The Status of Renewable Hydrogen and "Energy Station" Technologies and Policy Recommendations

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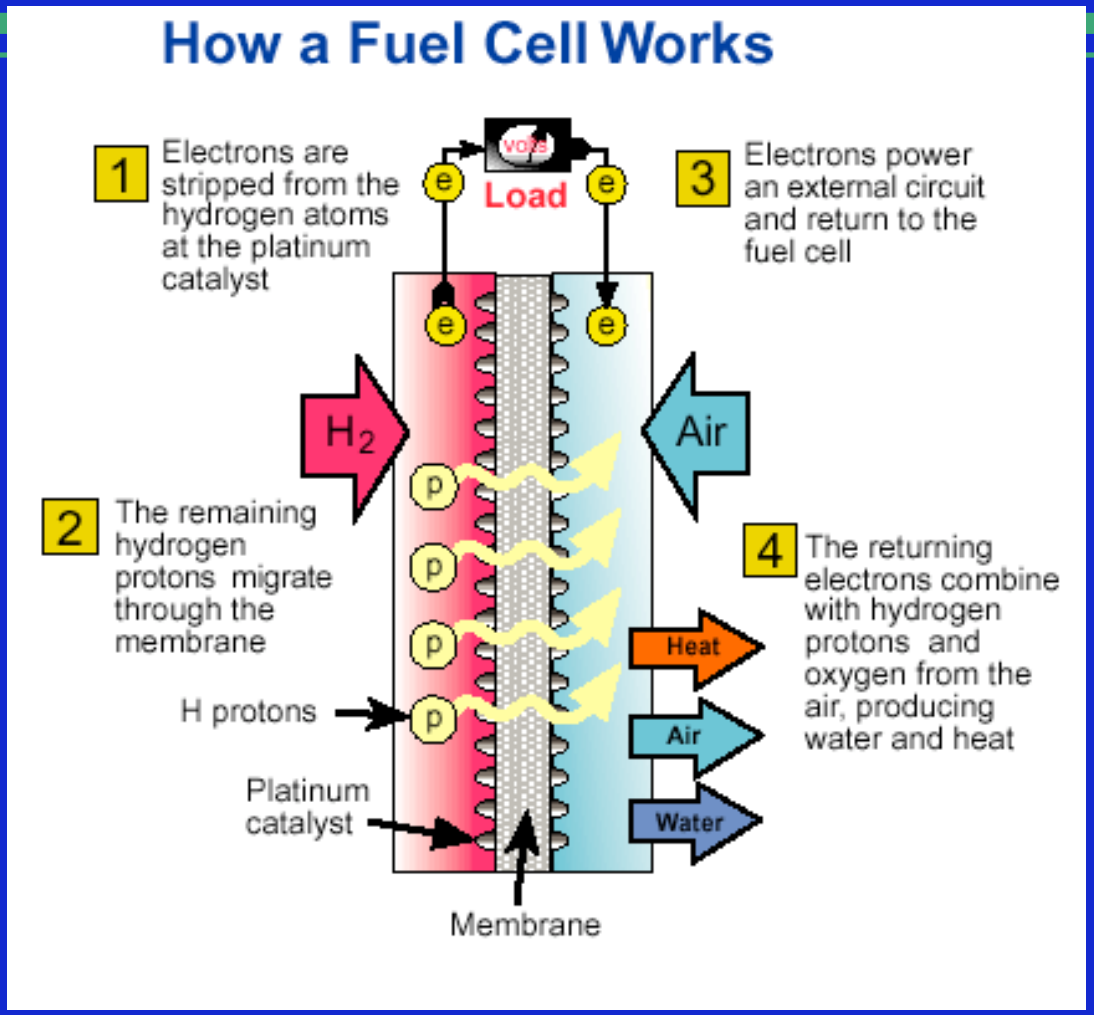
Prepared for the Public Fuel Cell Alliance and the Clean Energy States Alliance

Tim Lipman, PhD
telipman@berkeley.edu
Inst. of Transportation Studies
University of California, Berkeley
and Hydrogen Pathways Program, ITS-Davis

Outline

- Hydrogen / Fuel Cell Technology Status
- Major Hydrogen Production Pathways
- Hydrogen Production and Environmental Impacts
- Renewable Hydrogen Research and Development Activities
- Featured Demonstration Projects
- Hydrogen Energy Stations
- Conclusions and Recommendations

