

Fuel Cells Operating on Renewable Bio-Gas



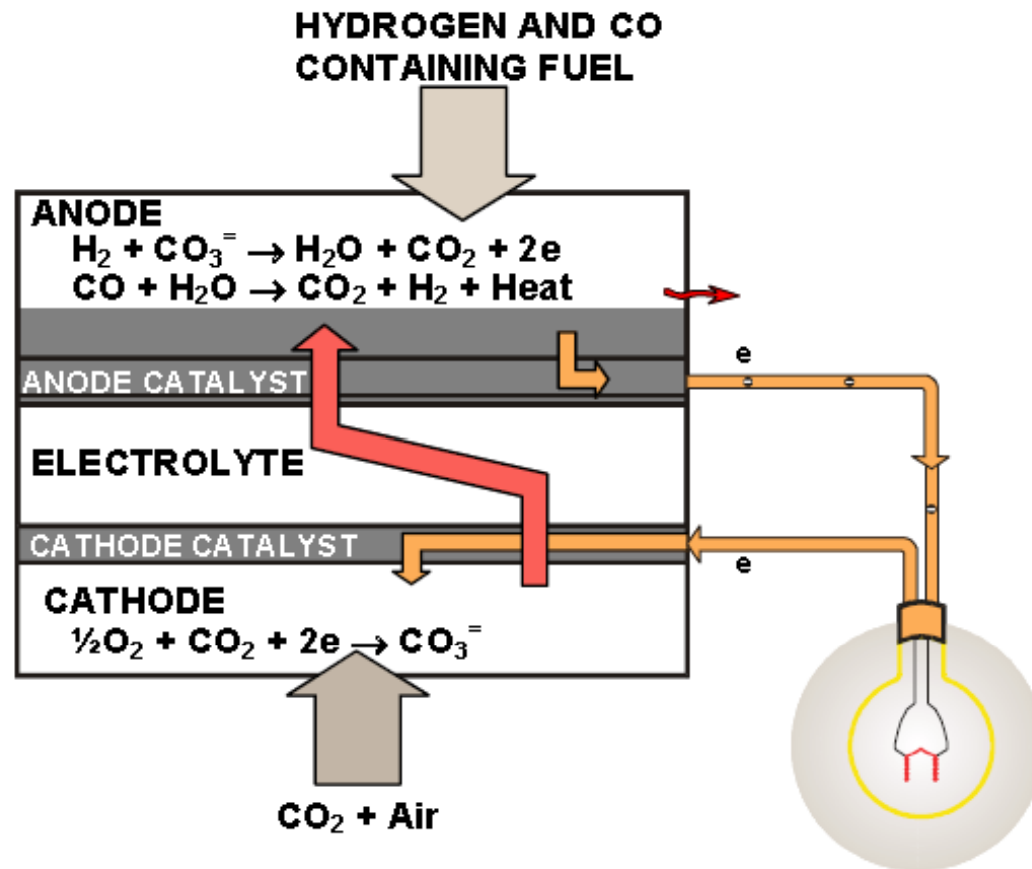
**Municipal Utilities 2030
Conference**

Robert J. Remick, PhD

April 8, 2010

What's a Fuel Cell

A fuel cell is a device that produces electricity by electrochemical reaction of the fuel with oxygen (air).

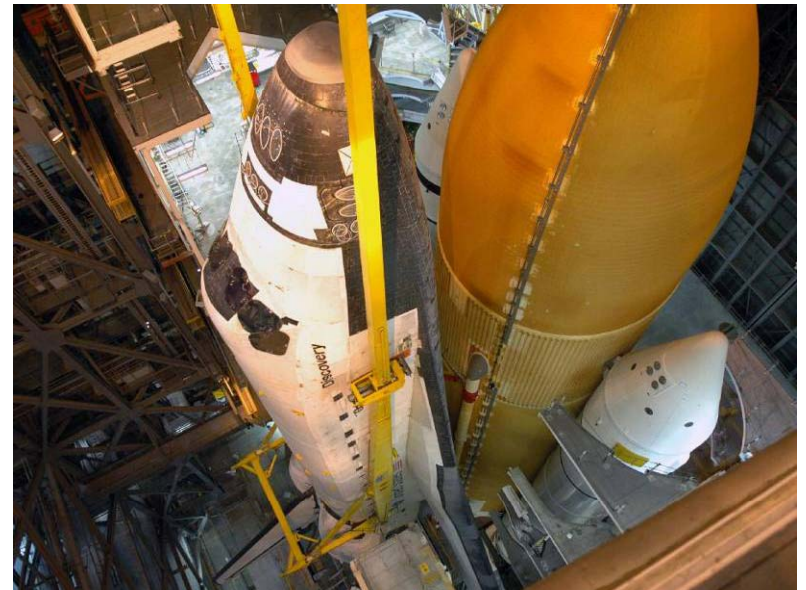


Schematic of MCFC operation (EG&G Technical Services 2004)

