
Interest rate on debt, if applicable (%)		
Debt period (years)		
% of fixed operating costs during startup (%)	100%	
% of revenues during startup (%)	40%	
% of variable operating costs during startup (%)	50%	
Decommissioning costs (% of initial capital investment)	10%	☑ Default
Salvage value (% of initial capital investment)	10%	☑ Default
Inflation rate (%)	1.9%	☑ Default
After-tax real IRR (%)	10.0%	☑ Default
State taxes (%)	6.0%	☑ Default
Federal taxes (%)	35.0%	☑ Default
Total tax rate (%)	38.90%	
Working capital (% of yearly change in operating costs)	15%	☑ Default

- **Verify and update economic assumptions**

Step 3D: Capital Costs

Direct Capital Cost Specification ("Input_Sheet_Template" tab)

Direct capital costs (enter costs on equipment sheet)

High-temperature fuel cell and/or reformer process direct capital cost ($)	$2,339,362	Go to Detail Sheet
Electrolyzer direct capital cost ($)		Not Selected
Hydrogen fuel cell direct capital cost ($)		Not Selected
Auxiliary heater direct capital cost ($)	$0	Unlink
Solar (PV) direct capital cost ($)		Not Selected
Wind turbine(s) direct capital cost ($)		Not Selected
Hydrogen compression storage and dispensing direct capital cost ($)		Not Selected
Total direct capital costs	$2,339,362	

- This section provides links to the fuel cell system and hydrogen storage tabs

Step 3E: Remove Hydrogen Co-production

Hydrogen Demand ("H2 Demand" tab)

Enter zero for daily hydrogen demand

Hydrogen Demand (% of total daily de
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
50.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
0.0%
50.0%
0.0%

Average daily hydrogen demand	0 kg/day
Hourly Hydrogen Demand Statistics (% of avg daily demand)	
Maximum	50.00%
Minimum	0.00%
Average	4.17%
Standard deviation	13.82%
Surge: % above the system average demand	0.0000
Friday average above weekly average (%)	0.0000
Adjusted average daily demand	0 kg/day

Hydrogen Storage Costs ("Hydrogen Storage" tab)

Enter zero for all hydrogen dispensing costs

Major Pieces/Systems of Equipment	Baseline Uninstalled Costs	Installation Cost Factor	Baseline Installed Costs
Low-pressure storage tanks	$ -	1.30	$ -
Cascade storage tanks	$ -	1.30	$ -
Compressor cost	$ -	1.20	$ -
Dispensers	$ -	1.20	$ -
Electrical upgrades	$ -	2.20	$ -
Control and safety equipment	$ -	1.20	$ -
300 ft pipeline to filling station	$ -	1.00	$ -
			$ -
			$ -
			$ -
			$ -
Totals	$ -		$ -

- Remove all hydrogen demand by zeroing daily H_2 demand
- Remove all capital cost for hydrogen dispensing

Step 3F: Fuel Cell Capacity

Fuel Cell Specifications
("Fuel Cell System" tab)

Enter fuel cell capacity

FUEL CELL SYSTEM SPECIFICATIONS		Descriptions
Maximum electricity output rating kW	300.0	AC average demand.
Minimum electricity output rating kW	249.0	
Efficiency of H2 production (kW H2 produced / kW CHP heat reduced)	96%	Coefficient is derived from matching thermodynamic models.
Efficiency of H2 over-production (kW H2 produced / additional kW fuel consumed)	80%	Coefficient is derived from matching thermodynamic models.
Maximum fraction of heat converteable to hydrogen	0.65	Coefficient is derived from matching thermodynamic models.
Maximum amount of hydrogen over-production as fraction of H2 production	0.50	Coefficient is derived from matching thermodynamic models.

- Maximum FC capacity of 300 is a good fit with available digester gas
- 83% of 300 kW allows for utilization factor specification = 249 kW of min. rating
- Remaining coefficients are not important for this analysis as they are for H_2 co-production

Step 3G: Inputting System Costs

Fuel Cell Cost Specifications

("Fuel Cell System" tab)

Enter fuel cell, digester, gas cleanup costs

INVESTMENT (Inputs REQUIRED in			
Major Pieces/Systems of Equipment	**Baseline Uninstalled Costs**	**Installation Cost Factor**	**Baseline Installed Costs**
Fuel cell CHP equipment uninstalled cost	$ 750,000	1.20	$ 900,000
Plug Flow Digester System		0.00	$ -
Digester, engineering, and installation	$ 1,166,477	1.00	$ 1,166,477
Total ancillary systems	$		$ -
Post-digestion solids separation system	$ 97,560	1.00	$ 97,560
Hydrogen sulfide treatment	$ 63,626	1.00	$ 63,626
Utility hookup	$ 111,699	1.00	$ 111,699
			$ -
			$ -
			$
Totals	$		$

