Alternative Transportation Options for the 21st Century

Presentation to the Hydrogen & Fuel Cell Technical Advisory Committee

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NHA Hydrogen Story Background

- Key issue at 2007 NHA Board Retreat: Hydrogen message was being drowned out by messages from other "fuel"/propulsion options
- Board top priority: develop a compelling and shared vision for hydrogen energy - a "Hydrogen Transportation Story"
- Frank Novachek (Xcel Energy) "volunteered" to head the Hydrogen Story Task Force

Task Force - Participating Organizations

- ARES Corp.
- BP
- Canadian Hydrogen Energy Company
- General Atomics
- General Motors
- H2Gen Innovations
- ISE Corporation
- National Renewable Energy Laboratory
- Plug Power, LLC
- Praxair
- Sentech
- University of Montana
- Shell Hydrogen
- Xcel Energy

NHA Disclaimer:

"This consensus presentation does not necessarily represent the organizational views or individual commitments of all members of the National Hydrogen Association."

NHA Overall Approach – Matrix

Illustrative

Simulations

	Lon - rm (2051-2100)								
	E i mental Respo ibili			E urity		Economic Vitality			
Propulsion Option	Pollution	ater Usa	Change Gases	Imports	S e D y	Life Cycle Ownership Cost	Consumer Acceptance	Additional Infrastructure Costs	National Competi-tiveness
Weighting Factor	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Gasoline ICEV (Baseline)	1	8	1	1	6	3	3	7	1
Gasoline HEV	2	10	4	2	6	6	4	8	2
Gasoline Plug-in HEV	5	8	5	4	6		6	9	4
Diesel HEV	6	8	5	5	7	3	5	8	5
EtOH ICEV	3	1	7	6	10	7		8	6
EtOH HEV	4	2	8	8	10	8		9	8
EtOH Plug-In HEV	6	3	7	10	10	9	8	10	10
H2 ICEV HEV	8	7	10	10	10	9	3	8	10
H2 FC HEV	10	10	10	10	10	10	7	9	10
H2 FC Plug-In HEV	9	8	8	10	10	9	8		10
All Electric Vehicle		6			10	5	4	10	10

Advanced Vehicle Computer Simulations

Two Objectives:

- Compare the societal costs of advanced vehicle/fuel options over the 21st century
- Estimate hydrogen infrastructure cost

Three Transportation Sector Goals

1) Greenhouse Gas Pollution
   -80% below 1990 levels
2) Oil Energy Quasi-Independence
   -Meet all non-transportation petroleum and some vehicle needs with domestic oil production (in a crisis)
3) Urban Air Pollution
   -Near-zero

What is best for society?

- Hybrid electric vehicles? (HEVs)
- Plug-in hybrids? (PHEVs)
- Biofuels?
- Fuel cell vehicles? (FCVs)

- Battery Electric Vehicles? (BEVs)
- Hydrogen ICE hybrids? (H2 ICE HEVs)
- Natural Gas Vehicles? (NGVs)

….or all of the above!

What fuels?

