National Renewable Energy Laboratory
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The Influence of Building Location on Combined Heat and Power/ Hydrogen (Tri-Generation) System Cost, Hydrogen Output and Efficiency

National Hydrogen Association Meeting

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Introduction

Goals:

Analyze the influence of building type and location on the economics of Combined Heat and Power/ Hydrogen (Tri-Generation) systems.

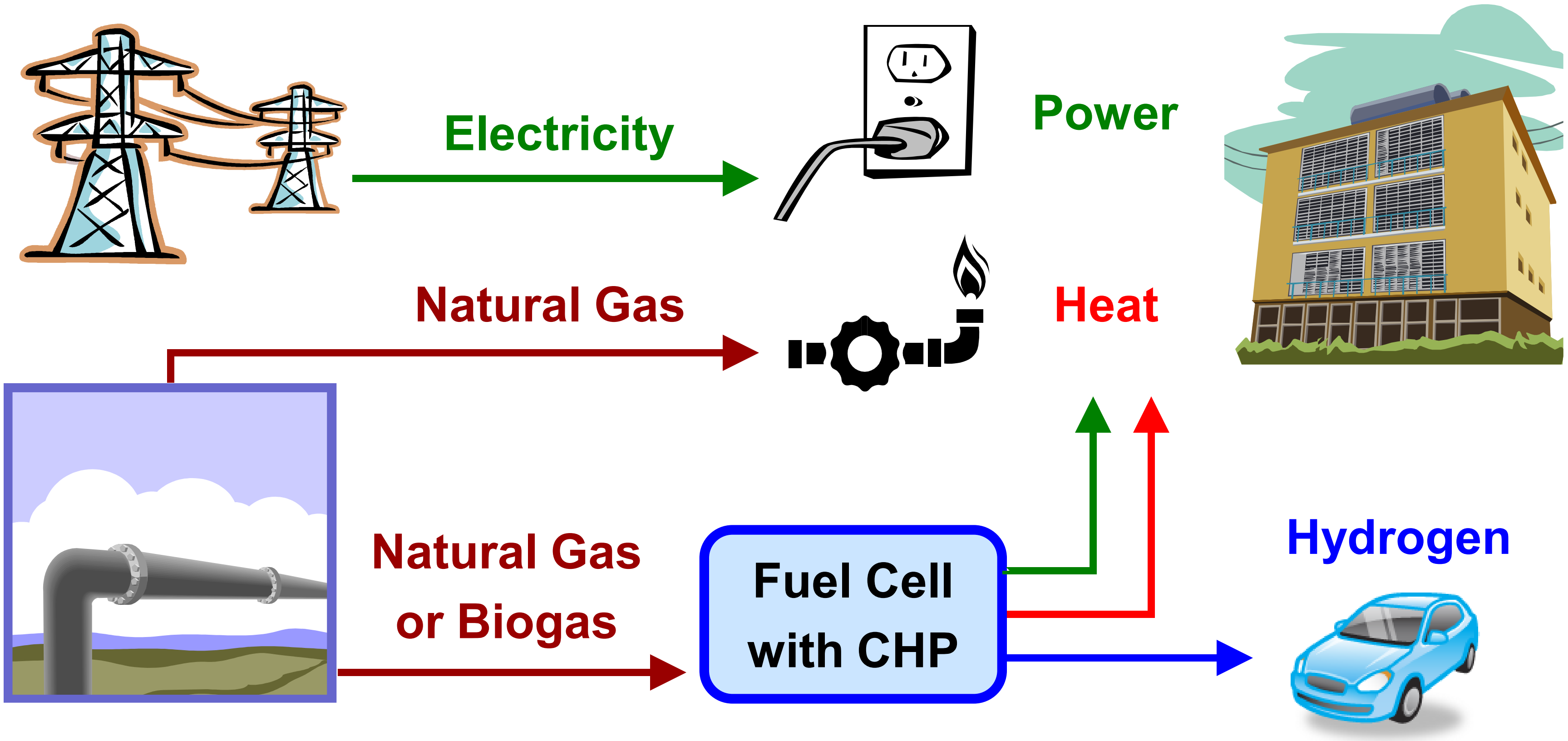
Identify building type (electricity and heat load) characteristics that are favorable for Tri-Generation applications

Identify geographic characteristics that are favorable or un-favorable for tri-generation applications

Combined Heat & Power / Hydrogen Production Cost Model Allows Analysis of New Transition Strategies

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

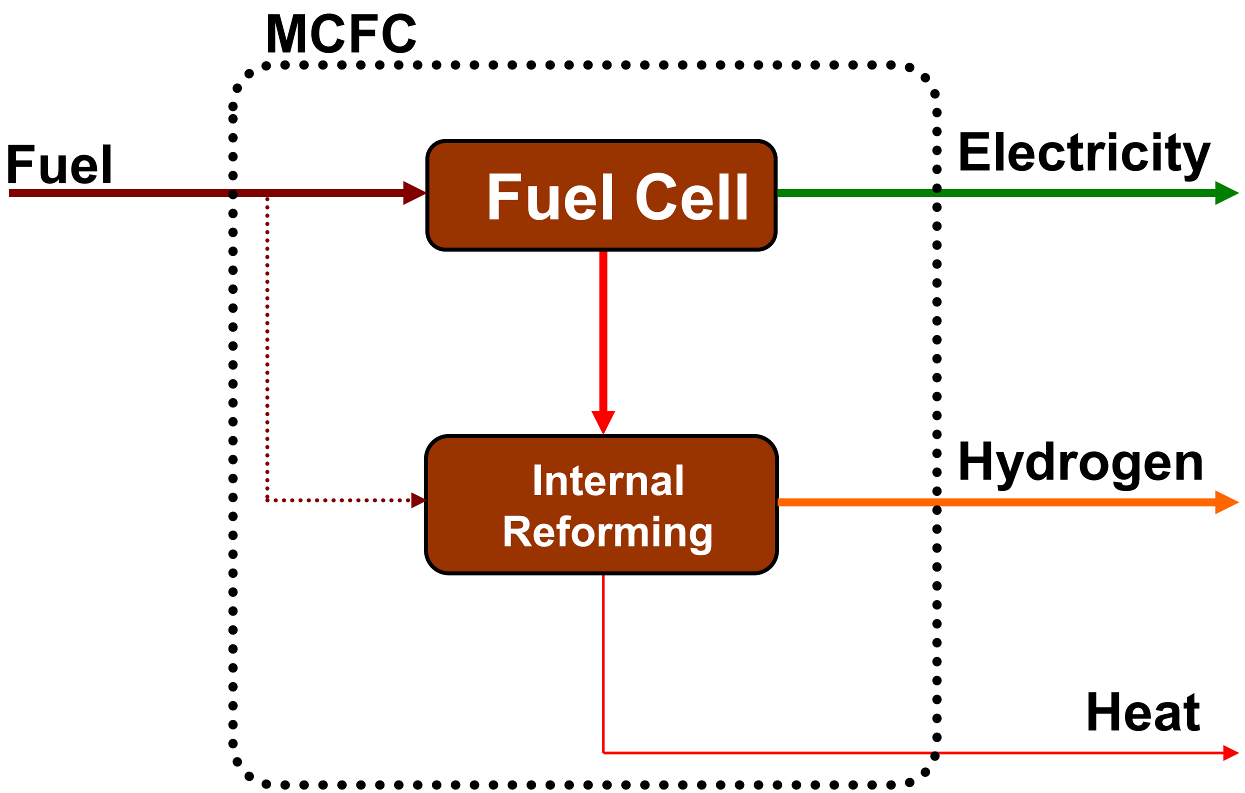
Combining hydrogen production with CHP capability may reduce upfront costs and reduce investment risks