247,435

2,436,796

2,339,362

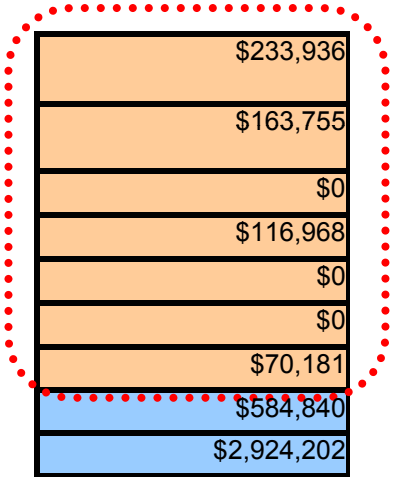
-

- This sheet would contain all hardware capital costs
- If installed costs are used, enter installation cost factors of 1.0

Step 3H: Input Indirect Capital Costs

Indirect Capital Costs Specification
("Input_Sheet_Template" tab)

Indirect depreciable capital costs	
Site preparation ($)	$233,936
Engineering & design ($)	$163,755
Process contingency ($)	$0
Project contingency ($)	$116,968
Other (depreciable) capital ($)	$0
One-time licensing fees ($)	$0
Up-front permitting costs ($)	$70,181
Total indirect capital costs	$584,840
Total Direct & Indirect Capital Investment	$2,924,202

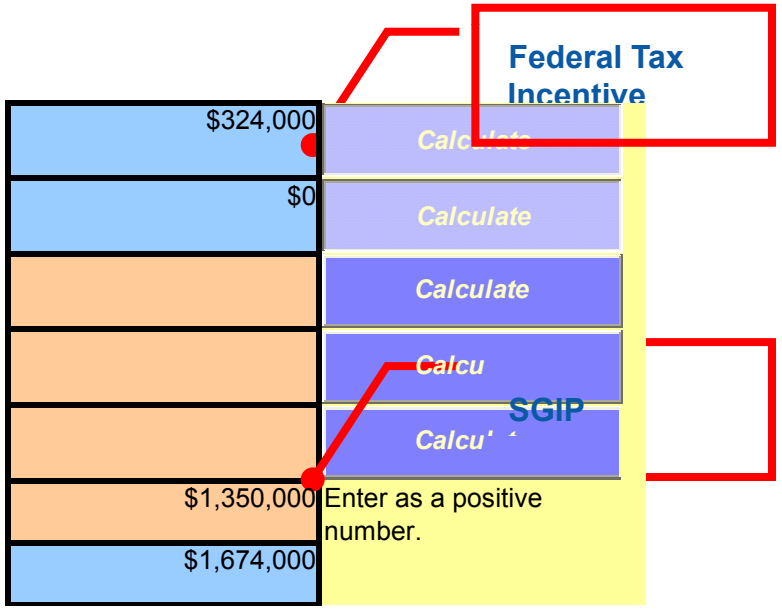


The power model provides default values for each value above, but it can be overridden

Step 3I: Incentives Specification

Incentives Specification
("Input_Sheet_Template" tab)

Incentives and credits (enter as positive numbers)	
Federal business energy tax credit - fuel cells ($)	$324,000
Federal alternative fuel infrastructure tax credit ($)	$0
Federal combined heat and power tax credit ($)	
Federal business energy tax credit - solar ($)	
Federal business energy tax credit - wind ($)	
Other one-time tax incentive credits ($)	$1,350,000
Total incentives and credits	$1,674,000



- Federal tax incentive is 30% of capital or 3,000 $/kW, whichever is less
- Self Generation Incentive Program (SGIP), is a CA program that pays up to 4,500 $/kW of installed capacity of renewable electric production