PEM Fuel Cell Diagram



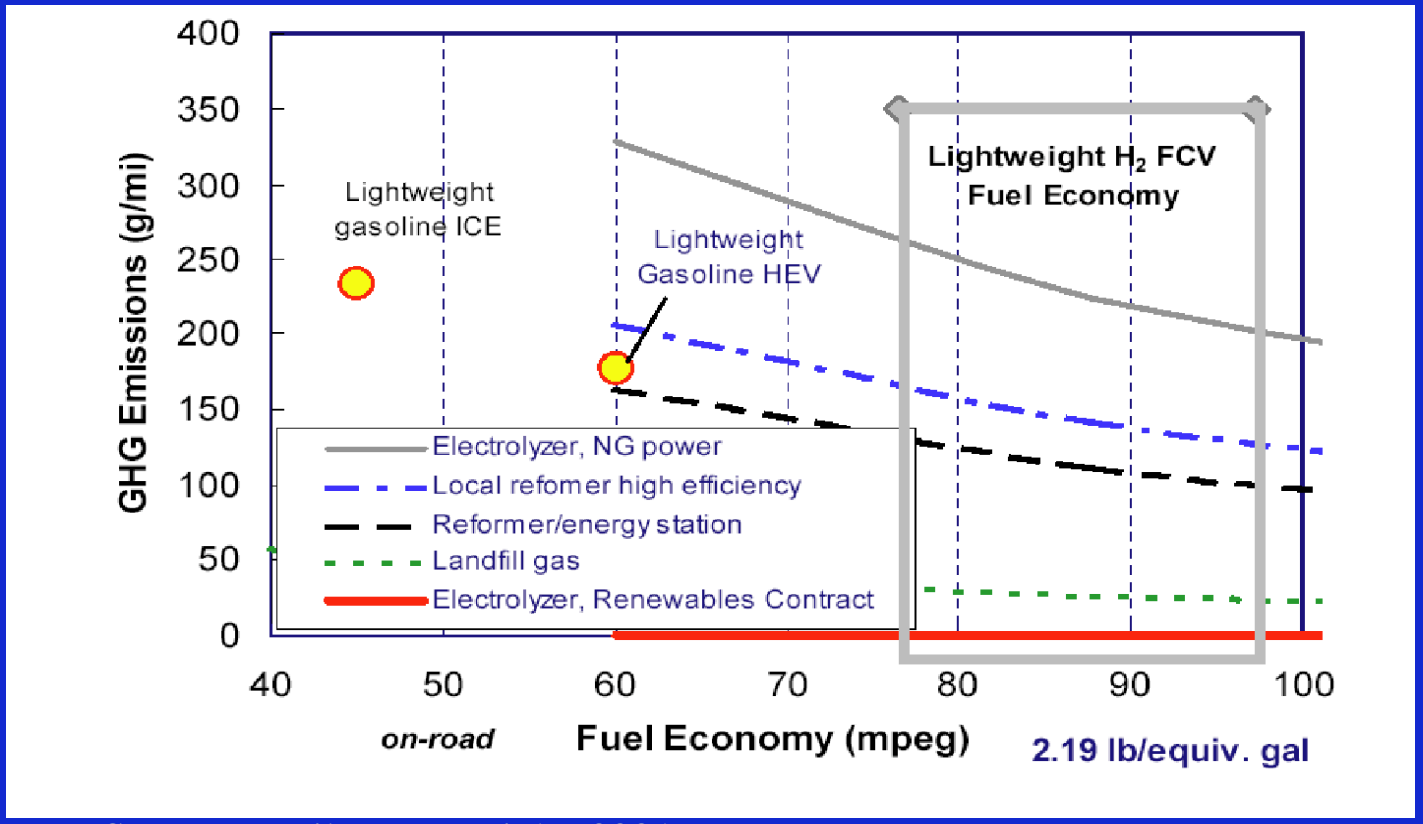
Fuel Cell Types

	PEFC	AFC	PAFC	MCFC	ITSOFC	TSOFC
Electrolyte	Ion Exchange Membranes	Mobilized or Immobilized Potassium Hydroxide	Immobilized Liquid Phosphoric Acid	Immobilized Liquid Molten Carbonate	Ceramic	Ceramic
Operating Temperature	80°C	65°C - 220°C	205°C	650°	600-800°C	800-1000°C
Charge Carrier	H^+	OH^-	H^+	$CO3^=$	$O^=$	$O^=$
External Reformer for CH_4 (below)	Yes	Yes	Yes	No	No	No
Prime Cell Components	Carbon-based	Carbon-based	Graphite-based	Stainless-based	Ceramic	Ceramic
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskites	Perovskites
Product Water Management	Evaporative	Evaporative	Evaporative	Gaseous Product	Gaseous Product	Gaseous Product
Product Heat Management	Process Gas + Independent Cooling Medium	Process Gas + Electrolyte Calculation	Process Gas + Independent Cooling Medium	Internal Reforming + Process Gas	Internal Reforming + Process Gas	Internal Reforming + Process Gas

Note: ITSOFC is intermediate temperature SOFC and TSOFC is tubular SOFC

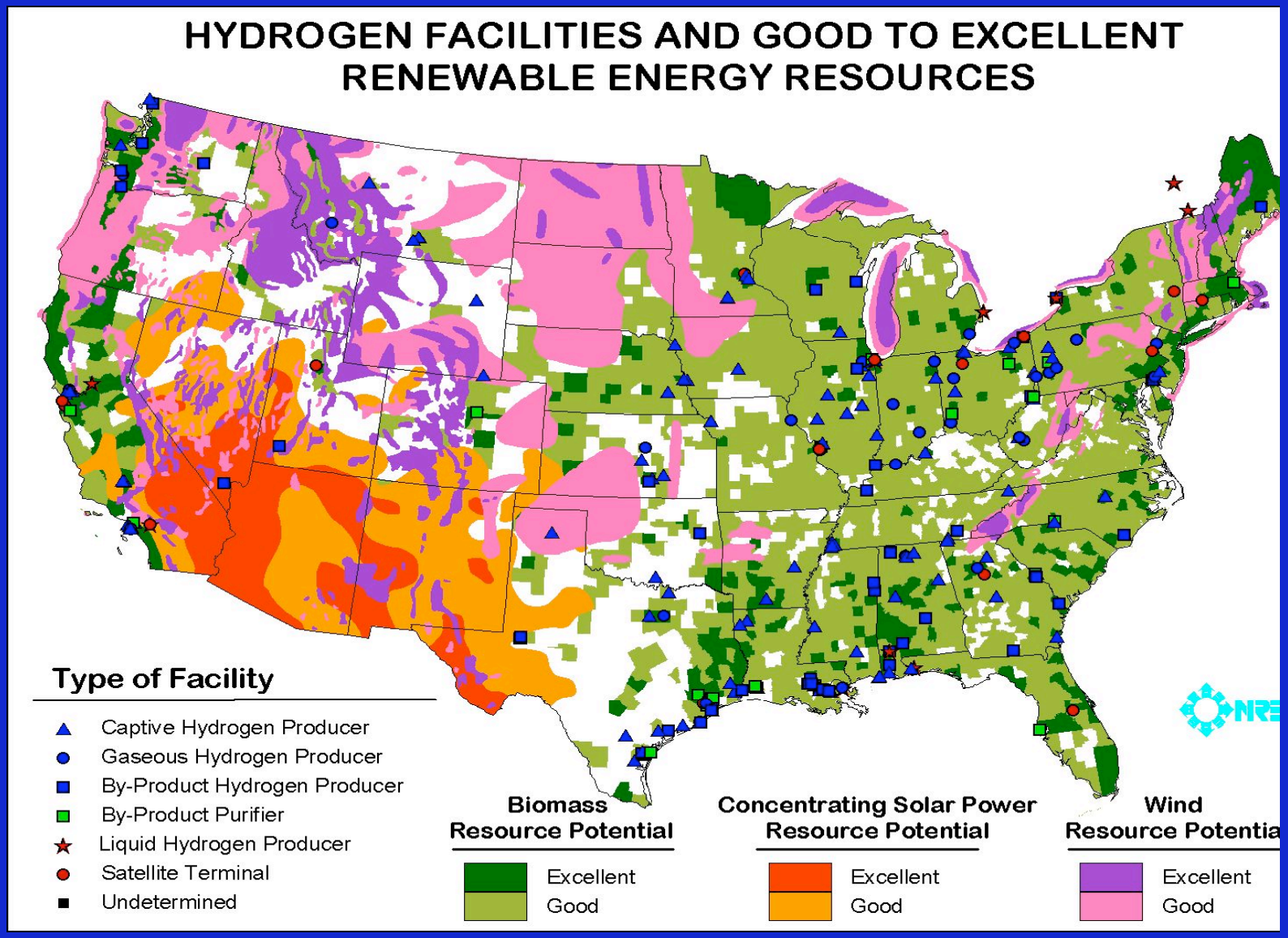
Why H2 Fuel Cells for Vehicles?