Combined Heat & Power / Hydrogen Production Concept

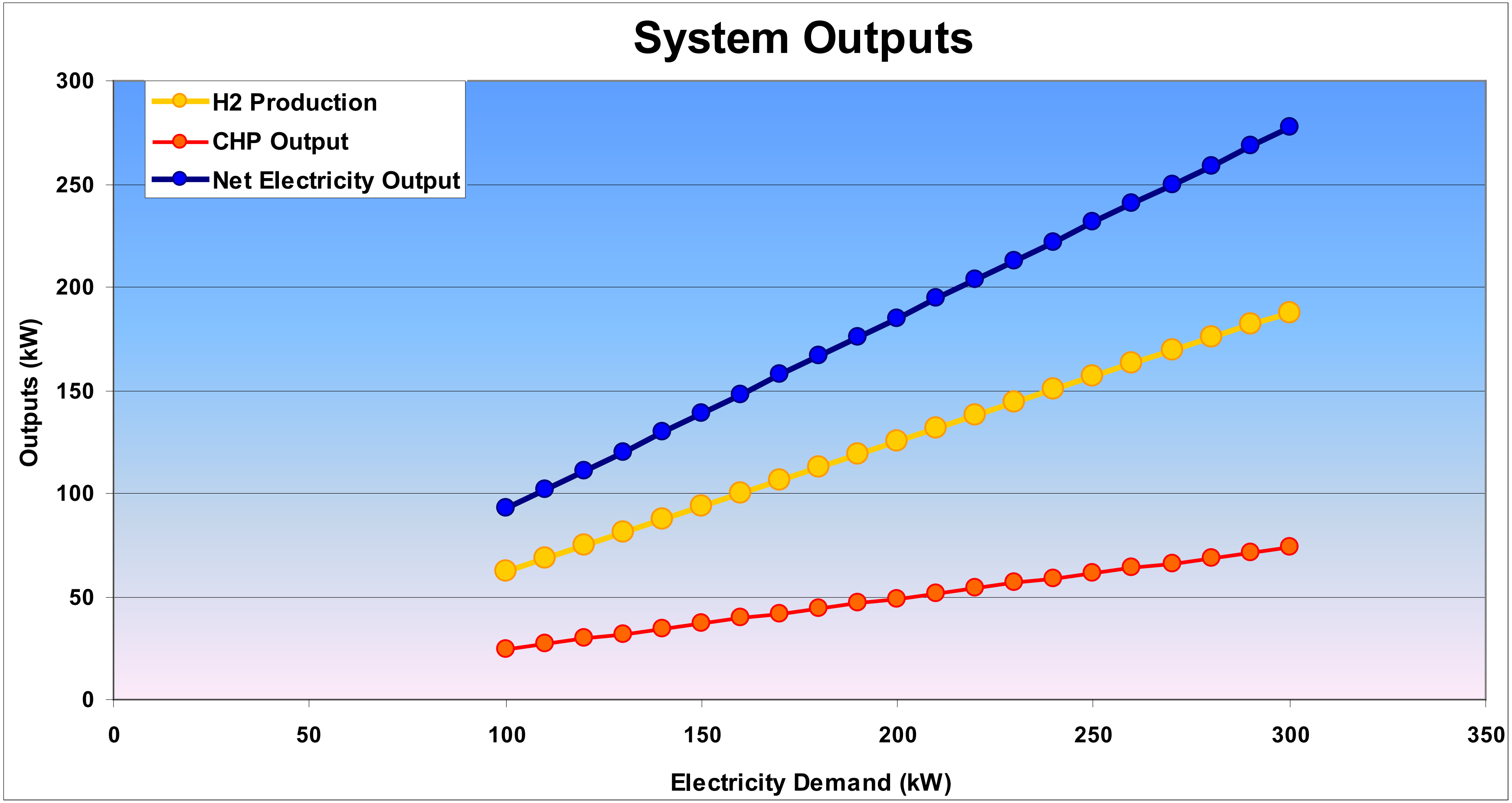
- System provides both electricity and heat; replaces electricity from the grid and heat from a furnace or boiler
  – More efficient; Heat from the facility is used for space and water heating rather than being wasted.
  – Small scale: Heat and electricity are only provided for one or several nearby buildings
  – Other advantages such as providing backup power when the grid is not available
- Early transition strategy combines above system with hydrogen production capability
  – Hydrogen can be produced and stored when electricity and heat demand are low
  – Stored hydrogen can be used later to produce more electricity or as vehicle fuel

Example Molten Carbonate Fuel Cell Tri-Generation System



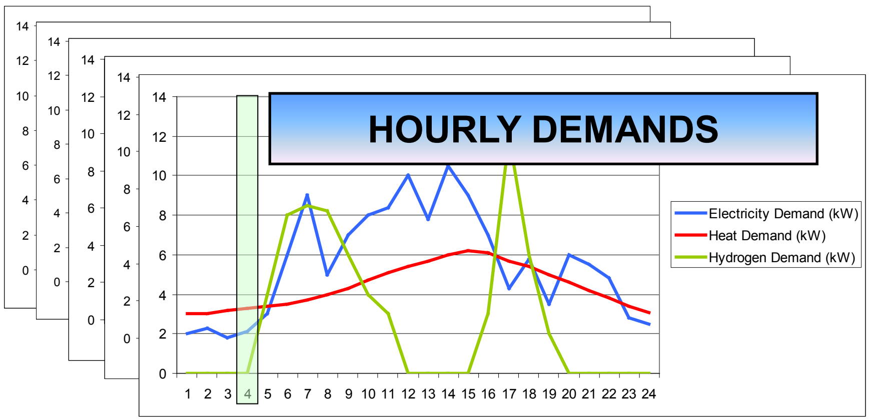
- Heat from electricity production efficiency losses is used to produce H_2
- Heat output is reduced as more hydrogen is produced
- H_2 co-production technology is in the prototype stage
- H_2 co-production technology could be commercial in next few years

MCFC Tri-Generation Profile vs. Turn-Down

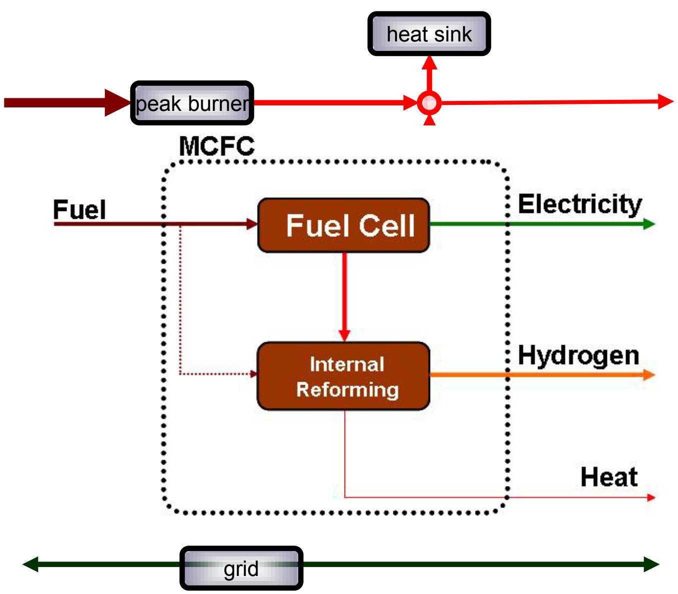


- MCFC's produce more H2 at higher electric power outputs

H2A Power Model Concept



GRID ELECTRICITY AND FUEL PRICE SCHEDULES



LEVELIZED COST OF ENERGY SUPPLIED BY THE SYSTEM

H2A NET PRESENT VALUE/CASH FLOW ANALYSIS

- Financial inputs
- Capital cost input
- Replacement costs
- Operating costs

HOURLY ENERGY FLOWS AND $

- Delivered electricity
- Delivered heat
- Delivered hydrogen
- Fuel used
- Used grid electricity
- Sales to grid

Strategy

- Optimally Configure Fuel Cell System with Regard to Building Type and Location
  - Molten carbonate fuel cell /hydrogen generation equipment installed at the point of use
  - Electricity load following
  - Hydrogen compression, storage, and dispensing equipment included in installation
  - Tri-generation system size optimized for the building electrical load
- Model energy use, costs, and emissions for fuel cell CHP /hydrogen installations for representative building types and locations
  - Hourly analysis of fuel cell system response to building electricity heat, and hydrogen demand
  - Full year of analysis (8760 hours)
- Use results as input into a life-cycle discounted cash flow economic model

Methodology

H2A Power Model for analysis of energy use, costs, and emissions for fuel cell CHP /hydrogen installations for representative building types and locations.

Building Information:

- Electricity and heat demand profiles obtained from NREL building systems model
  - Electricity demand includes air conditioning
  - Heat demand includes fuel demand for space and hot water heating