Step 3J: Specifying Fixed Operating Costs

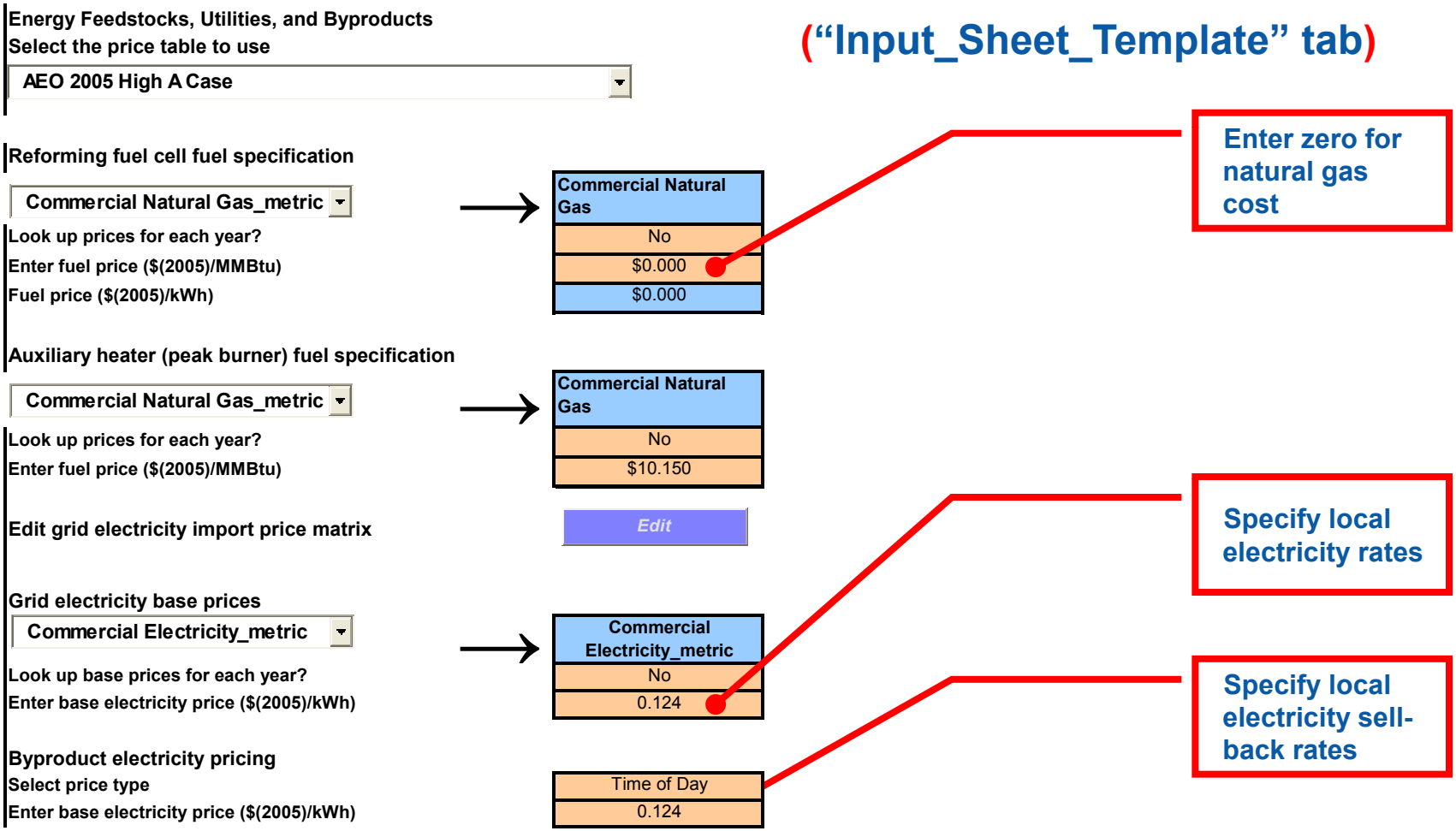
Fixed Operating Costs Specifications ("Input_Sheet_Template" tab)

Fixed Operating Costs		
Production facility plant staff (number of FTEs)		
Burdened labor cost, including overhead ($/man-hr)		
Production facility labor cost, $/year	$0	
Storage/dispensing labor required (hours/year)	0.0	
Storage/dispensing labor cost ($/man-hr)	$0.00	
Storage/dispensing labor cost ($/year)	$0	
G&A rate (% of labor cost)	20%	☑ Default
G&A ($/year)	$0	
Licensing, permits, and fees ($/year)	$2,339	
Property tax and insurance rate (% of total capital investment)	2%	☑ Default
Property taxes and insurance ($/year)	$25,004	
Rent ($/year)	$0	
Material costs for maintenance and repairs ($/year)		
Production maintenance and repairs ($/year)	$46,787	
Forecourt maintenance and repairs ($/year)	$0	
Other fees ($/year)		
Other fixed O&M costs ($/year)	$0.00	
Total fixed operating costs	$74,131	

- Note that some costs for hydrogen production would not apply
- For this analysis we assumed that the fuel cell is installed onsite - so land leasing is not needed.