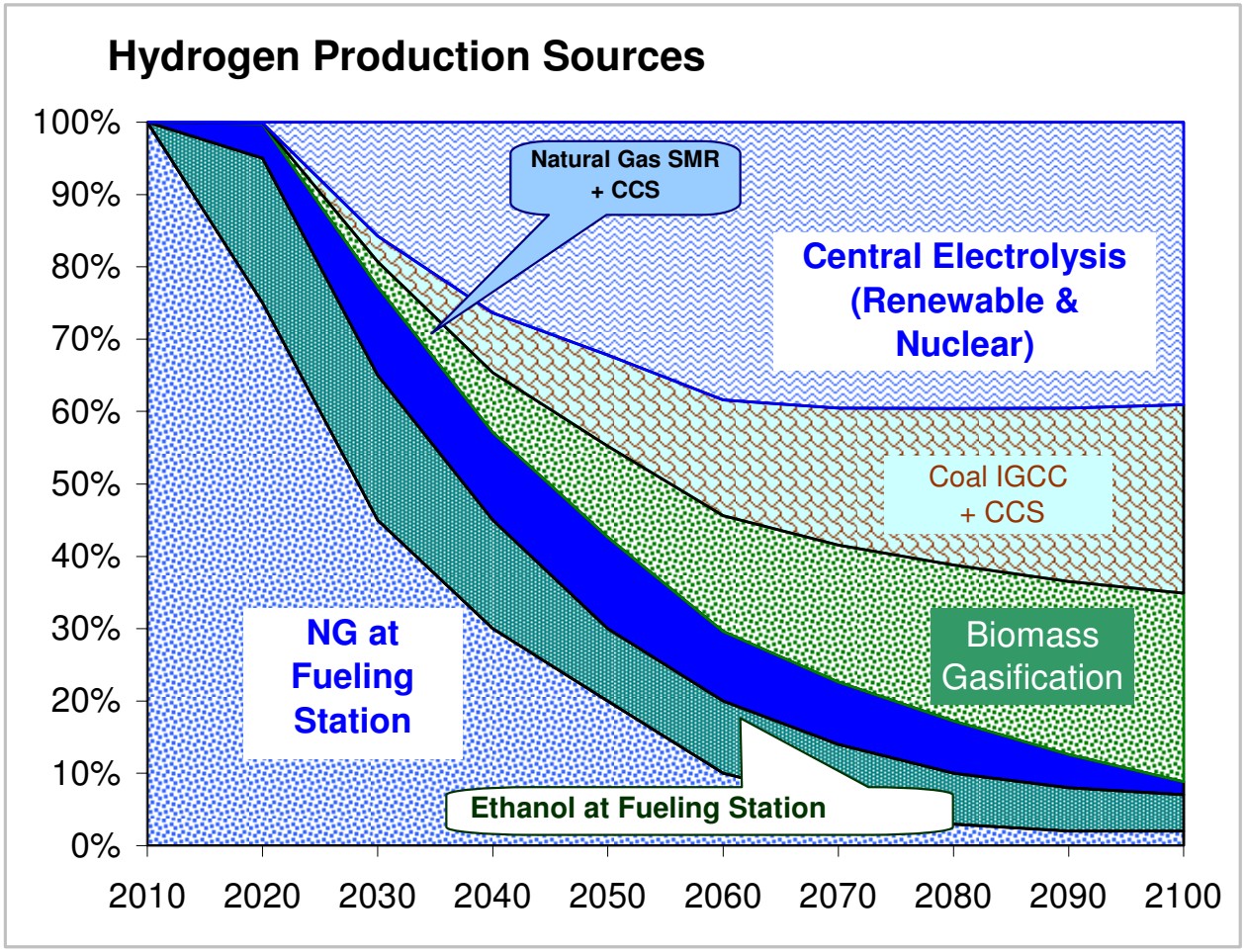
- Gasoline?
- Ethanol?
- Hydrogen?
- Diesel?
- Natural Gas?
- Electricity?

Renewable Fuels

Key Assumptions

- Assume success for all vehicle options
  - Technical success
  - Economic success
- Assume stringent climate change constraints
  - Hydrogen becomes green over time
  - Electricity becomes green over time