Building Types

High School

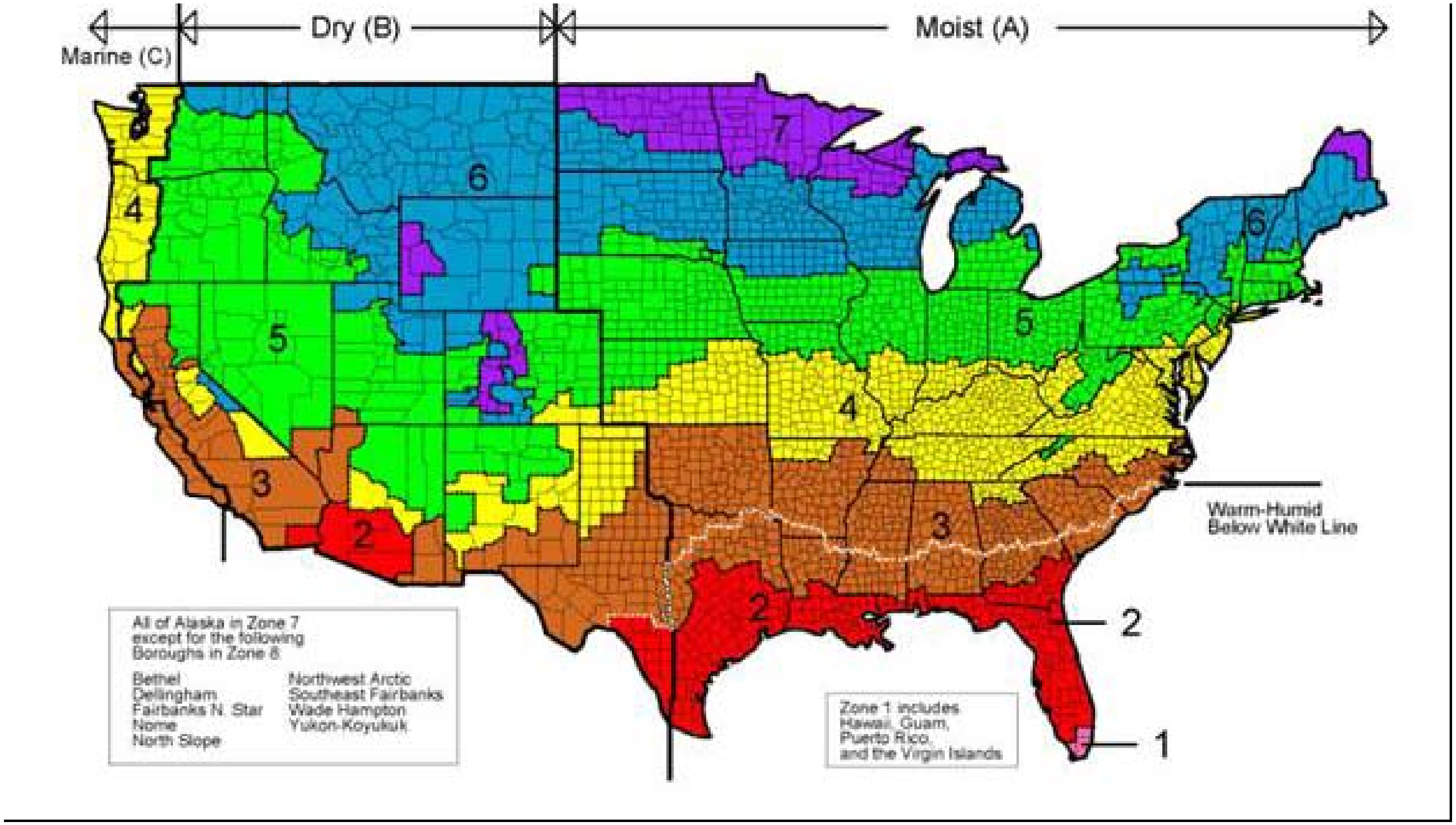
Hospital

Large Office Building

Large Hotel

Supermarket

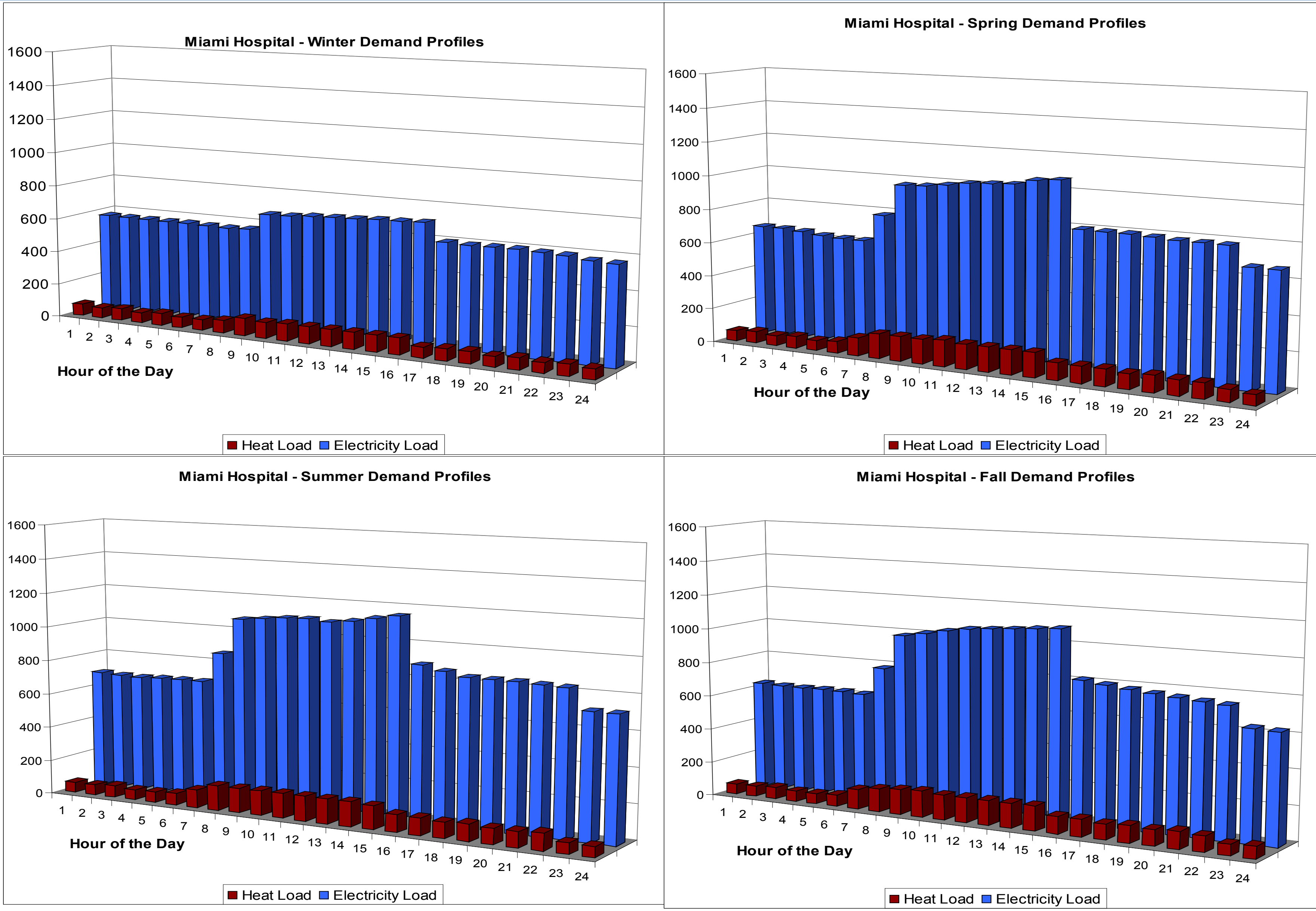
Building Model Climate Zones



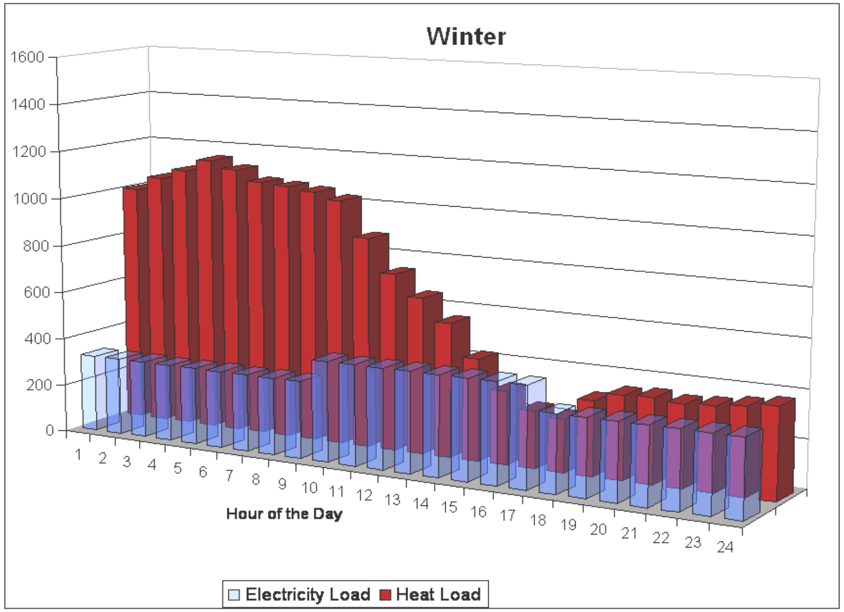
Climate Zone	Representative City	Climate Zone	Representative City
1	Miami, FL	4	Baltimore, MD
2	Houston, TX	5	Chicago, IL
3	Los Angeles, CA	6	Helena, MT

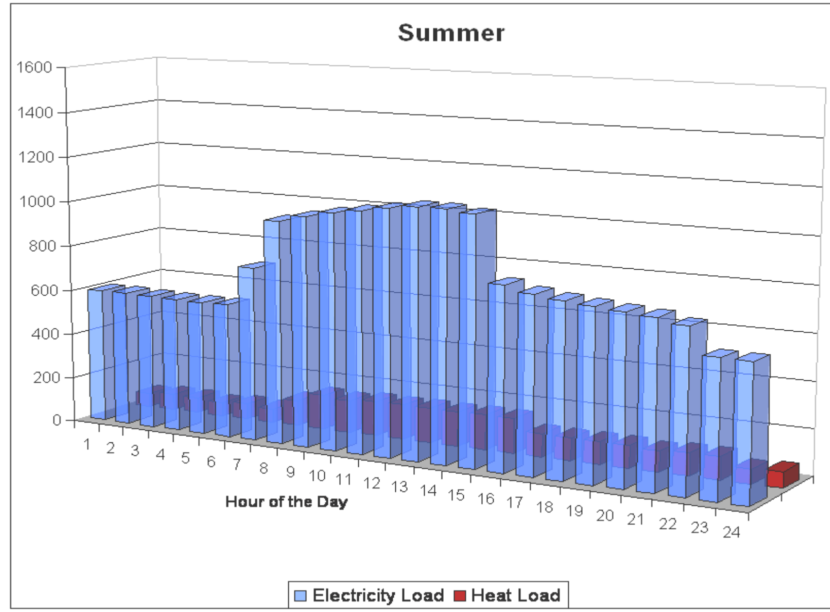
Source: DOE Commercial Building Research Benchmarks for Commercial Buildings, Second Draft, June 2008.