Step 3K: Feedstock Cost Specification

Feedstock Costs ("Input_Sheet_Template" tab)



- Water costs can be specified as well, but they are typically relatively low
- Note: Detailed grid cost structure can be accommodated by this model

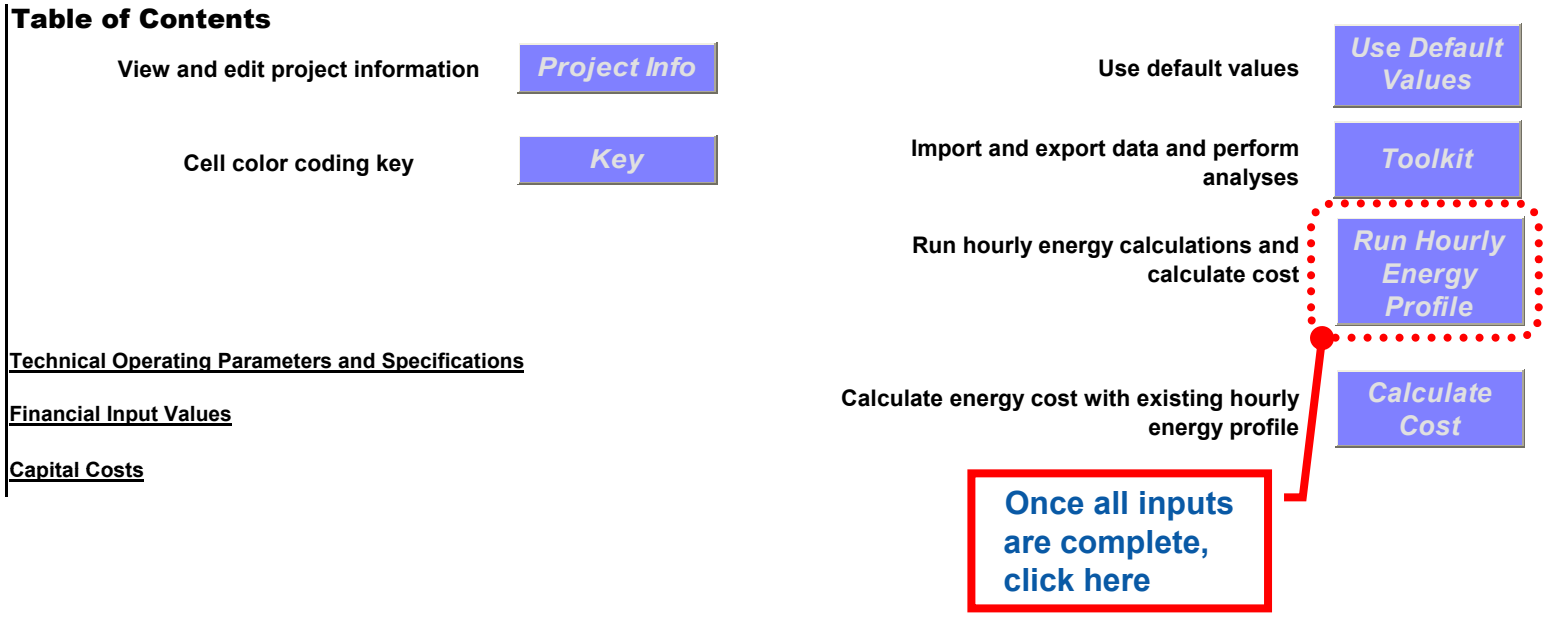
Step 3L: Verify Other Variable Operating Costs

Other Variable Operating Costs	
Other variable operating costs (e.g., environmental surcharges) ($/year)	$0
Other material costs ($/year)	$0
Grid peak charges ($/year)	$0
Waste treatment costs ($/year)	
Solid waste disposal costs ($/year)	
Total unplanned replacement capital cost factor (% of total direct depreciable costs/year)	1.50%
Royalties ($/year)	$0.00
Operator profit ($/year)	$0.00
Subsidies and tax incentives based on production ($/year)	$0.00
Refueling station O&M costs ($/year)	
Total variable operating costs excluding fuel ($/year)	$172

- **Note that this is the place to define maintenance costs (1.5% of cap is default)**
- **Detailed capital cost replacements can be specified within the "Replacement Costs" sheet**
- **At this point, the model specifications are complete!**

Step 4: Running and Results

"Input_Sheet_Template" tab:



- Running the model performs an hourly energy analysis
- After energy analysis is complete, economic analysis and emissions are evaluated
- Completed running will place you on the results tab