Greening of Hydrogen



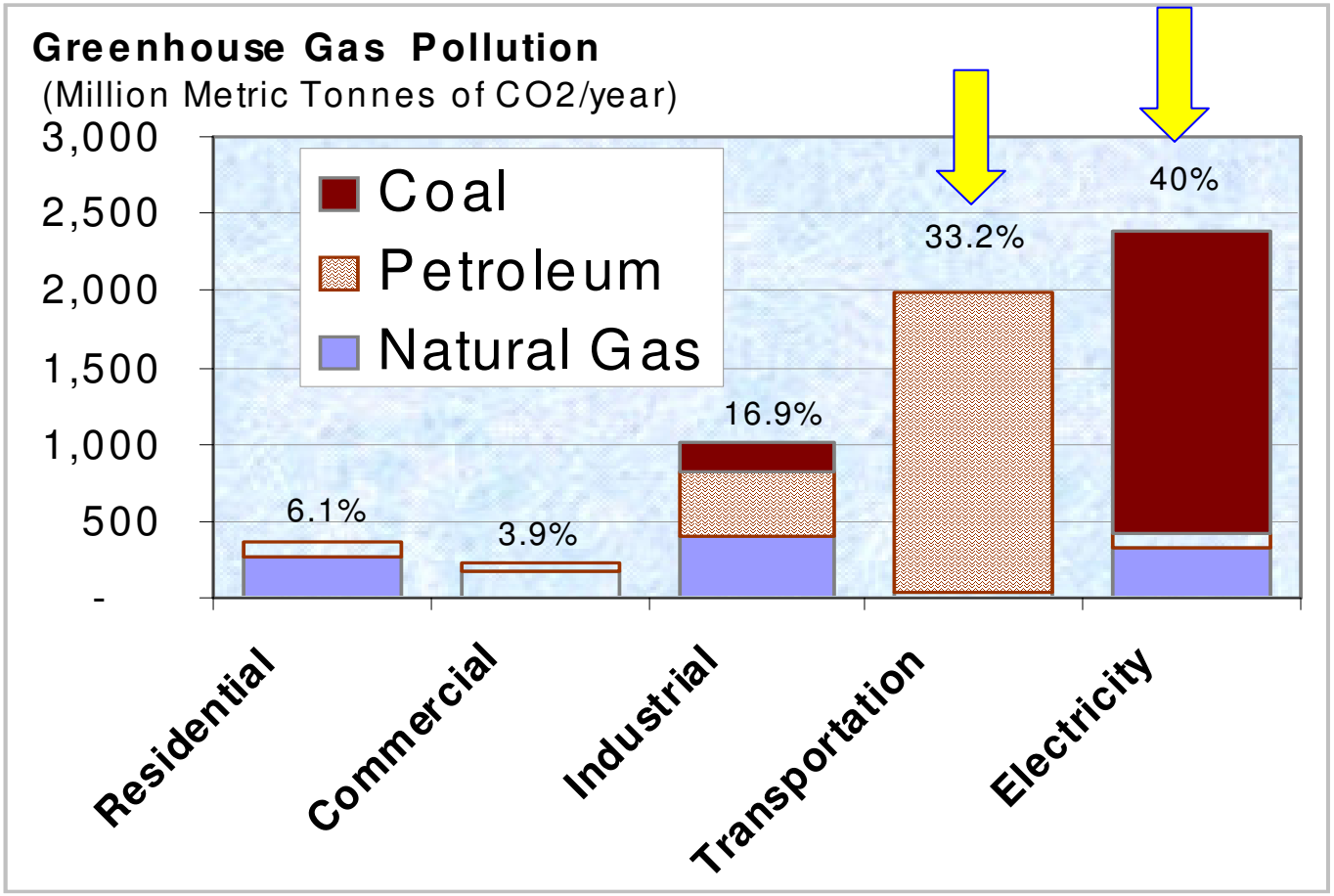
SMR = steam methane reformer (hydrogen from natural gas)