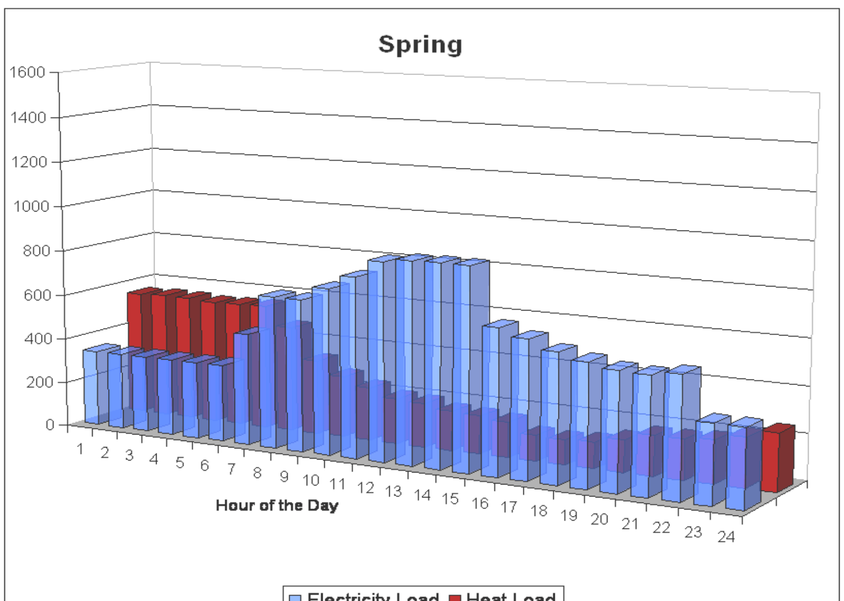
NREL Building Model – Miami Hospital kW of Electricity and Heat Demand Each Hour

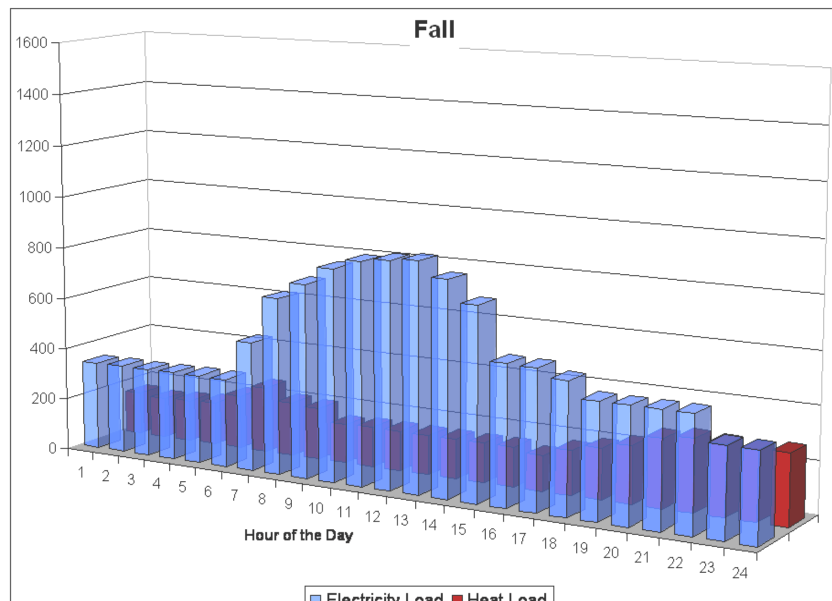


NREL Building Model – Chicago Hospital kW of Electricity and Heat Demand Each Hour

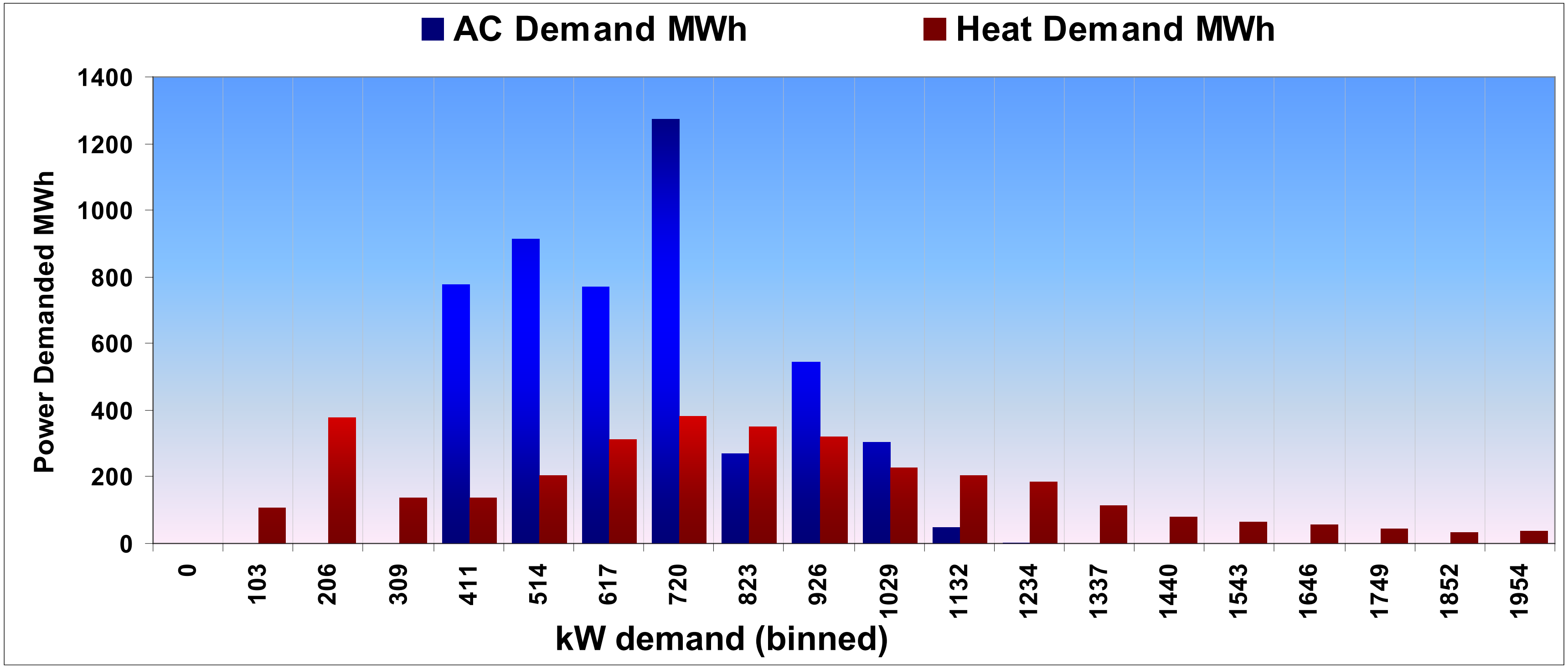








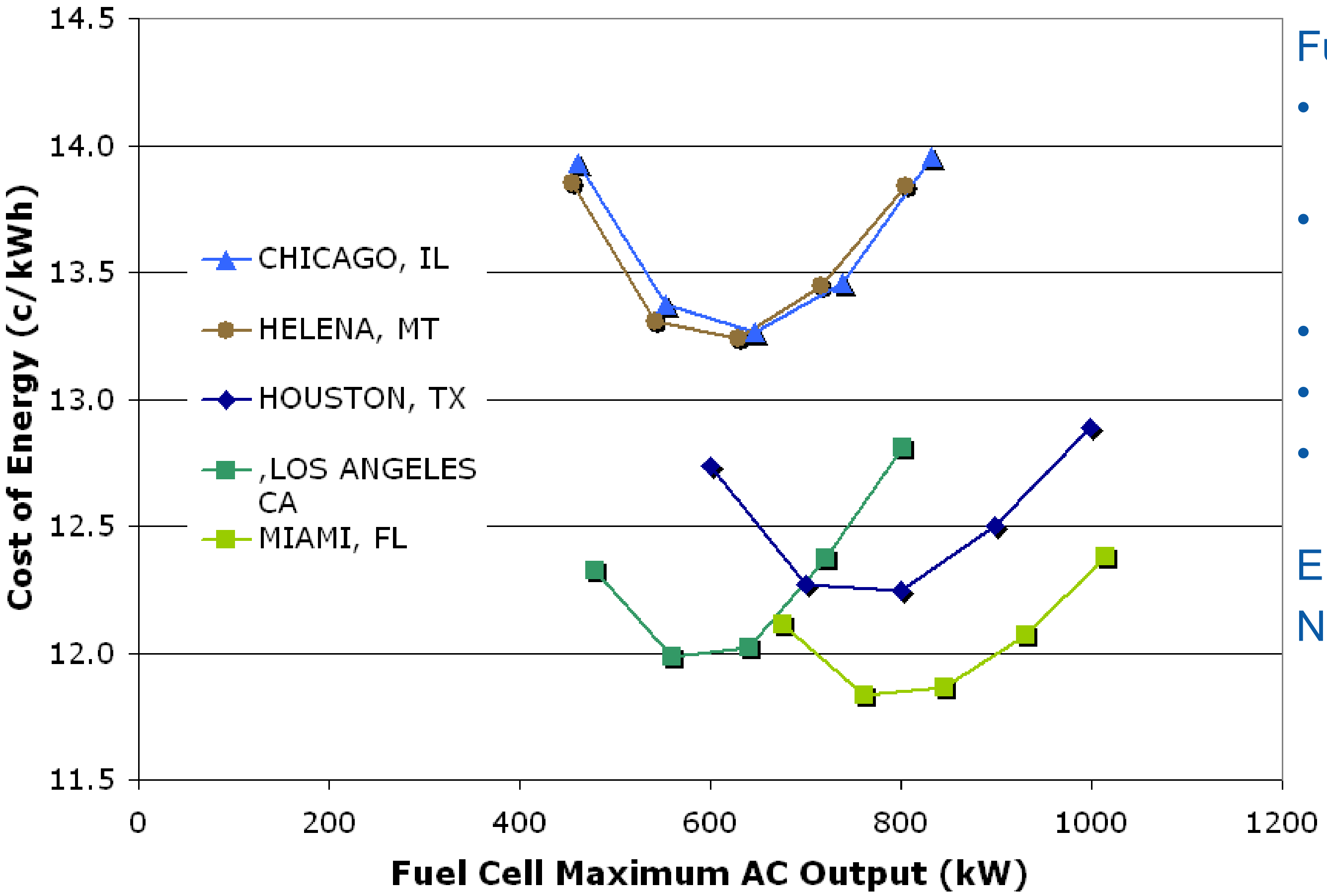
Demand Profile of Chicago Hospital



Building Demand Profiles	
Electricity	**Heat**
Maximum = 1160 kW	Maximum = 1950 kW
Average = 554 kW	Average = 390 kW
Total annual = 4,850 MWh	Total annual = 3,440 MWh