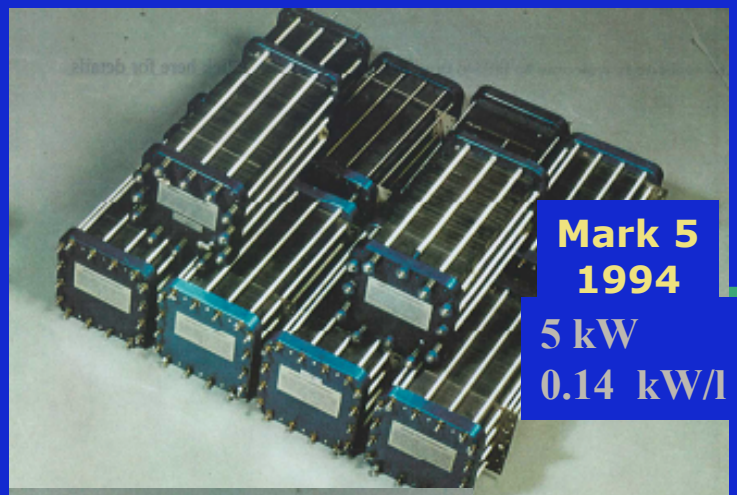
GHGs for Hydrogen FCVs vs. ICE Vehicles



Source: Bevilacqua-Knight, 2001

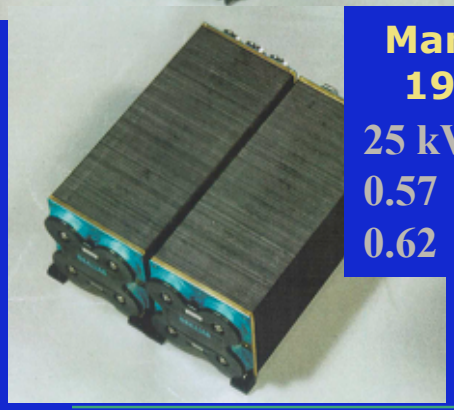
U.S. Renewable Energy Potential





Mark 5
1994
5 kW
0.14 kW/l

Mark 513
1995
10 kW
0.30 kW/l



Mark 7
1996
25 kW
0.57 kW/l
0.62 kW/Kg

Mark 8
1997
50 kW
0.73 kW/l

BALLARD
power to change the world

Evolution of Ballard Fuel Cell Stacks

Mark 9
2002
85 kW
1.1 kW/l
0.92 kW/Kg

Mark 9
2000
75 kW
1.04 kW/l
0.89 kW/Kg

DaimlerChrysler "F-Cell" Vehicle

New Chevron / AC Transit Station

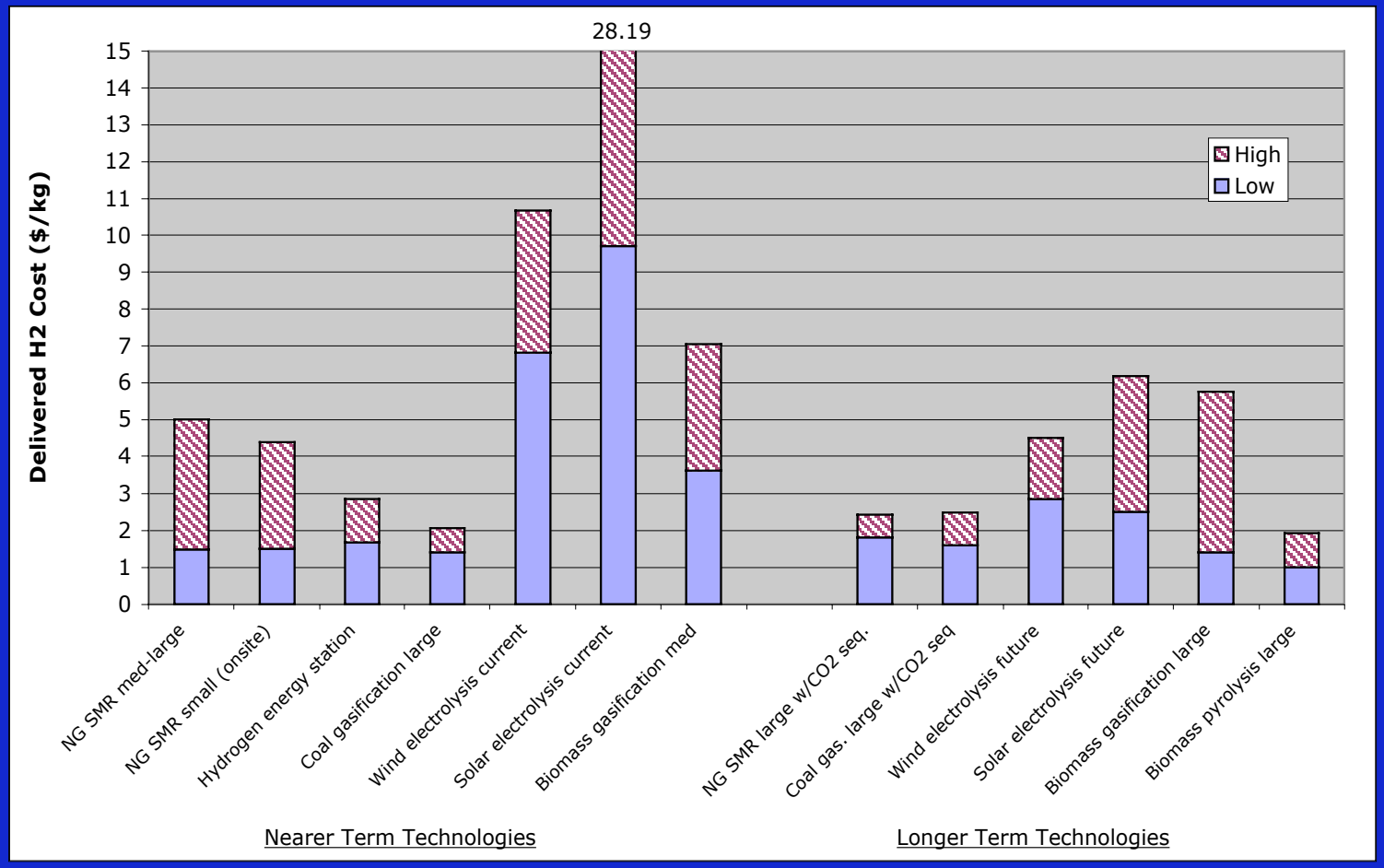
Hydrogen Production/Distribution

- Many Production Methods, Including Steam Reformation of Natural Gas (Methane), Electrolysis of Water Using Any Source of Electricity (including renewables), and Coal Gasification Among Others
- Various Production Scales and Transport/Delivery Options (e.g. trucks, pipelines, mobile refuelers)
- Onsite Production Has Advantage of No Need for Transportation
- “Energy Stations” for Hydrogen and Electricity Co-Production
- Again, Widely Varying Economics and Environmental Impacts