CCS = carbon capture and storage

IGCC = integrated (coal) gasification combined cycle

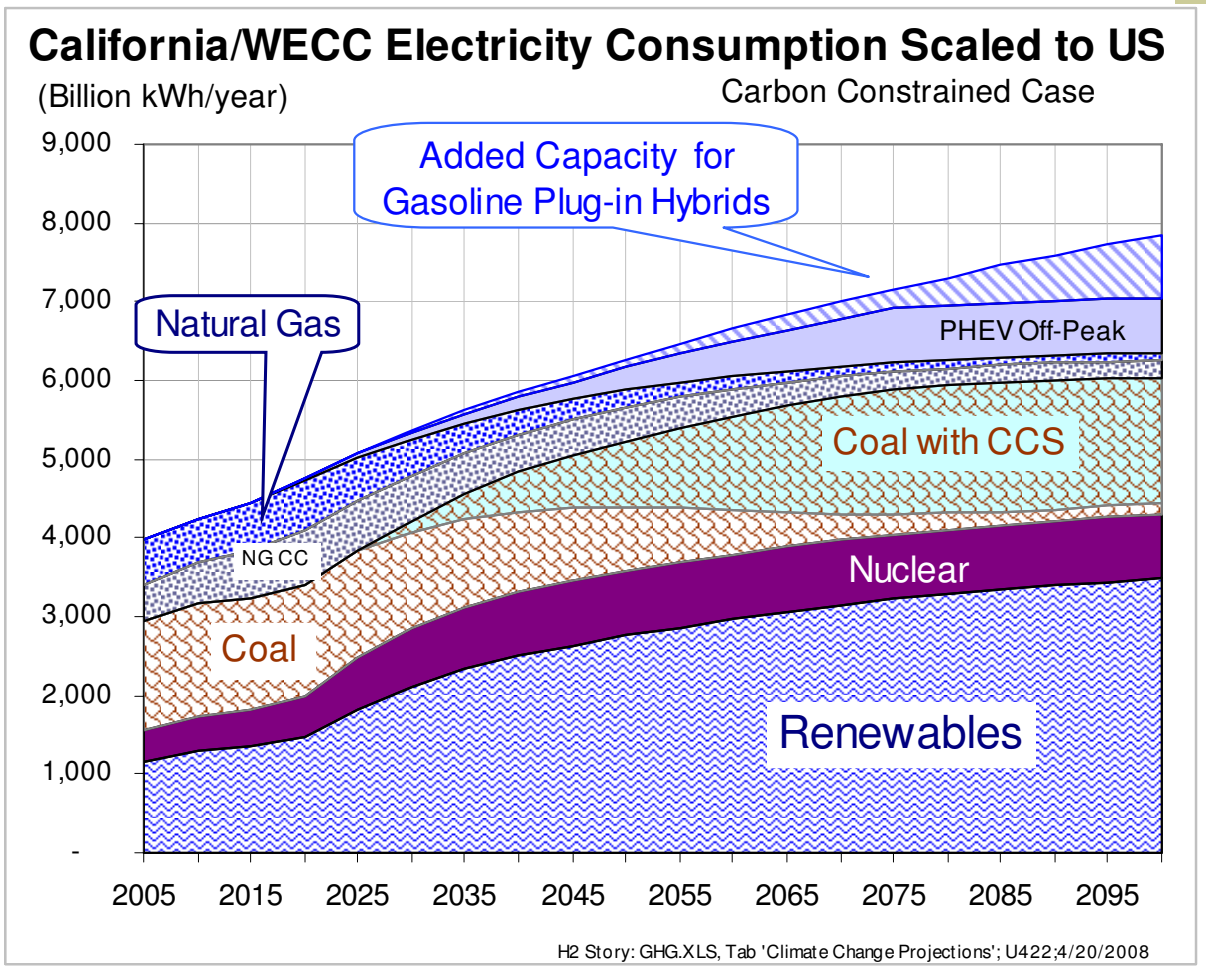
Summary Greet 1.8a.XLS; Tab 'Fuel TS'; G 81 5/30 /2008