DRAFT

Optimal Size of the Fuel Cell System as a Function of Building Location - Cost of Electricity/Heat/Hydrogen



Fuel cell sized at;

- Average Electricity Load - 0.5 STDev
- Average Electricity Load
- Average + ½ STDev
- Average + 1 STDev
- Average + 1.5 STDev

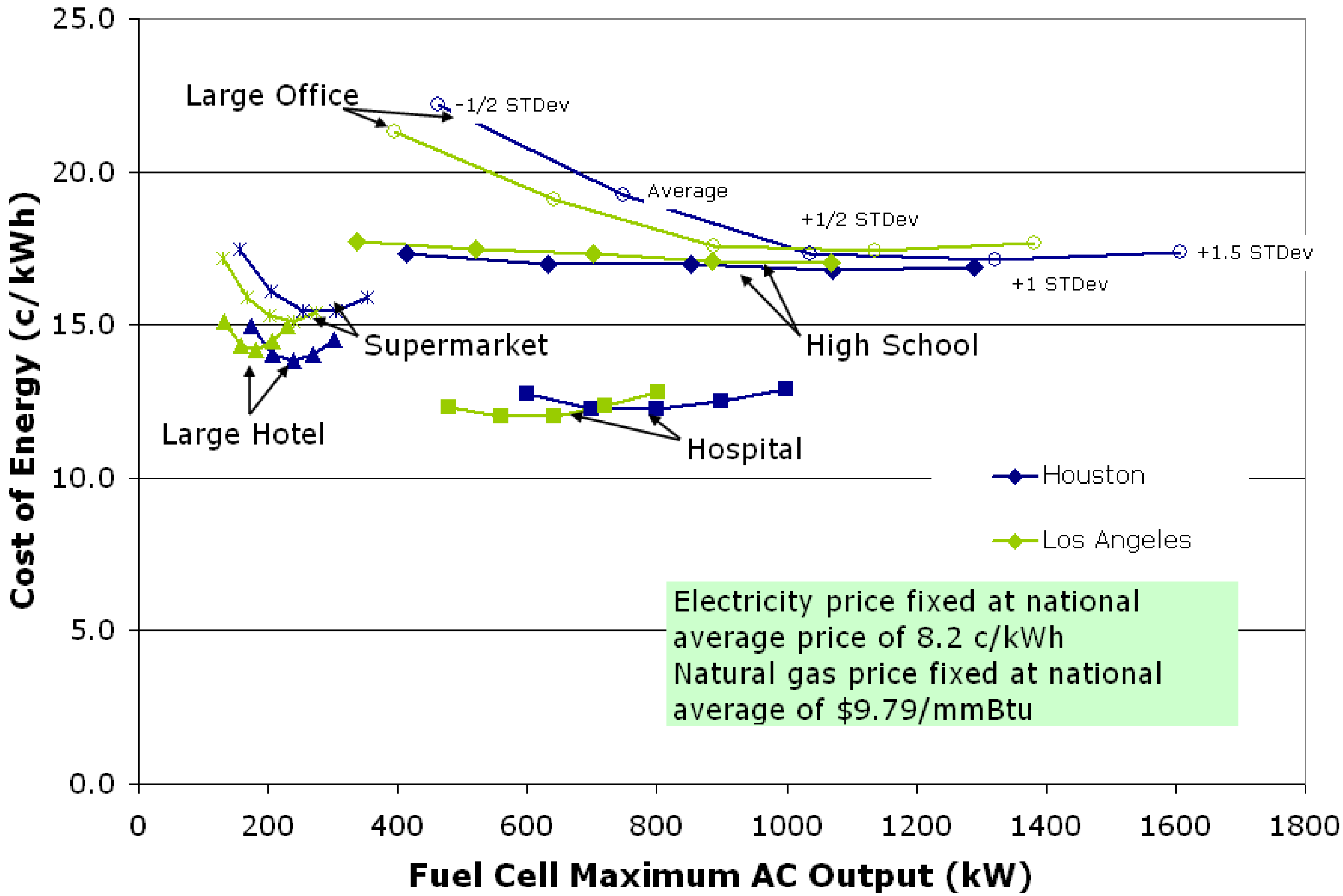
Electricity @ 8.2 c/kWh

Natural Gas @ $9.79/mmBtu

For the same type of building (hospitals) in different locations;

The optimal FC size for minimum cost of energy is about the average electrical demand + 1/2 standard deviation

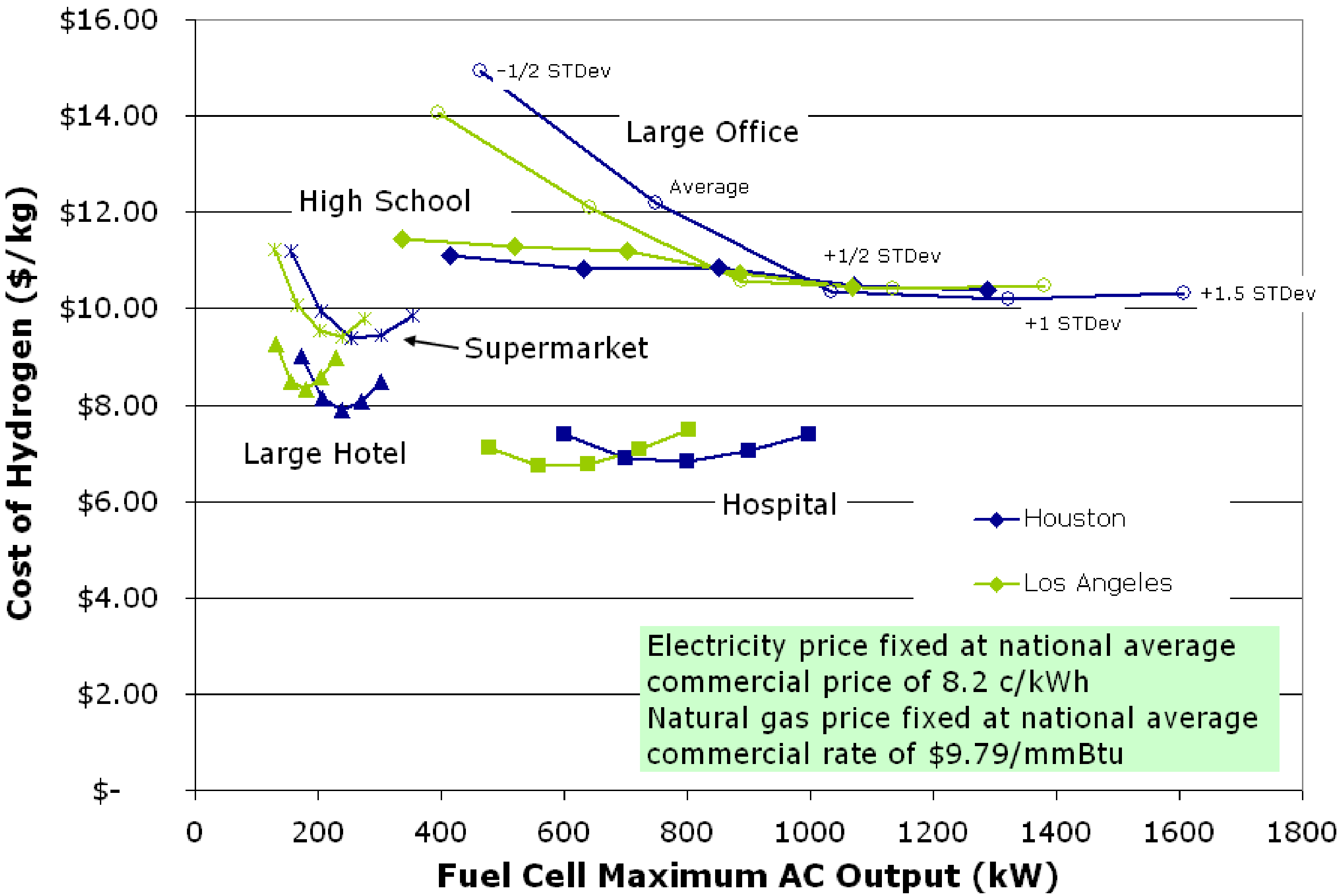
Optimal Size of the Fuel Cell System as a Function of Building Type - Cost of Energy



For different types of building in the same location;

The optimal FC size for minimum cost of energy is between the average electrical demand + 1/2 standard deviation and average demand + 1 standard deviation

Optimal Size of the Fuel Cell System as a Function of Building Type - Cost of Hydrogen