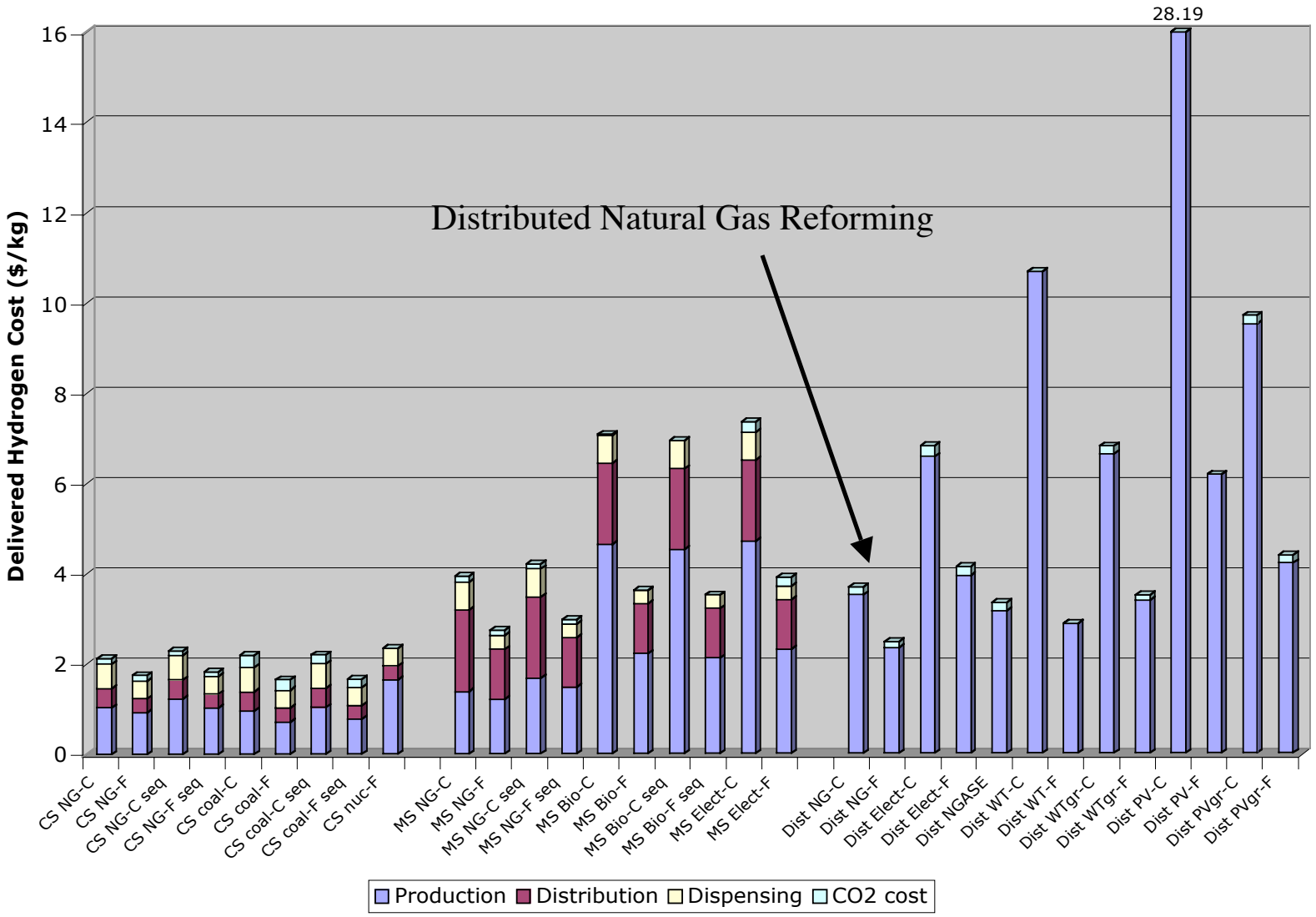
Hydrogen Production

- Reforming of Natural Gas or Other Fuel
- Coal Gasification
- Electrolysis
- Biomass Gasification and Pyrolysis
- Algal Production
- Photo-Electrochemical
- Nuclear Cycles