Fuel Cell types are named by their electrolyte

- **Proton Exchange Membrane (PEM)**
 - Ion-conducting polymer
 - Operates at 80° C (176° F)
- **Phosphoric Acid (PAFC)**
 - Liquid electrolyte
 - Operates at 180° C (356° F)
- **Molten Carbonate (MCFC)**
 - Liquid electrolyte
 - Operates at 650° C (1200° F)
- **Solid Oxide (SOFC)**
 - Ceramic electrolyte
 - Operates at 800° C (1470° F)
- **Other Types:**
 - direct methanol (DMFC)
 - alkaline (AFC)

Electrical power on the space shuttle is supplied by alkaline fuel cells using hydrogen and oxygen.



Stationary Fuel Cell Power Plants

- There are two US manufacturers with a track record for supplying fuel cell power plants for use with natural gas and renewable bio-gas
- **FuelCell Energy, Inc** (Molten Carbonate Technology)
 - Danbury, Connecticut
 - Power plants sizes: 300 kW, 1.4 MW, and 2.8 MW
- **UTC Power, Inc.** (Phosphoric Acid Technology)
 - South Windsor, Connecticut
 - Power plant size: 400 kW

UTC Power PureCell® Model 400

New Product



- 400 kW electric output
- Natural gas/ADG
- 42% electrical efficiency***
- 1.7 MMBtu/hr heat output (60°C)
- Up to 85% system efficiency
- Meets CARB 2007 standard
- 20 year powerplant life**
- Modular approach for MW size applications

** with overhaul at end of **year 10**

*** LHV at beginning of life

UTC Power has over 250 installations world-wide of an earlier PureCell®200 Model

For more information go to:

www.utcpower.com

FuelCell Energy DFC 1500

- 1.4 MW electric output
- Natural gas/ADG
- 47% electrical efficiency ***
- 2.7 MMBtu/hr heat output at 60°C (0.5 MMBtu/hr at 300°C)
- Up to 74% system efficiency
- Meets CARB 2007 standard
- 20 year powerplant life**

** with overhaul at end of **year 5**

*** LHV at beginning of life



Used with the permission of:
FuelCell Energy, Inc.

Bloom Box

- 100 kW electric output
- Natural gas/ADG
- 52% electrical efficiency ***
- Heat output-unknown
- Total system efficiency-unknown
- Meets CARB 2007 standard
- Power plant life -10 years

*** LHV at beginning of life

For photo go to:

www.bloomenergy.com

Cost Comparison (approximate)

Technology	UTC PAFC PC 400	FCE MCFC DFC 1500	Gas turbine Mercury 50	Recip. Cat. C3250
Output size	400 kW	1,400 kW	4,600 kW	1,930 kW
Electrical Efficiency (LHV)	42%	47%	37%	36%
Capital + O&M \$/kW (20 yrs)	\$4,375	\$4,245	\$1,896	\$1,342
	Without incentives			
Cost of electricity \$/kWh (NG)	\$ 0.132	\$ 0.123	\$ 0.085	\$ 0.115

Wastewater Treatment Plants

- WWTP operators are looking for opportunities to utilize biogas as a **renewable energy source**.
- Majority use biogas through boilers for reheating
- Interest is growing in distributed generation especially where both electricity and fuel costs are high.
- Drivers for the decision to purchase fuel cells
 - Reliability
 - Availability of Government Incentives
 - Near zero criteria pollutants (smog formers)

Anaerobic Digestion and Biogas

- Anaerobic digestion is a process used to stabilize wastewater sludge before final disposal.
- The process uses microorganisms in the absence of oxygen to convert organic materials to biogas

Range of Biogas Compositions

Methane	50 to 75%
Carbon Dioxide	25 to 50%
Nitrogen	0 to 10%
Hydrogen	0 to 1%
Sulfur species	0 to 3%
Oxygen	0 to 2%

WWTP Co-gen Market

- There are over 16,800 WWTP in the US
- 615 facilities with flows > 3 mgd that use anaerobic digestion
- 215 do not use their biogas but flare it instead.
- California has the highest number of municipal facilities using anaerobic digestion, about 102, of which 25 do not use their biogas.