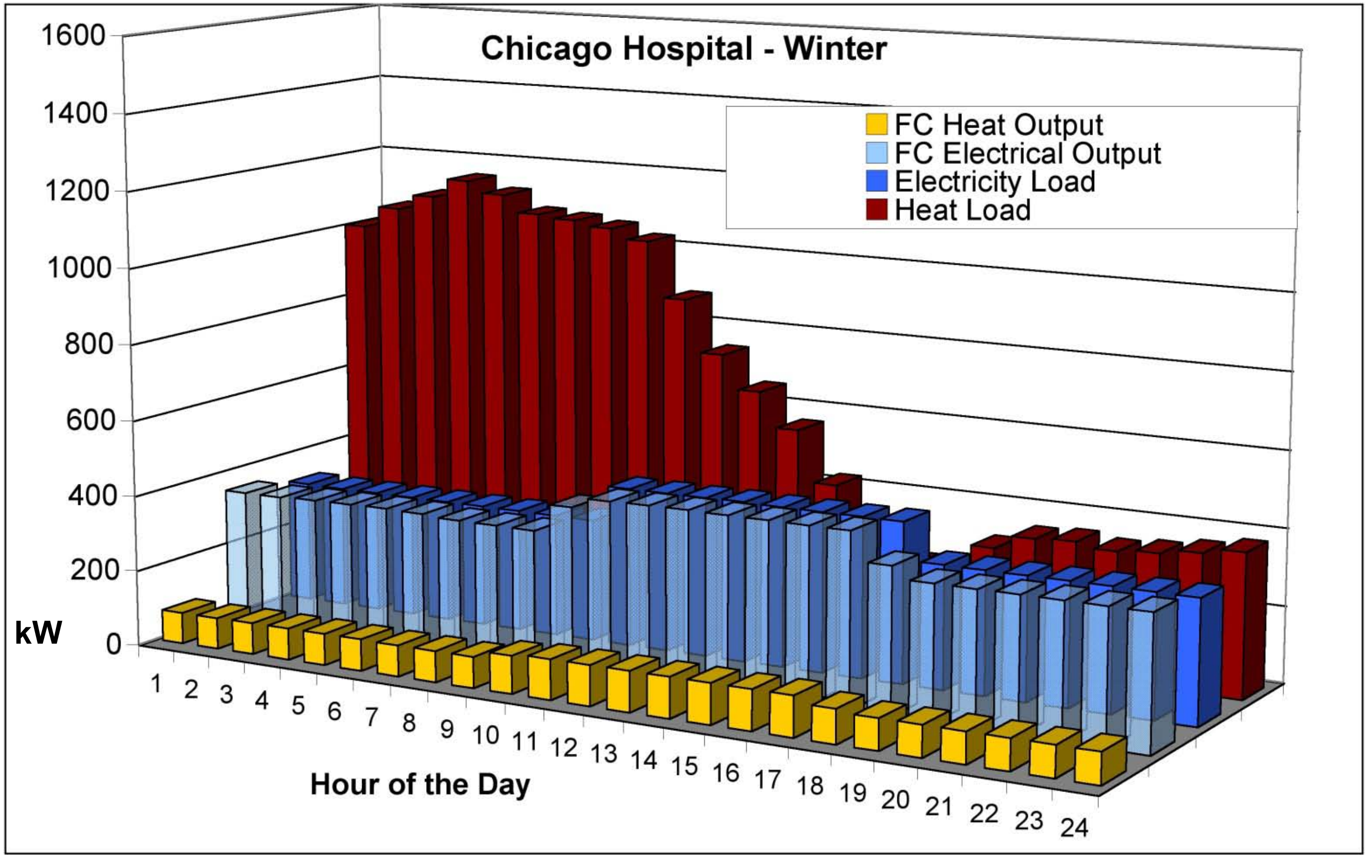


For different types of building in the same location;

The optimal FC size for minimum hydrogen cost is about the average electrical demand + 1/2 to 1 standard deviation

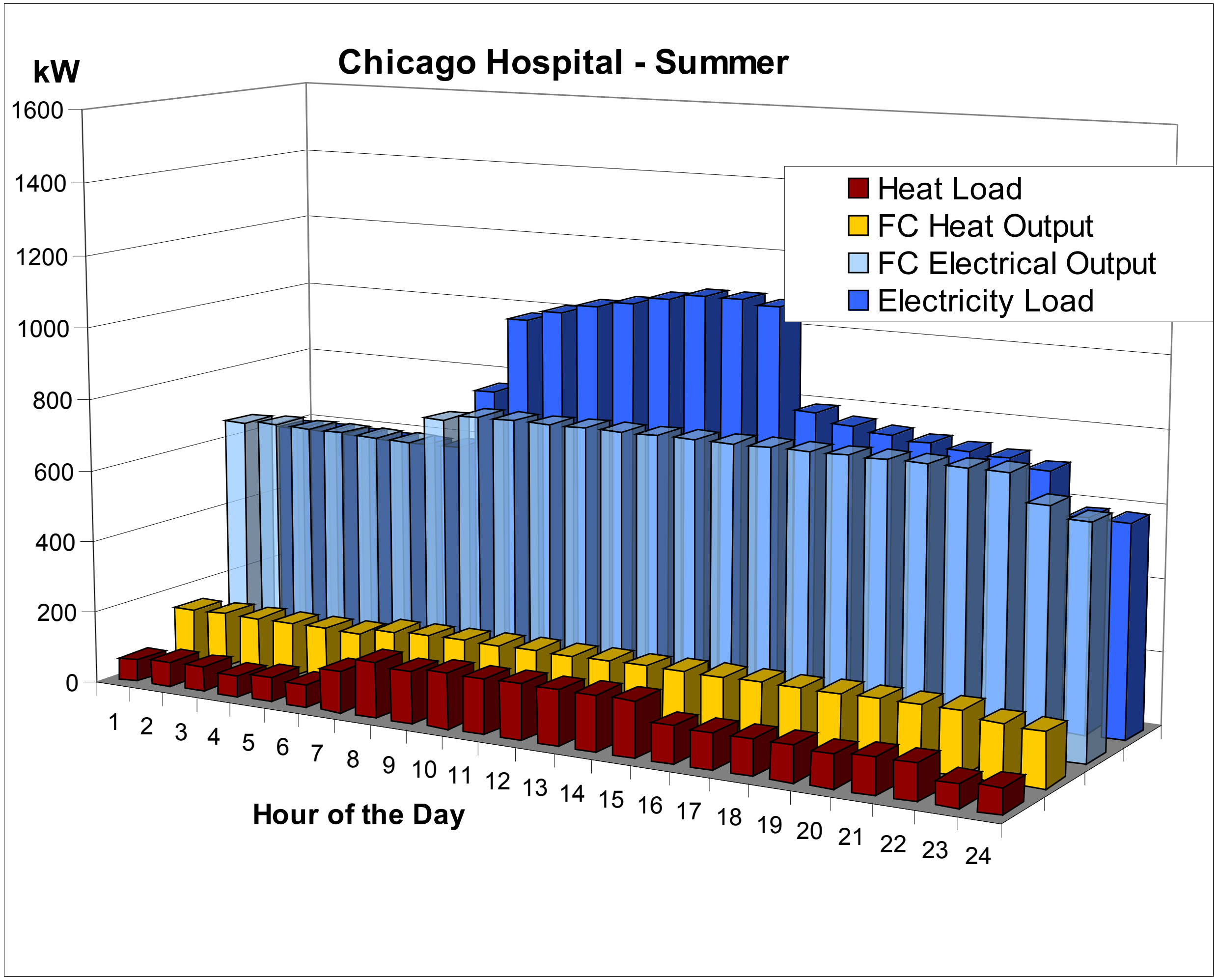
Fuel Cell Response to Electricity Demand Changes

- Fuel cell electrical output follows electricity load



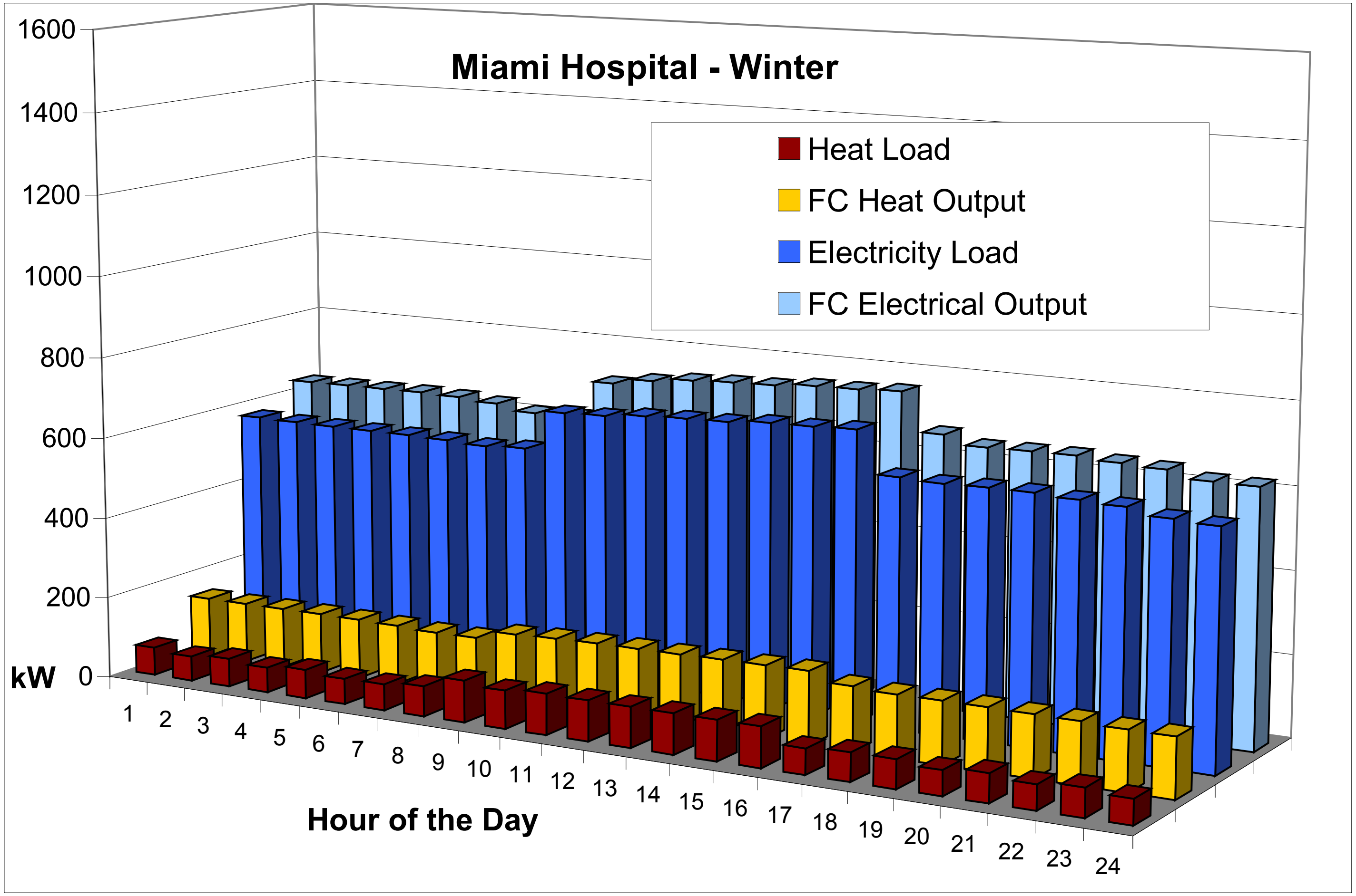
- Winter electricity demand is well below maximum FC output of 739 kW – FC meets electricity demand
- Winter heat production meets only 13% of heat load