US Greenhouse Gas Sources

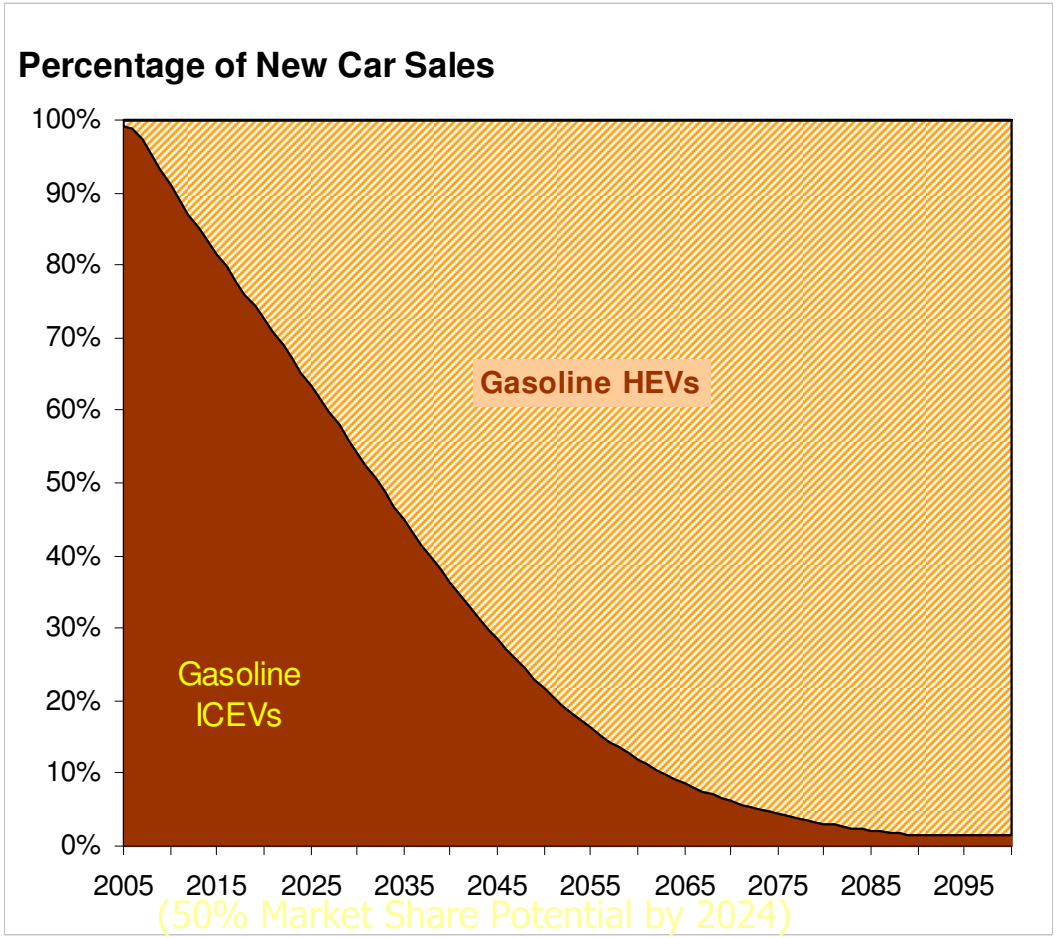


GHG emissions since 1949 EIA.XLS, Tab 'All,ElecPrw'; G99;3/11/2008

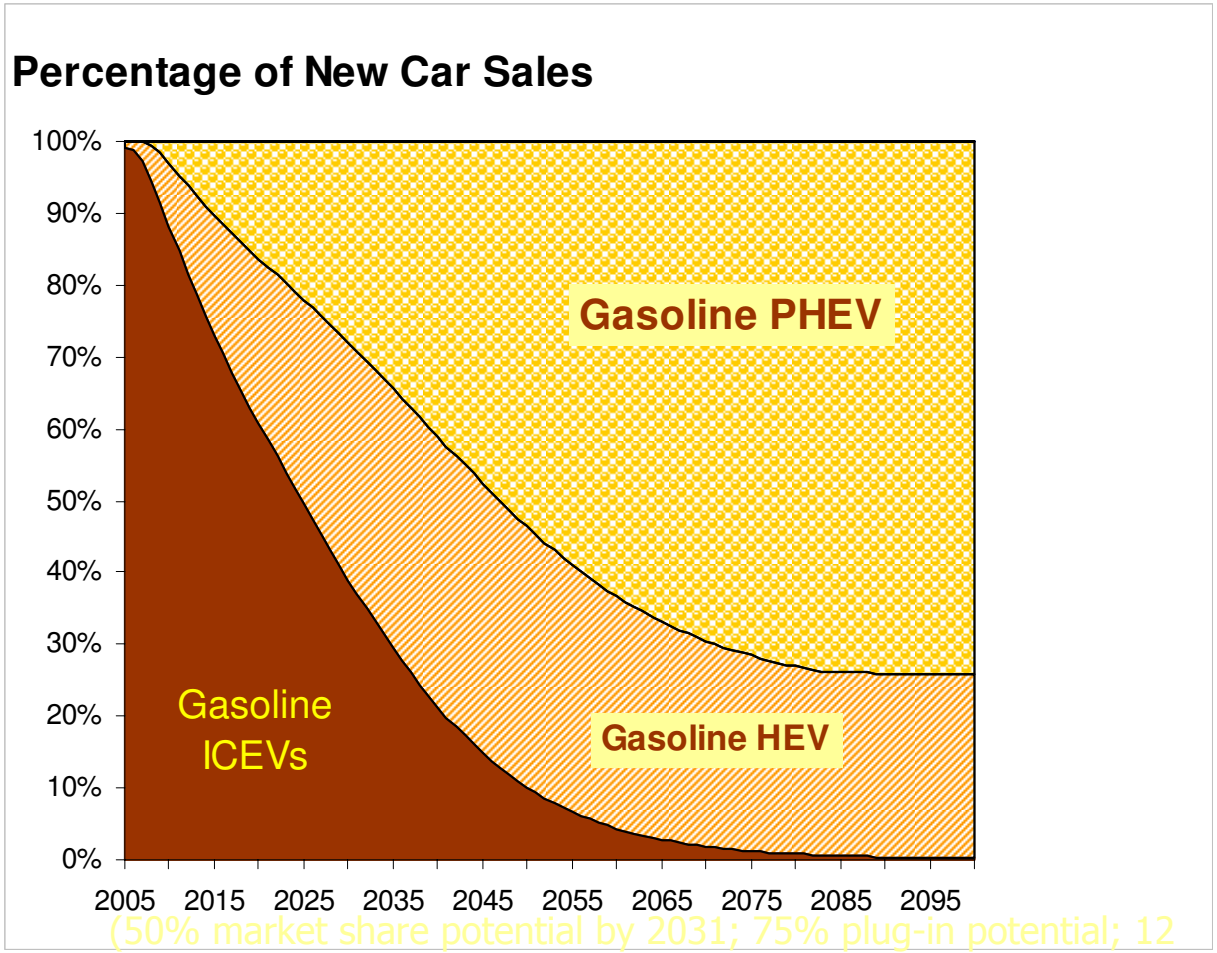