Case Study: City of Tulare

Facility size: 11.5 million gallons per day
Biogas generated: 600,000 SCF per day
Fuel cells: Three - 300 kW units from FCE
Gas cleanup: Applied Filter Technology

Startup: September 2007
Total cost: \$7 million
State & Federal
Incentives: \$4.05 million
Cost to city: \$2.95 million
Payback period: 4.5 years

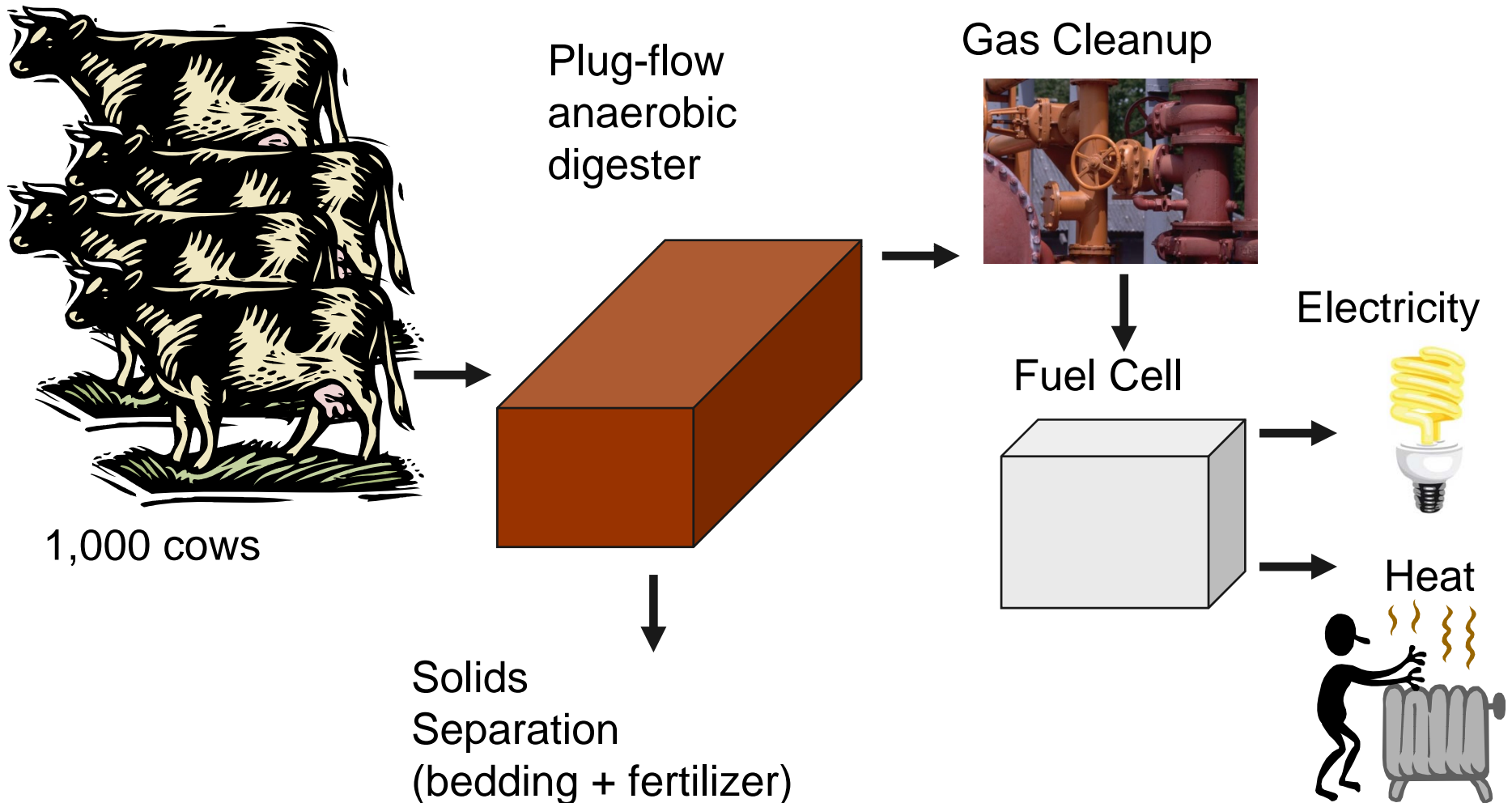


Photo courtesy of City of Tulare.