Fuel Cell Response to Electricity Demand Changes



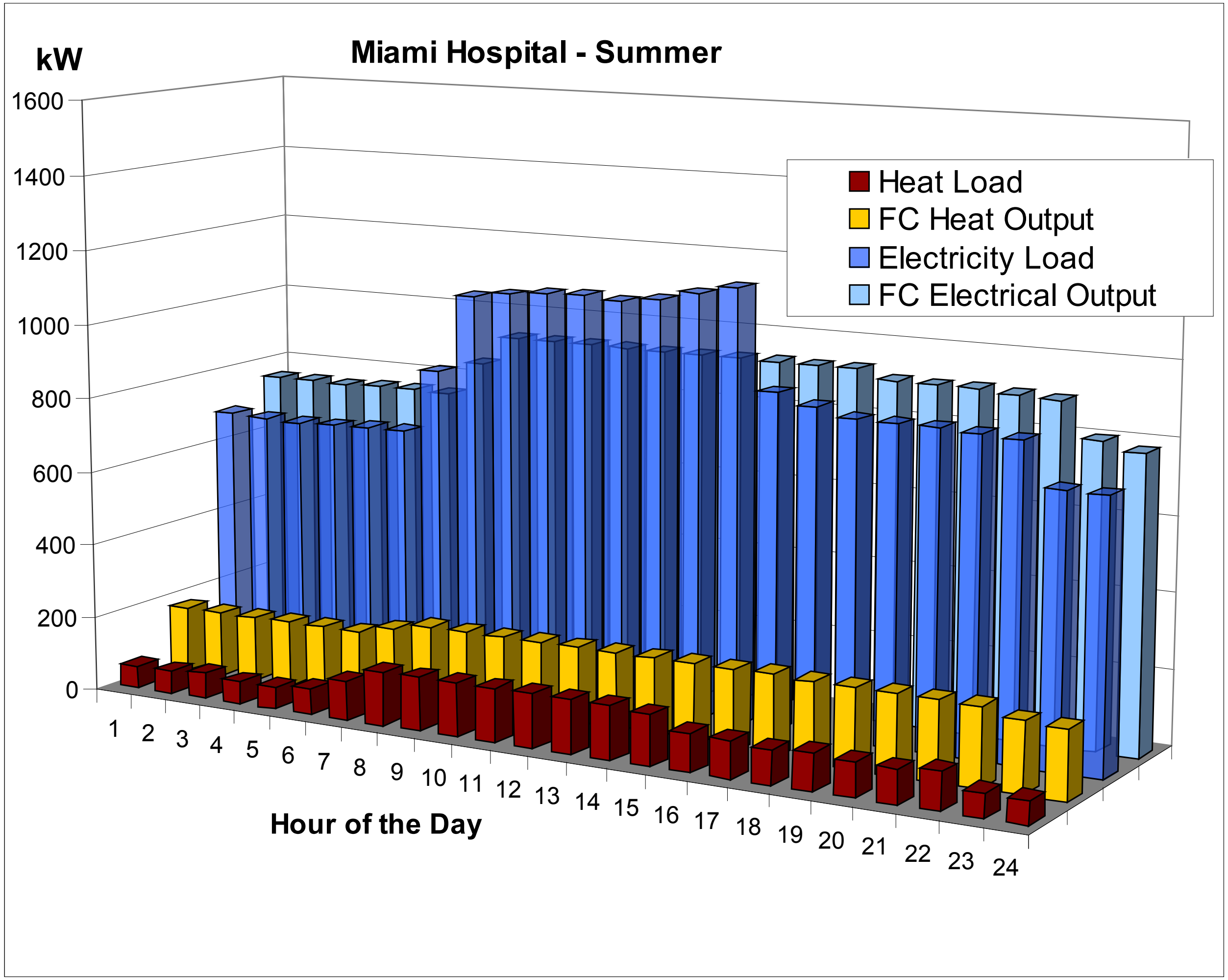
- Summer electricity demand exceeds maximum FC output of 739 kW
- Summer heat production meets 100% of heat load

Fuel Cell Response to Electricity Demand Changes



- Winter electricity demand is below maximum output of 930 kW
- Winter heat production meets 100% of heat demand

Fuel Cell Response to Electricity Demand Changes



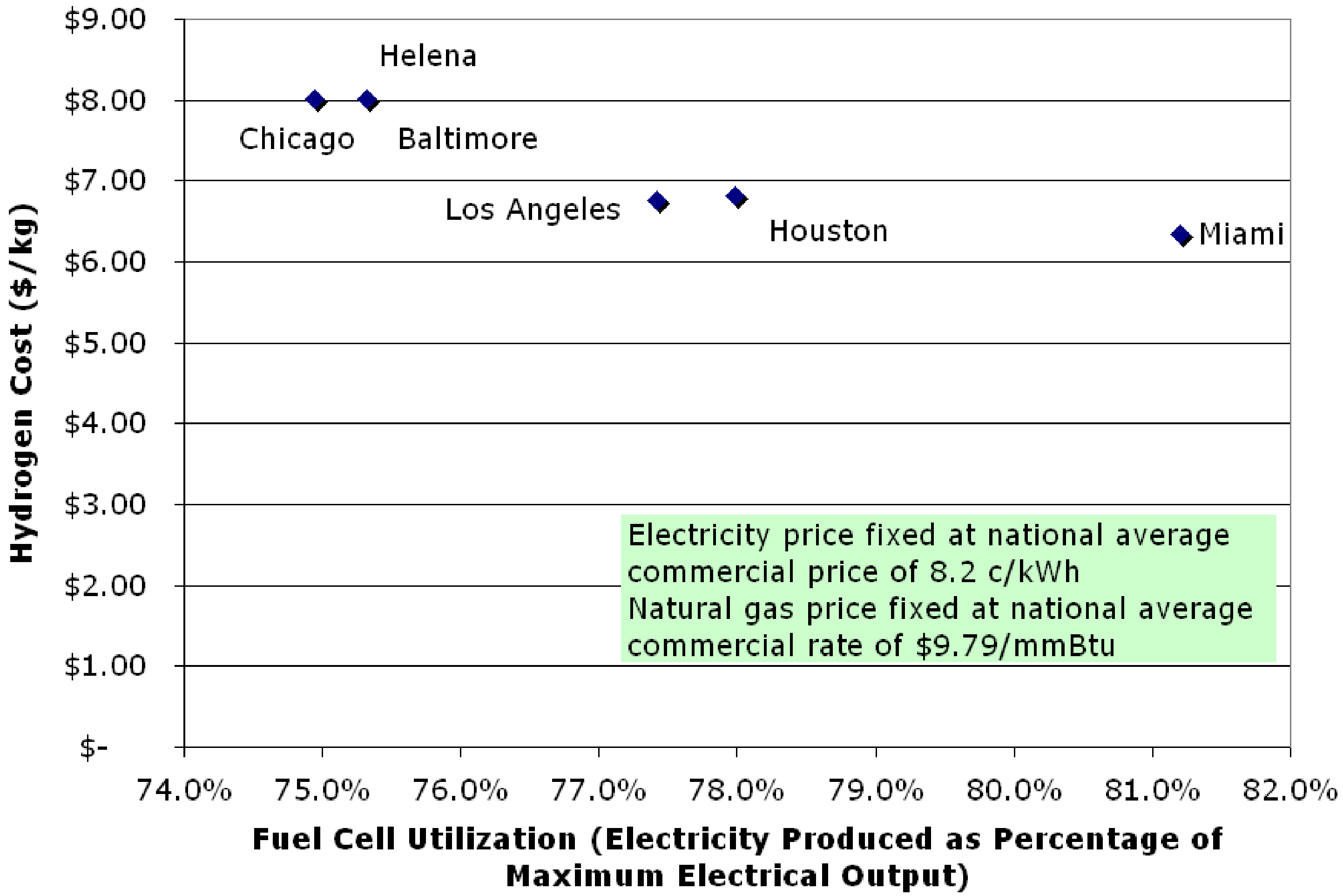
- Summer electricity production does not meet peak demand
- Summer heat production meets 100% of heat load

Fuel Cell Utilization and Hydrogen Production for Hospitals in Various Climates

	Fuel Cell Size (kW)	Hydrogen Delivered (kg/day)	Fuel Cell Utilization (AC Output/Max AC Output)
MIAMI	846	328	81.2%
HOUSTON	799	296	78.0%
LOS ANGELES	640	236	77.4%
HELENA	629	225	75.3%
BALTIMORE	684	244	75.2%
CHICAGO	646	230	74.9%