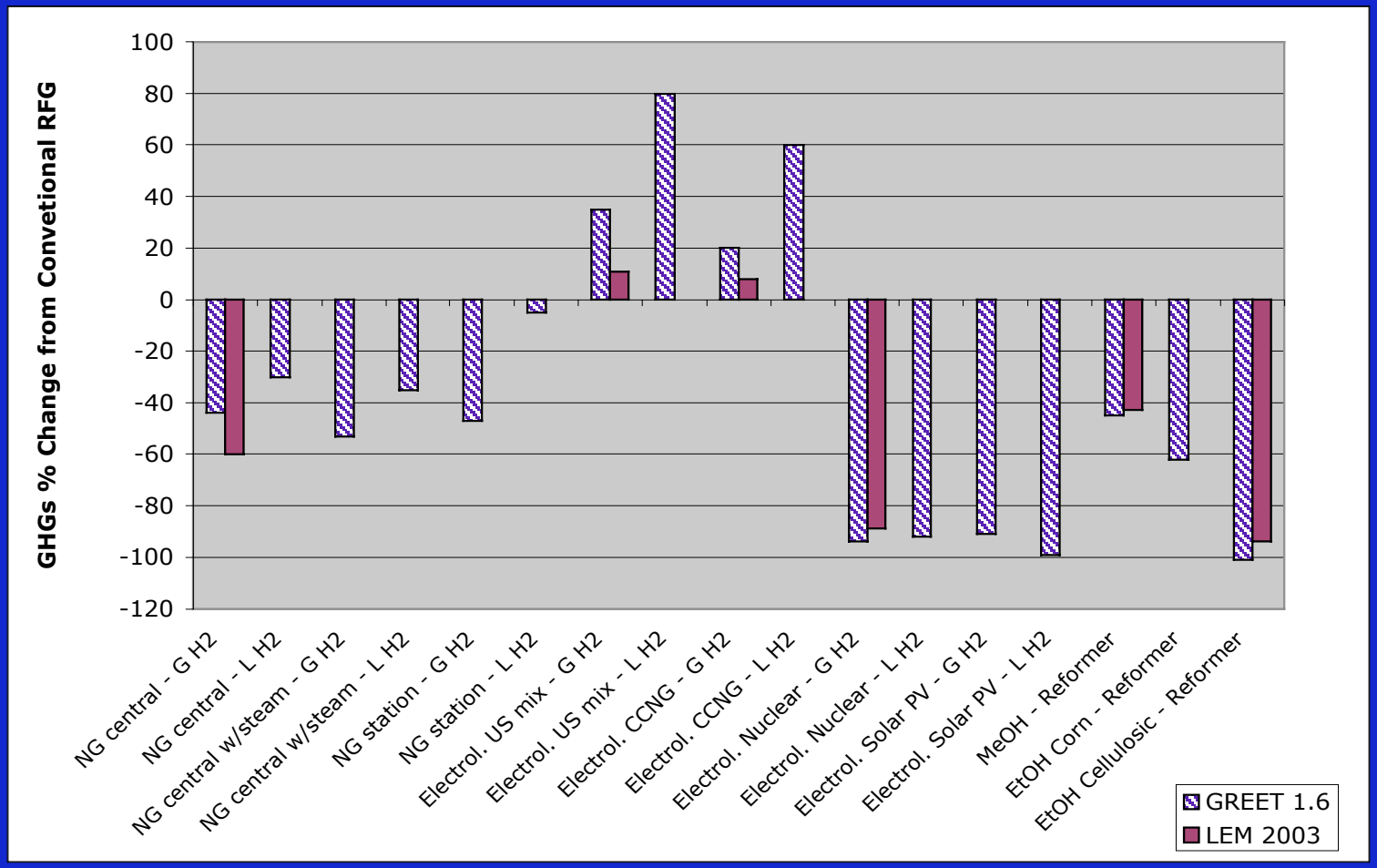
Ranges In Delivered Hydrogen Costs



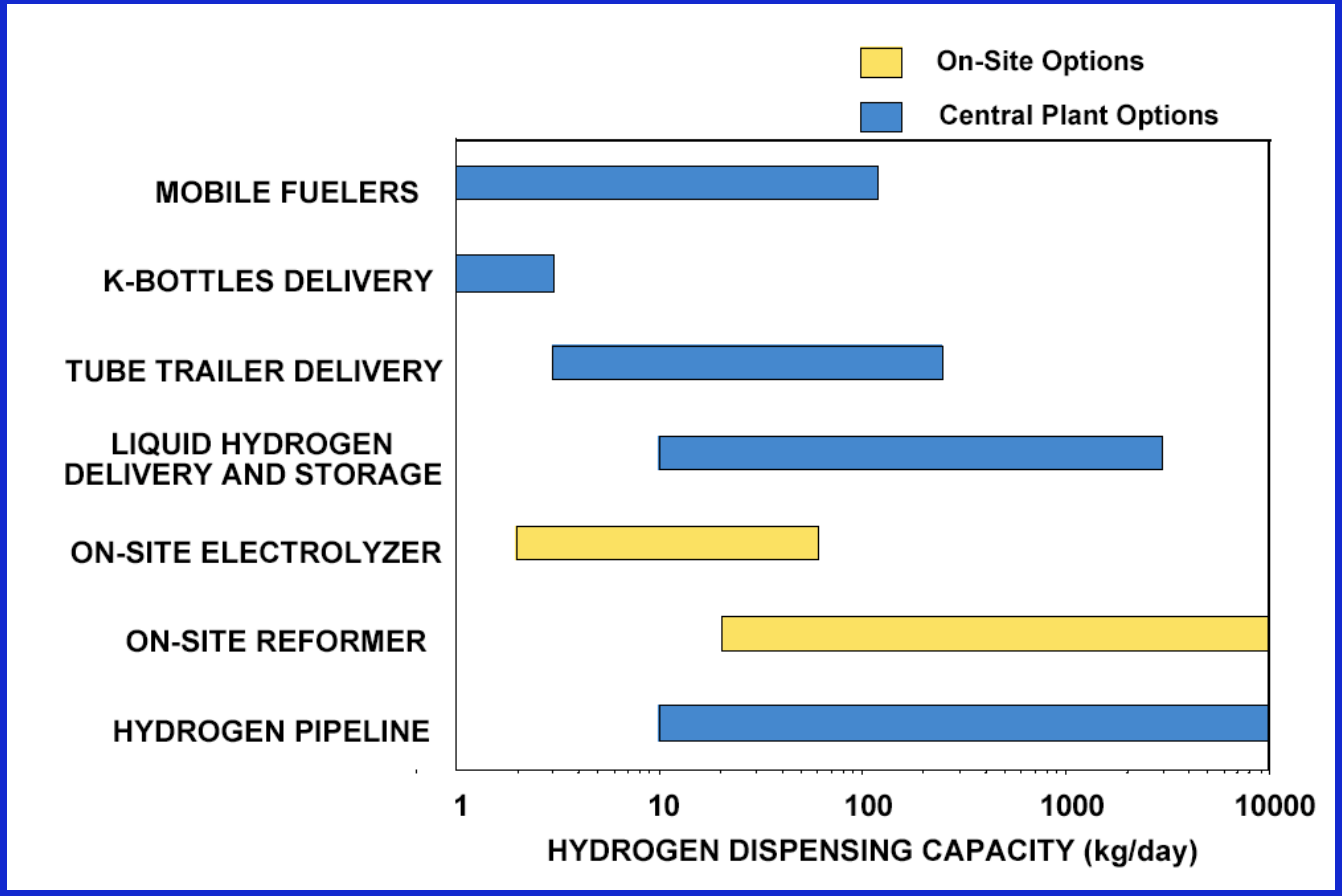
National Research Council H_2 Study



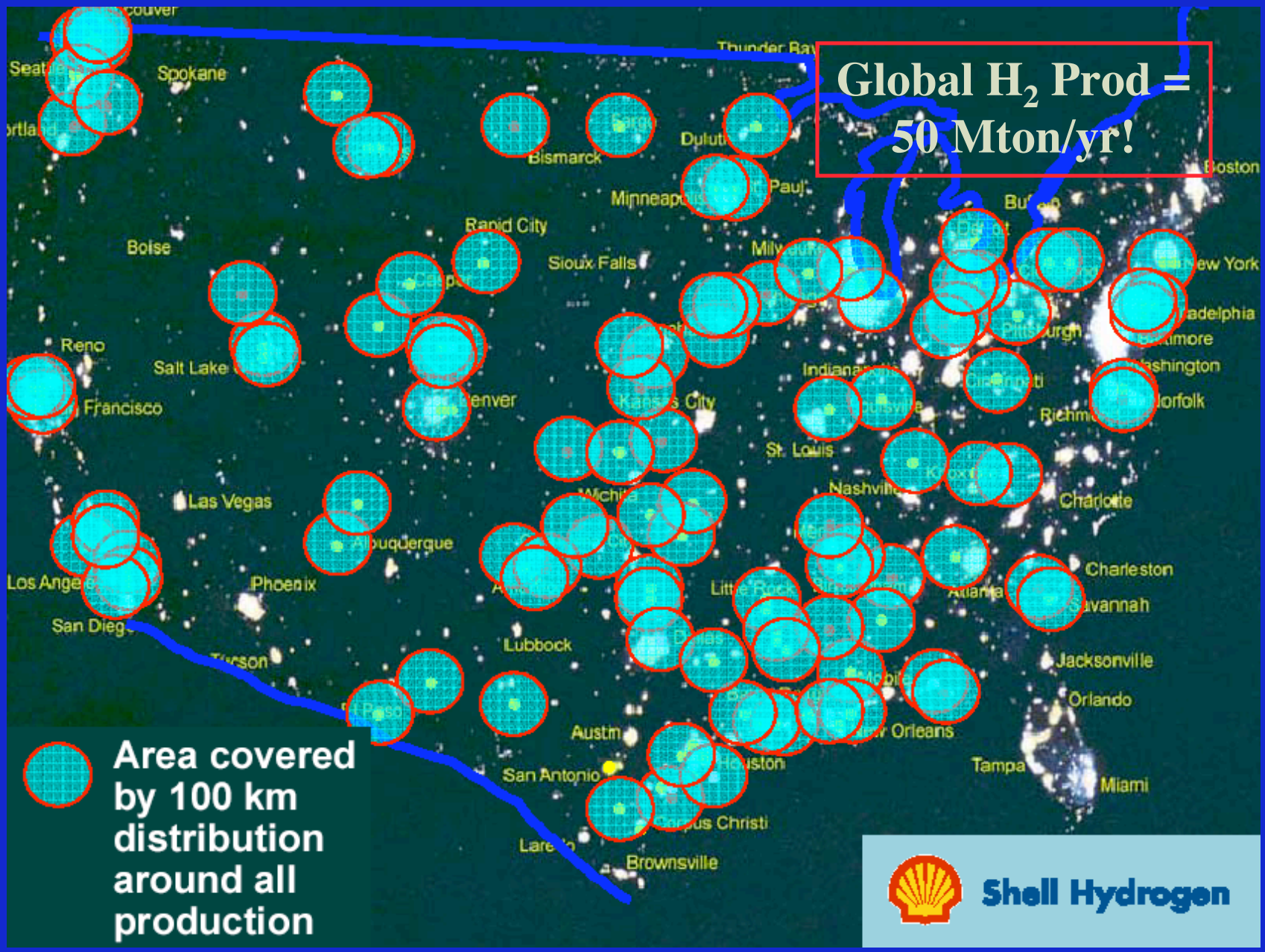
GHG Emissions from H_2 Pathways: Hydrogen is Not Always Good for Env't