Fuel Cell Value Proposition

- **Increased energy efficiency**
 - 42 to 47% net electrical efficiency
 - Cogenerate heat to offset natural gas purchase
 - Combined electric + heat \approx 75% efficient
- **Emissions savings**
 - Low NO_x and SO_x
 - 40% lower GHG emissions compared to grid
- **High availability and reliability**
 - Single unit availability >97%
 - Multiple unit availability exceeds five 9's.

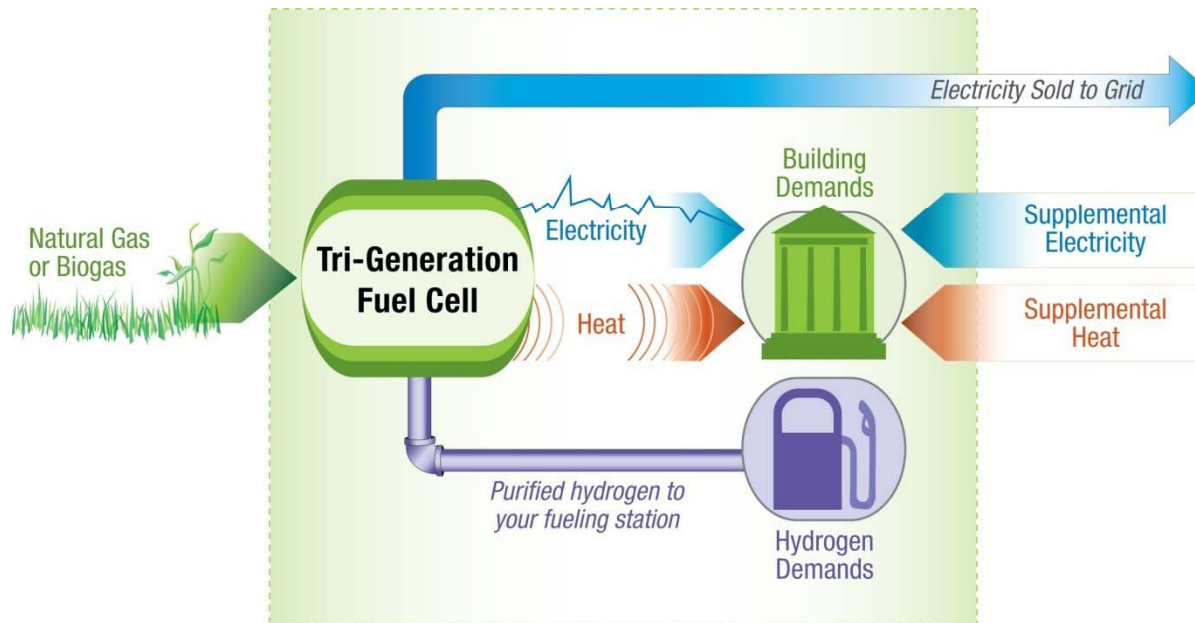
Agricultural Systems Being Considered



California Biogas Case Study



FCpower Model

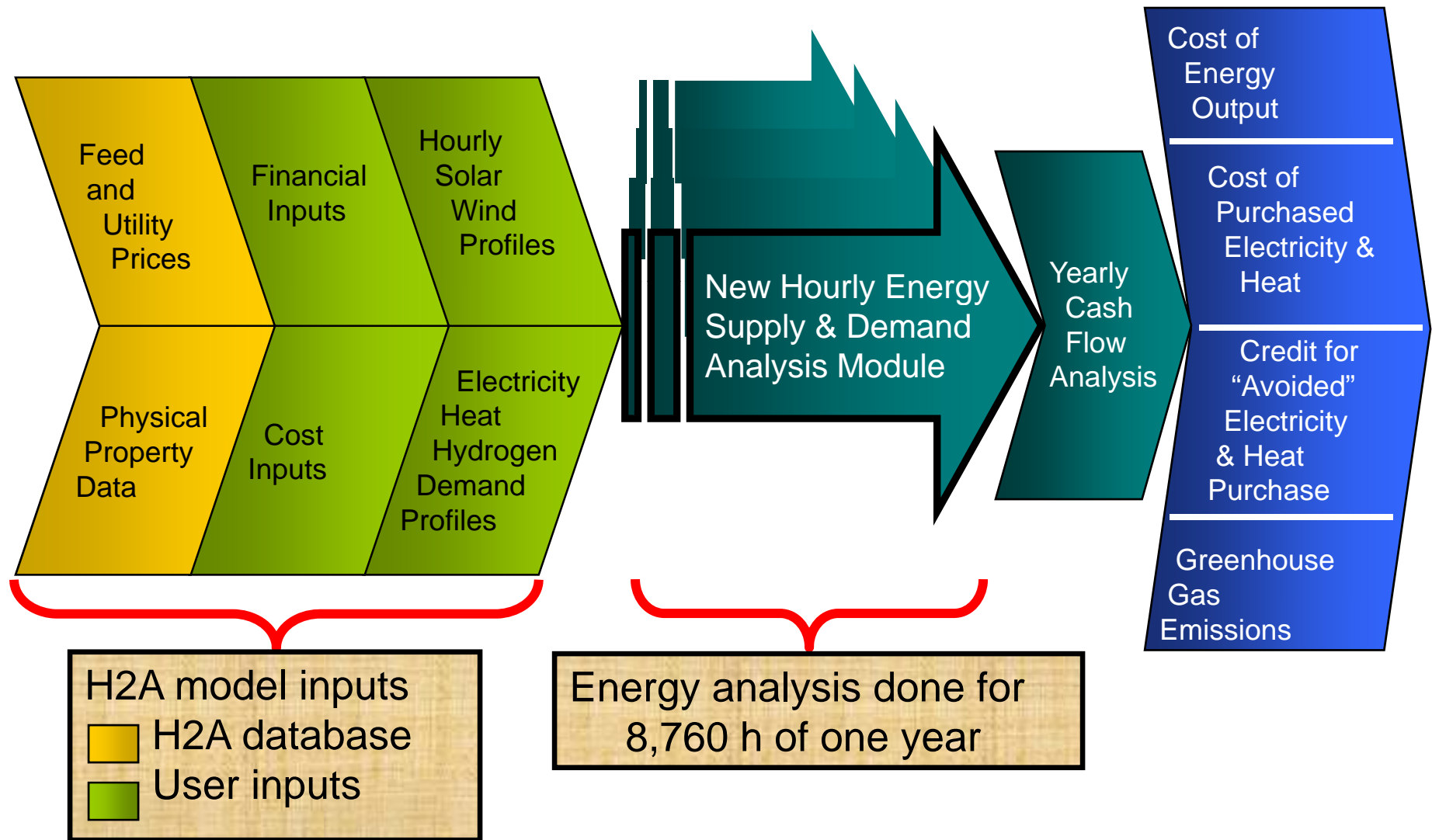


http://www.hydrogen.energy.gov/fc_power_analysis.html

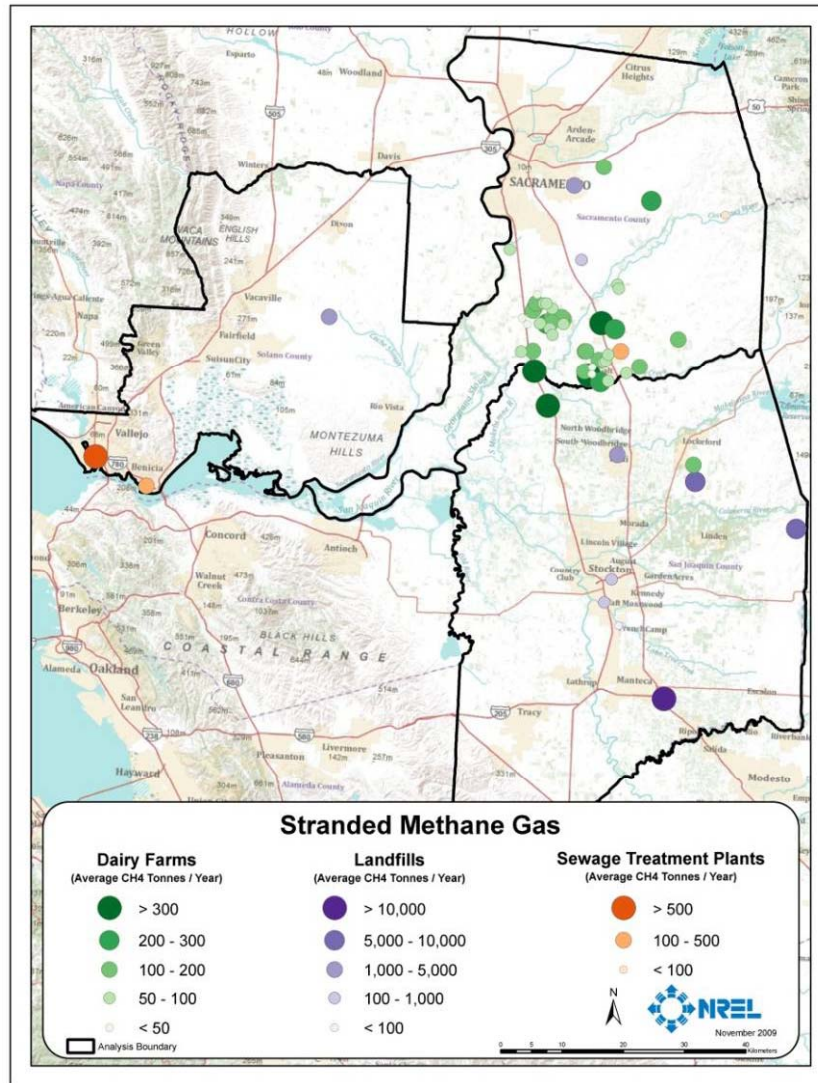
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FCPower Model with Hourly Energy Analysis