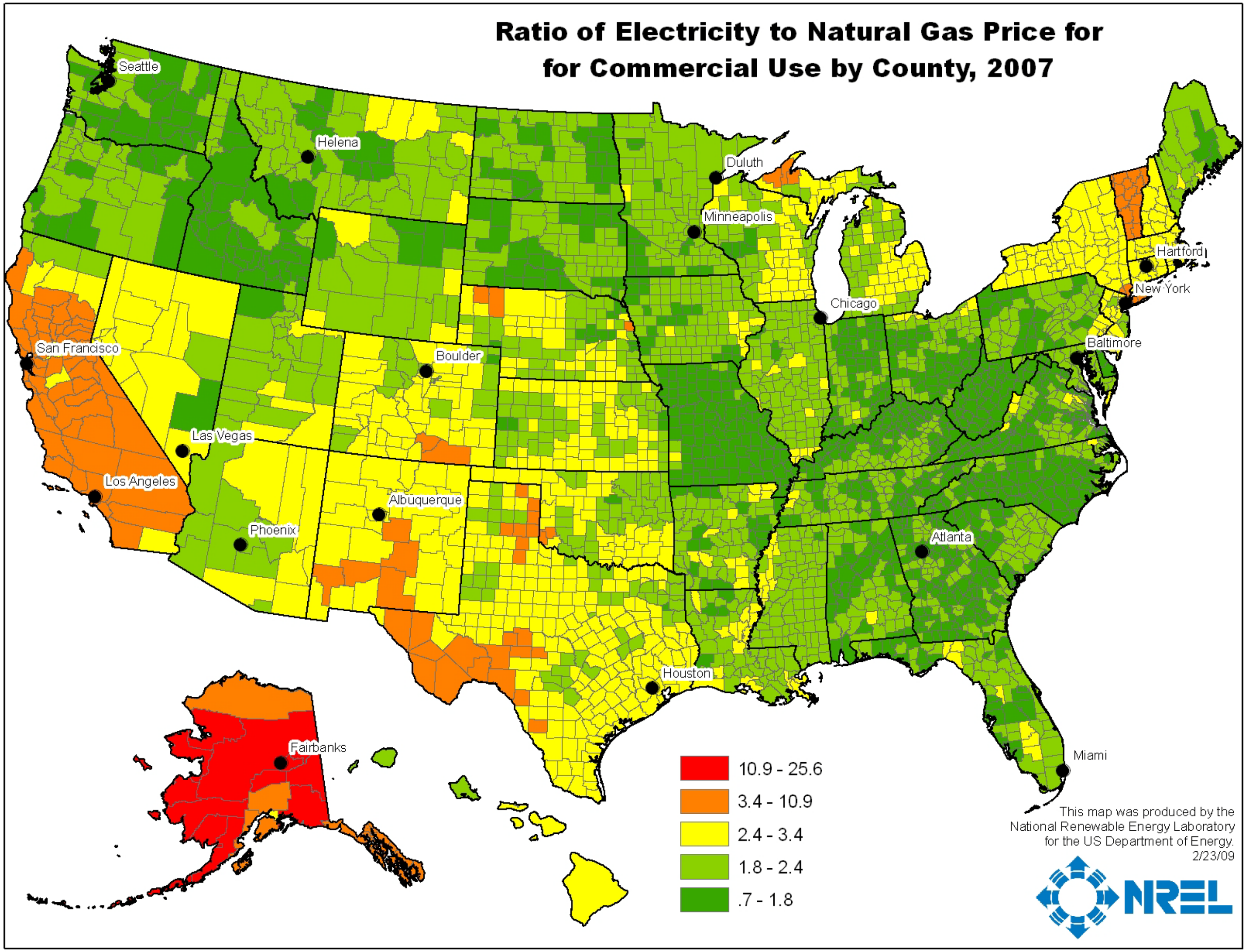
- Fuel cell sized at average electricity demand + ½ standard deviation
- Higher fuel cell utilization reduces cost

Fuel Cell Response to Electricity Demand Changes



- For fixed (national average) electricity and natural gas prices, hydrogen cost decreases with increasing fuel cell utilization.
- Fuel cell utilization increases for more southern climates because electricity and heat load profiles are more uniform between summer and winter

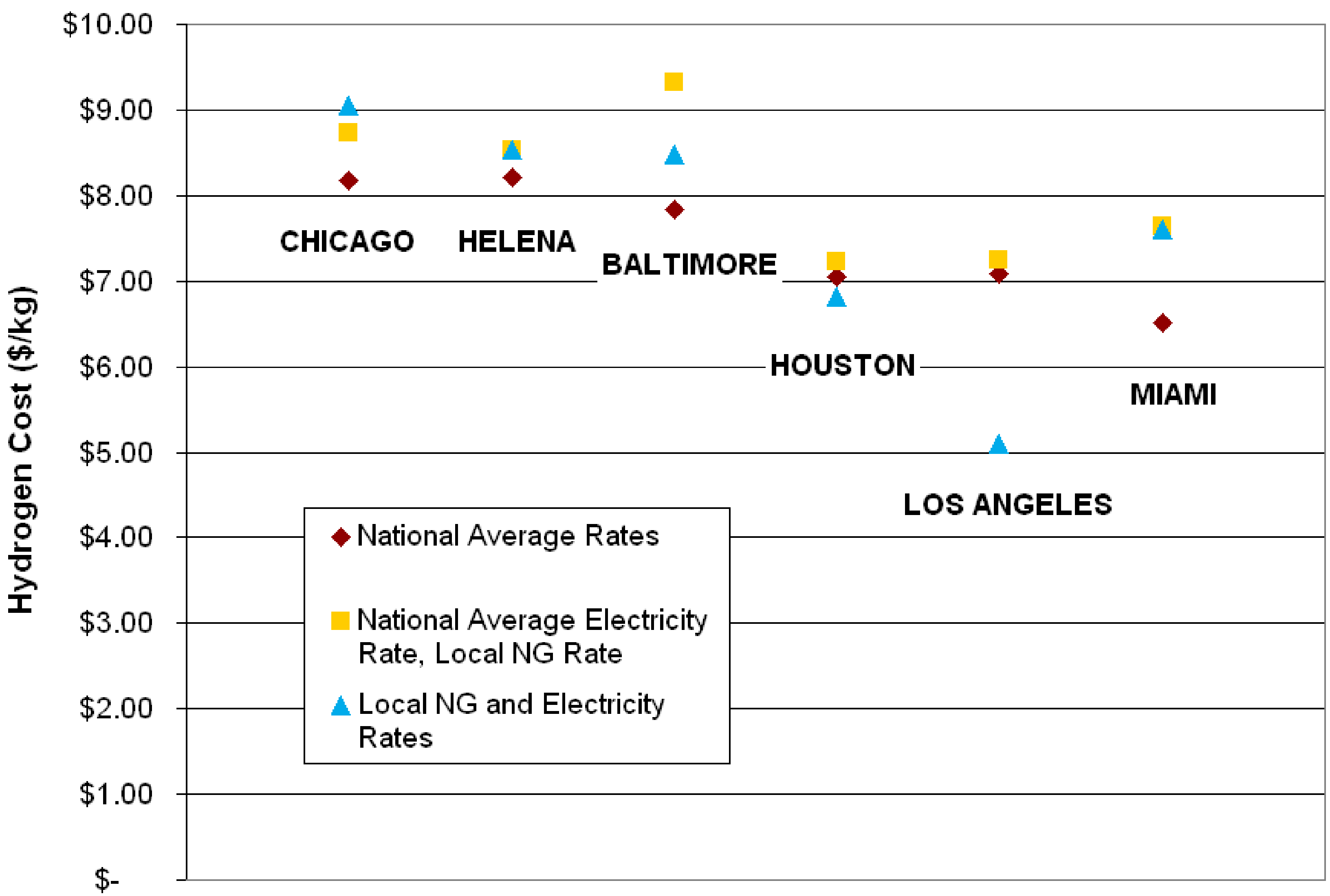
Electricity and Natural Gas Rates



Spark Spread – Ratio of Electricity to Natural Gas Price

	Commercial Electricity Rate (¢/kWh)	Commericial NG Rates ($/mmBtu)	Spark Spread (ratio of electricity to NG price)
Fairbanks	30.0	4.80	18.3
New York	17.8	10.78	4.8
San Francisco	13.2	10.70	3.6
Los Angeles	12.4	10.15	3.6
Albuquerque	7.7	8.63	2.6
Hartford	11.6	13.12	2.6
Houston	9.0	10.18	2.6
Las Vegas	8.3	9.99	2.4
Boulder	7.7	9.49	2.4
Helena	8.2	10.34	2.3
Baltimore	9.8	12.56	2.3
Phoenix	7.5	9.69	2.3
Seattle	7.3	10.10	2.1
Chicago	7.6	10.78	2.1
Duluth	7.0	9.94	2.1
Miami	8.3	12.29	2.0
Minneapolis	6.6	10.15	1.9
Atlanta	7.5	12.21	1.8

Spark Spread Effect on Hydrogen Cost



Conclusions

Climate influences the cost of energy produced by fuel cell tri-generation systems because of it's effect on fuel cell utilization

The ratio of electricity to natural gas price influences the cost of hydrogen from a tri-generation system because of two factors

- If electricity prices are high, electricity produced by the fuel cell can be "priced" higher, thus reducing the cost of hydrogen
- If natural gas prices are low, the fuel cell tri-generation system produces electricity, heat, and hydrogen for a lower cost.

Questions ?