Hydrogen Production/Distribution




Vancouver
Thunder Bay
Seattle
Spokane
Fargo
Duluth
Billings
Bismarck
Minneapolis
St. Paul
Boston
Rapid City
Boise
Milwaukee
Sioux Falls
Cleveland
New York
Casper
Chicago
Philadelphia
Omaha
Pittsburgh
Baltimore
Reno
Salt Lake City
Indianapolis
Washington
Cincinnati
San Francisco
Denver
Kansas City
Louisville
Norfolk
Richmond
St. Louis
Knoxville
Las Vegas
Nashville
Wichita
Charlotte
Tulsa
Albuquerque
Oklahoma City
Memphis
Charleston
Los Angeles
Phoenix
Amarillo
Little Rock
Birmingham
Atlanta
Savannah
Lubbock
Dallas
Jacksonville
Mobile
Baton Rouge
Orlando
El Paso
Austin
New Orleans
Houston
Tampa
San Antonio
Miami
Corpus Christi
Brownsville
USA at night
Shell Hydrogen


Global H_2 Prod = 50 Mton/yr!
Area covered by 100 km distribution around all production
Shell Hydrogen
Spokane
Bismarck
Rapid City
Boise
Sioux Falls
Reno
Salt Lake
Francisco
Denver
Las Vegas
Albuquerque
Phoenix
Los Angeles
San Diego
Tucson
Lubbock
Austin
San Antonio
Corpus Christi
Brownsville
St. Louis
Little Rock
Atlanta
Charlotte
Nashville
Indianapolis
Cincinnati
Pittsburgh
Richmond
Boston
New York
Philadelphia
Washington
Norfolk
Charleston
Savannah
Jacksonville
Orlando
Tampa
Miami
New Orleans
Houston
Dallas
Kansas City
Minneapolis
Duluth
Thunder Bay

Mobile Hydrogen Refuelers

Featured Projects

- Burlington, VT H2 Station
- Minnesota Wind-to-H2 Project
- Sierra Nevada Brewery In Chico, CA
- New Jersey Residential H2 Project
- Twenty-Five Projects Identified With Renewable Hydrogen Production Aspects

Four 250 kW MCFCs in Chico, CA

Hydrogen Energy Stations

- Co-Production of Hydrogen, Electricity and Heating/Cooling
- Use Stationary Fuel Cell to Produce Electricity With Excess Hydrogen Sold to Vehicles
- Reduce Risks of "Stranded Assets" When Hydrogen Demand is Low (Transition Strategy)
- Can Be Located at Gasoline Stations, Office Buildings, Fleet Refueling Locations, Even Residences (e.g. Honda Home Energy Station)
- Many Different Possible Designs

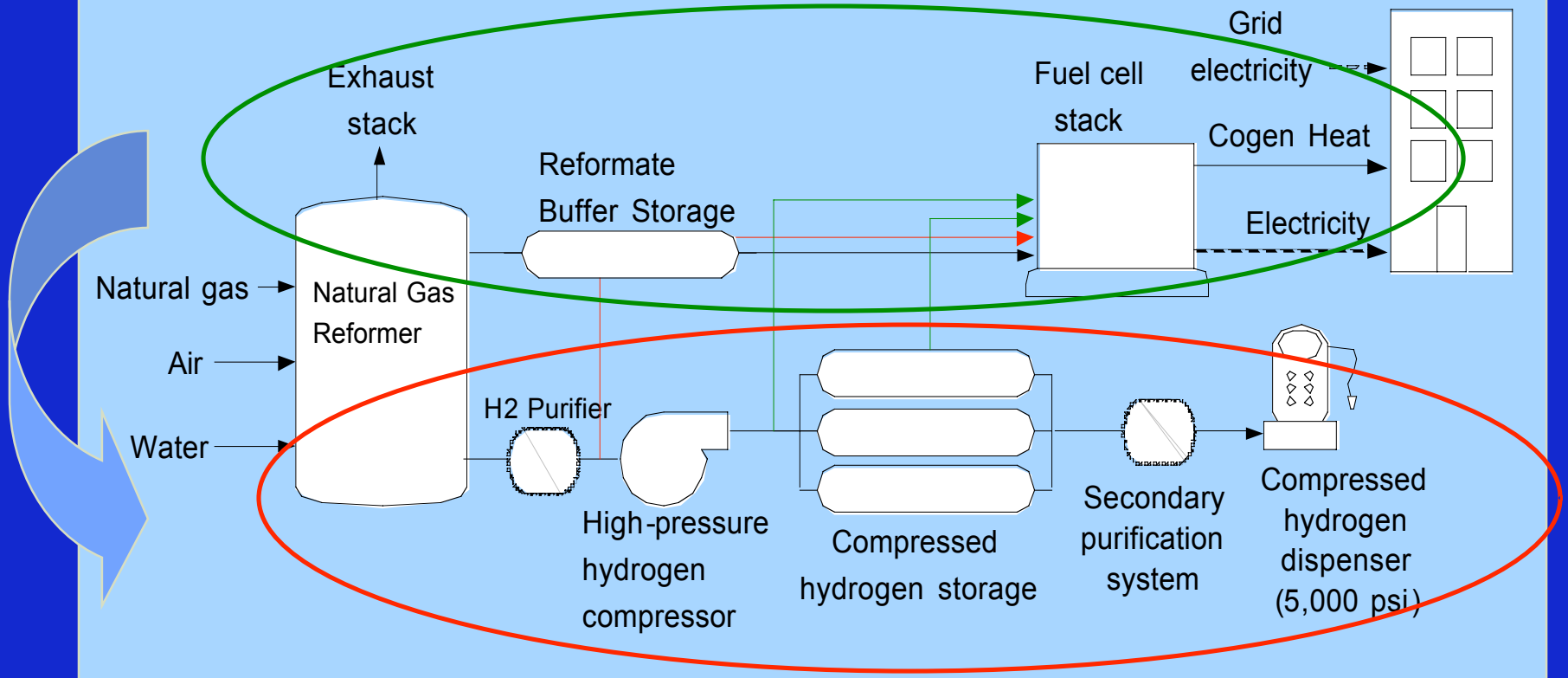
Hydrogen Energy Stations

Called out in the Governor's California Hydrogen Highway Network Executive Order:

"Whereas, the *economic feasibility* of a hydrogen infrastructure *is enhanced by* building *hydrogen energy stations* that power vehicles as well as supply electricity for California's power needs"

Hydrogen Energy Station: One Design Based on PEM Fuel Cell

Distributed Power Generation Can Be Good Biz Model



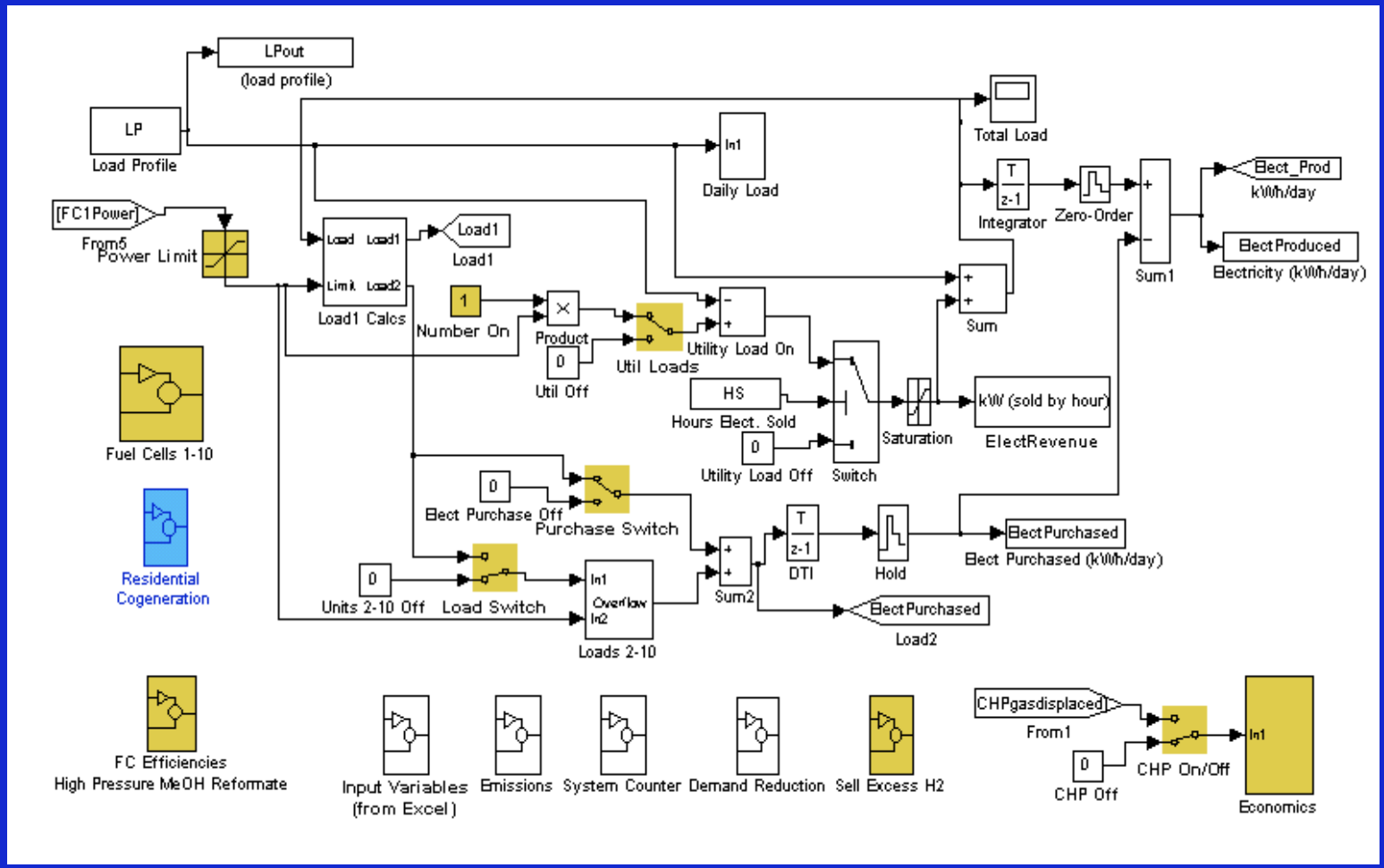
Distributed Hydrogen Production for <30-50 Veh/Day is Probably Bad Biz Model