Reviewing Results

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

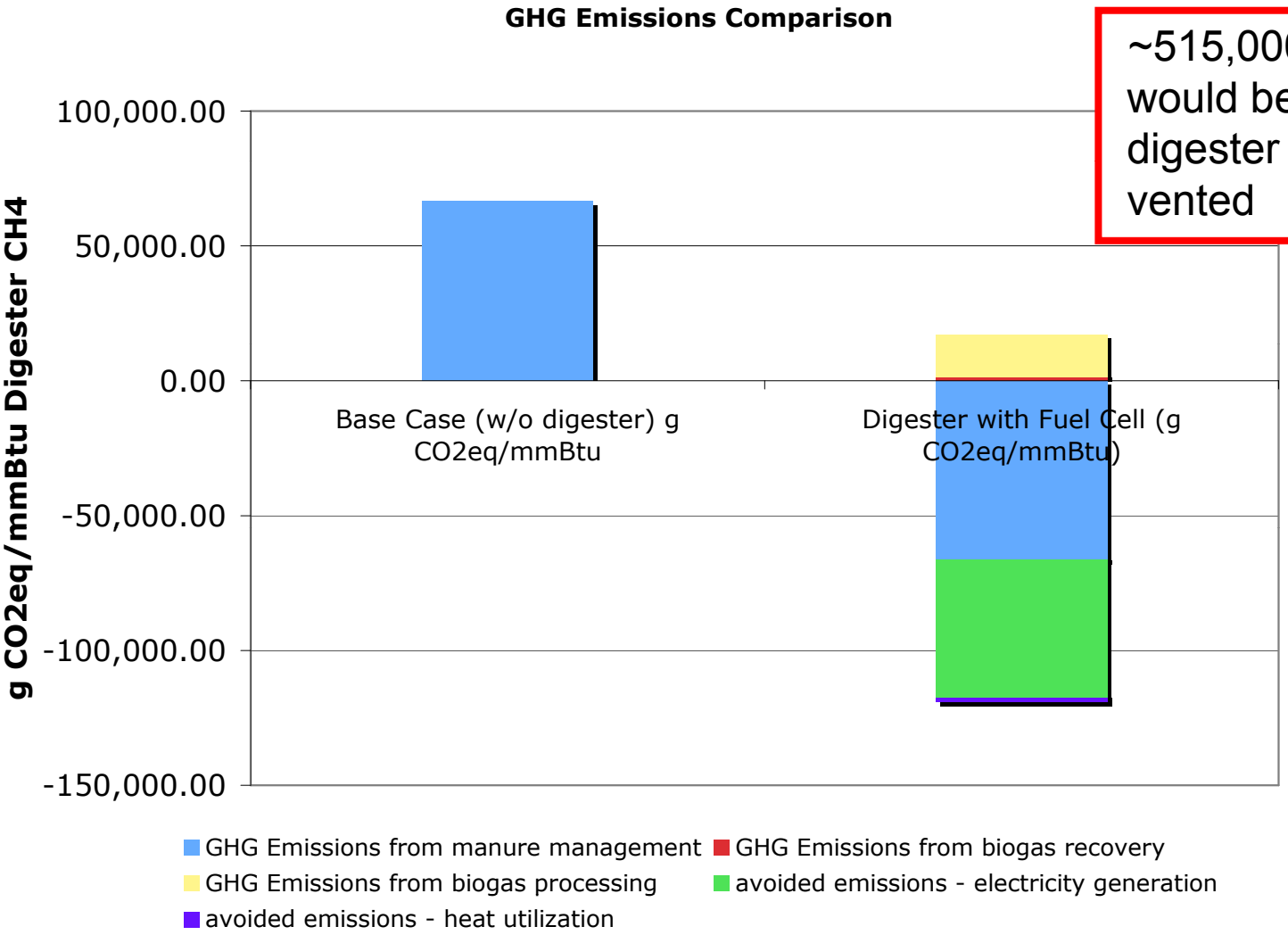
Baseline system energy costs (without to installation of fuel cell)	
Electricity	**($/year)**
Usage and Demand charges	$
Commercial Natural Gas	**($/year)**
	$
Hydrogen (supplied by forecourt SMR system)	$ 55,461
Hydrogen price = $0/kg	
Total baseline system energy cost per year	**$** 14,157

Cost of natural gas for chillers would be $14,157/year.

CHHP System Annualized Costs	- **69,618**
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

Fuel cell combined heat and power system with an 8.5% internal rate of return

GHG Emissions Comparison



~515,000 g of CO2eq would be emitted if the digester methane were vented

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
Michael.penev@nrel.gov