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

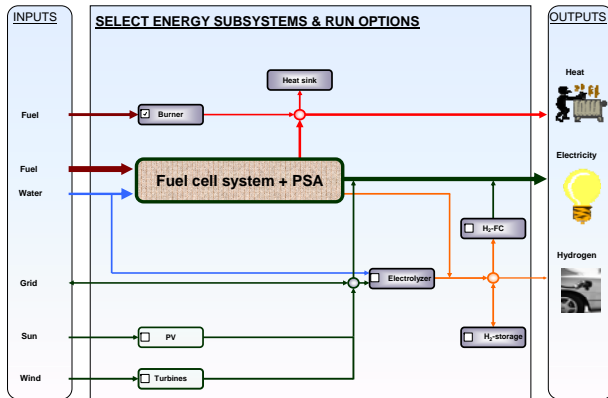
1 Click Process Flow Diagram

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:	

Process Flow Diagram

2 Configure system
• Click *Input sheet* button



Input Sheet

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

Click to run model after completing entire worksheet

Click to link to detailed capital cost worksheets

Click to enter specific replacement costs

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

Analysis Results

SUMMARY COST RESULTS

H2A Power Model Energy Cost Flows

System Energy to Building (kWh)	Select Value to Save For	\$/kWh	Total Revenue per Year
System Net Electricity to Building	1,664,139	0.144	\$ 240,004
Fuel Cell System Heat	4,157,225	0.036	\$ 150,959
Hydrogen	324,403	0.207	\$ 67,159
Annual Total	2,944,767	\$0.25	\$ 558,122
Electricity Sold (kWh)		\$/kWh	Total Revenue per Year
Electricity Sold	63,070	0.12	\$ 7,772
Supplementary Building Electricity, and Heat (kWh)		\$/kWh	Total Cost per Year
Supplementary Electricity	81,388	0.149	\$ 12,127
Supplementary Heat	1,689,013	0.036	\$ 61,325
Annual Total	1,770,401		\$ 73,452

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 costs, 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.

Analysis Results for 1,000 Cow Dairy

Baseline system energy costs (without to installation of fuel cell)	
Electricity	(\$/year)
Usage and Demand charges	\$ 55,461
Commercial Natural Gas	(\$/year)
	\$ 14,157
Hydrogen (supplied by forecourt SMR system)	(\$/year)
Hydrogen price = \$0/kg	\$ -
Total baseline system energy cost per year	\$ 69,618

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

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

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

What's Next? Tri-generation

Heat,
Hydrogen,
& Electricity
On-site



DFC Power Plant	Electrical Output [kW]*	Hydrogen Produced [lbs/Day]	Vehicles Supported at 1GGE/Day
DFC-300	250 kW	300	~130
DFC-1500	1000 kW	1,200	~540

* Note H₂ is produced at the expense of electricity production efficiency.

H₂ at WWTP can promote fuel cell vehicles.

H₂ can be used on-site for fueling a municipal vehicle fleet or can be offered for sale to the public



Summary Conclusions

- Fuel cells operating on Bio-gas offer a pathway to renewable electricity generation.
- With federal incentives of \$3,500/kW or 30% of the project costs, reasonable payback periods of less than 5 years can be achieved.
- Tri-generation of electricity, heat, and hydrogen offers an alternative route to solving the H₂ infrastructure problem facing fuel cell vehicle deployment.
- DOE will be promoting bio-gas fuel cells in the future under it's Market Transformation Programs