Hydrogen Energy Station in Las Vegas, Nevada

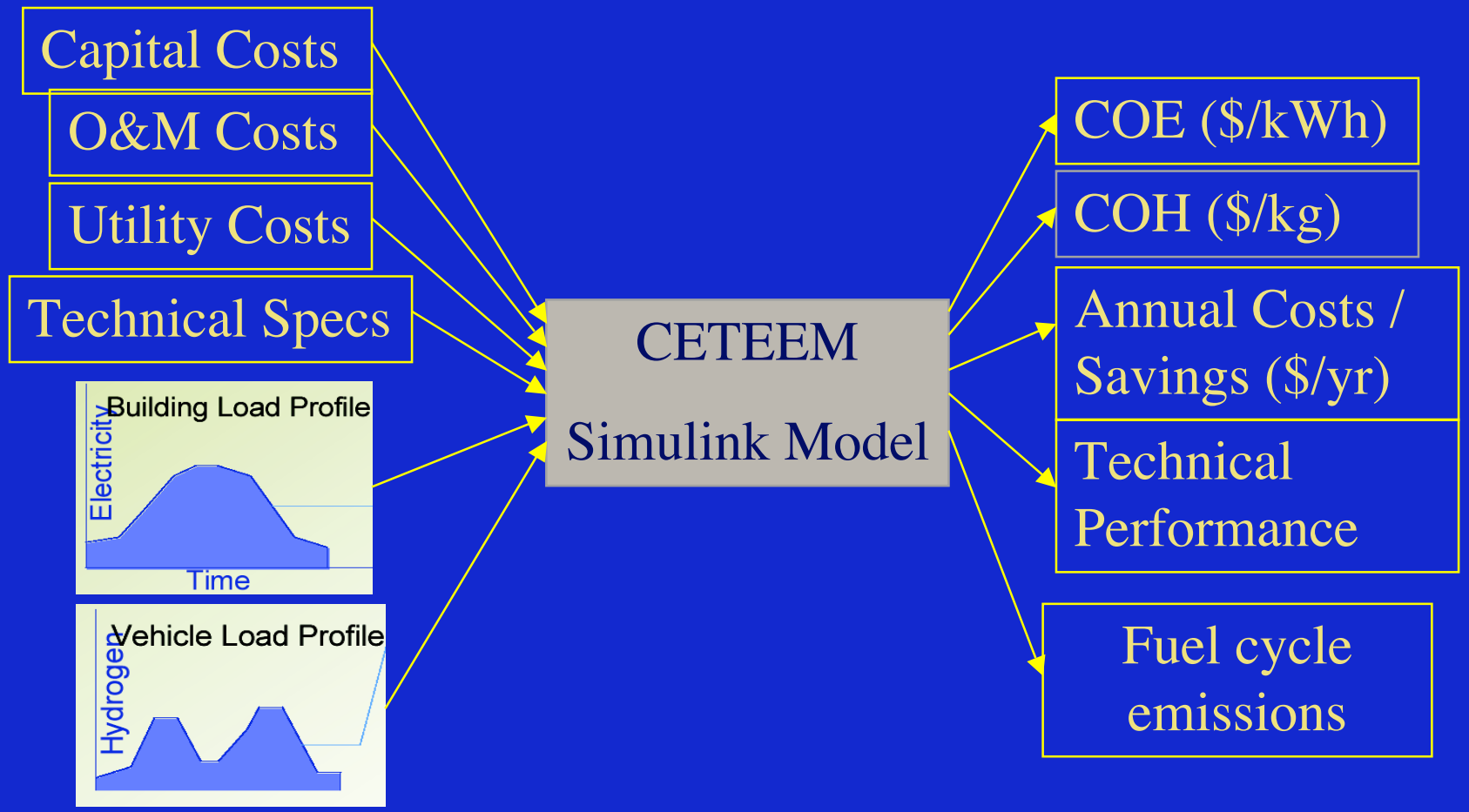
ChevronTexaco Energy Station Concept

CETEEM Top Level (Simulink)

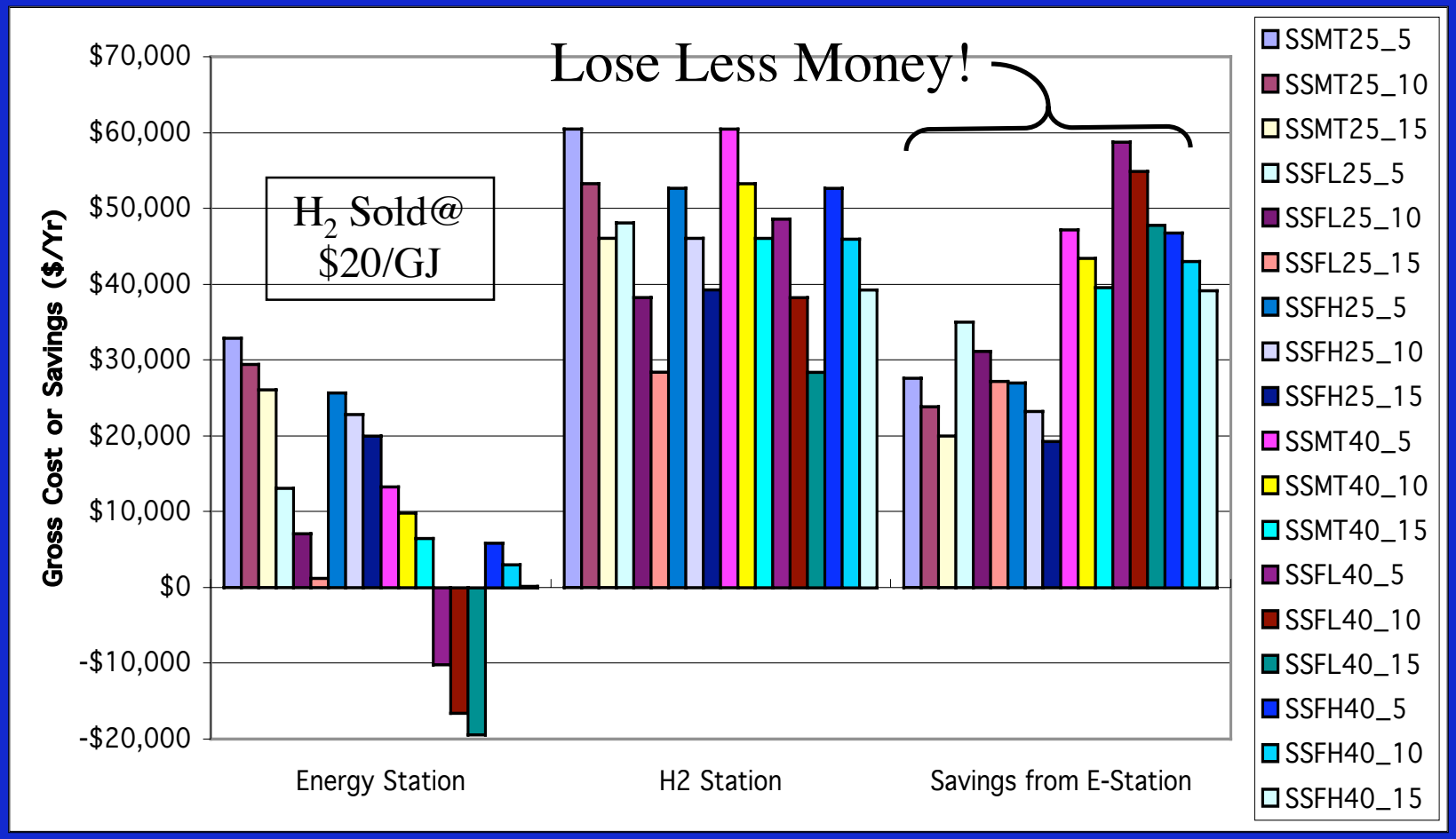
Clean Energy Technology Economics and Emissions Model



CETEEM Inputs and Outputs



Energy Service Stations Can Lower Cost Barriers During Transition



Hydrogen Highway Exec. Order

Hydrogen Highway Exec. Order

- Designates 21 Interstate Highways as the "California Hydrogen Highway Network"
- Calls for Plan to Develop Refueling Infrastructure by 2010
  - So that "every Californian will have access to hydrogen fuel, with a significant and increasing percentage produced from clean, renewable sources"
- California Hydrogen Economy Blueprint Plan
  - Reports Released in 2005
  - Defines path "for the rapid transition to a hydrogen economy in California"
- Negotiations with Automakers to Ensure Availability of Hydrogen-Powered Vehicles
- Development of Safety Standards, Building Codes, and Emergency Response Procedures
- Incentives for Vehicle Purchase and Renewable Hydrogen Production

New Hydrogen Station RFP

- RFP for 3 New CA Stations Issued Last Week
- $5.5 Million to be 50/50 Cost Shared with Industry
- Stations to Be Operational by End of 2007
- Renewable Content (20%) and E-Station Features

Policy Recommendations

- Dedicate Significant Funding for Hydrogen R&D
- Demonstrate The Viability of Hydrogen Storage and Production for Critical Applications
- Visibly Link Hydrogen Production and Clean Energy Technologies
- Establish Incentives for High-Value, On-Site Applications
- Proactively Address Regulatory Incentives
- Accelerate Private Investment
- Develop Compelling Communications Strategies

Conclusions

- Stationary Fuel Cells and Fuel Cell Vehicles
  - Coming on strong but still key economic and technical hurdles, especially for vehicles
- Hydrogen Production
  - Lots of potential pathways with very different envt'l implications
  - Upstream vs. downstream impacts
  - Economics of the cleanest options remain a challenge
- Government Initiatives
  - Lots of activity at both federal and state levels
  - Funding for key activities is an issue (tight federal and state budgets)
- Final Thoughts
  - Overall "no regrets" clean energy strategy is critical
  - Important to manage public expectations