Greening of the Grid



Gasoline Hybrid Scenario Market Shares

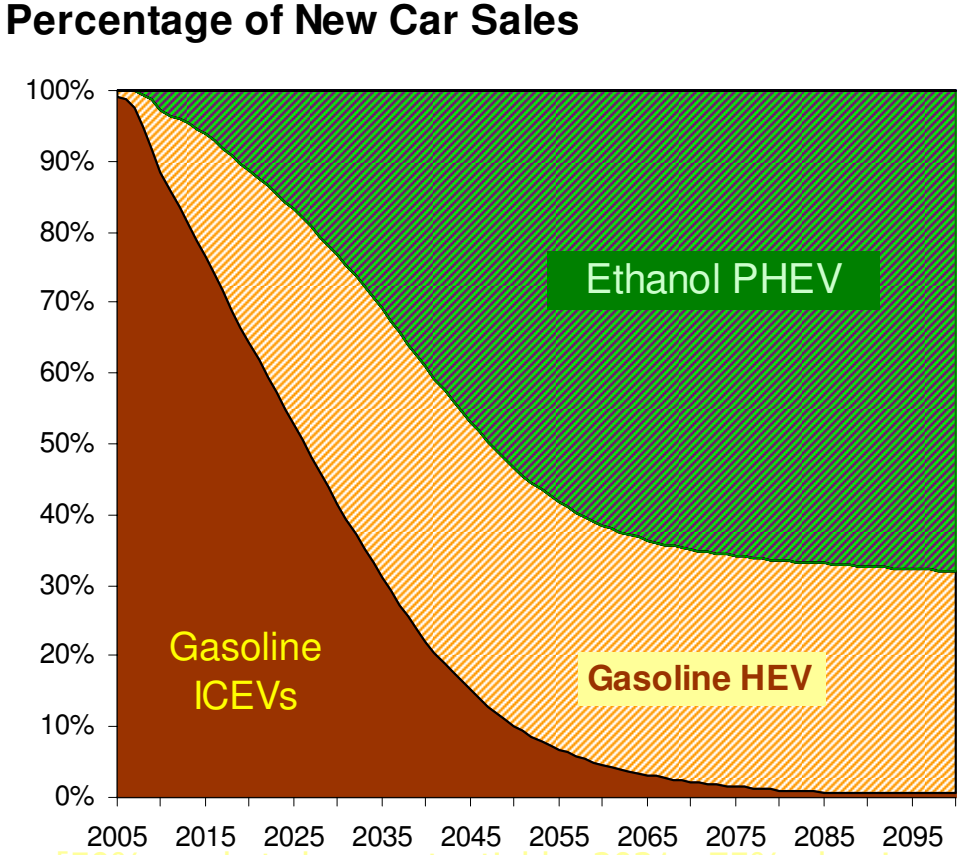


Gasoline Plug-In Hybrid Scenario Market Shares



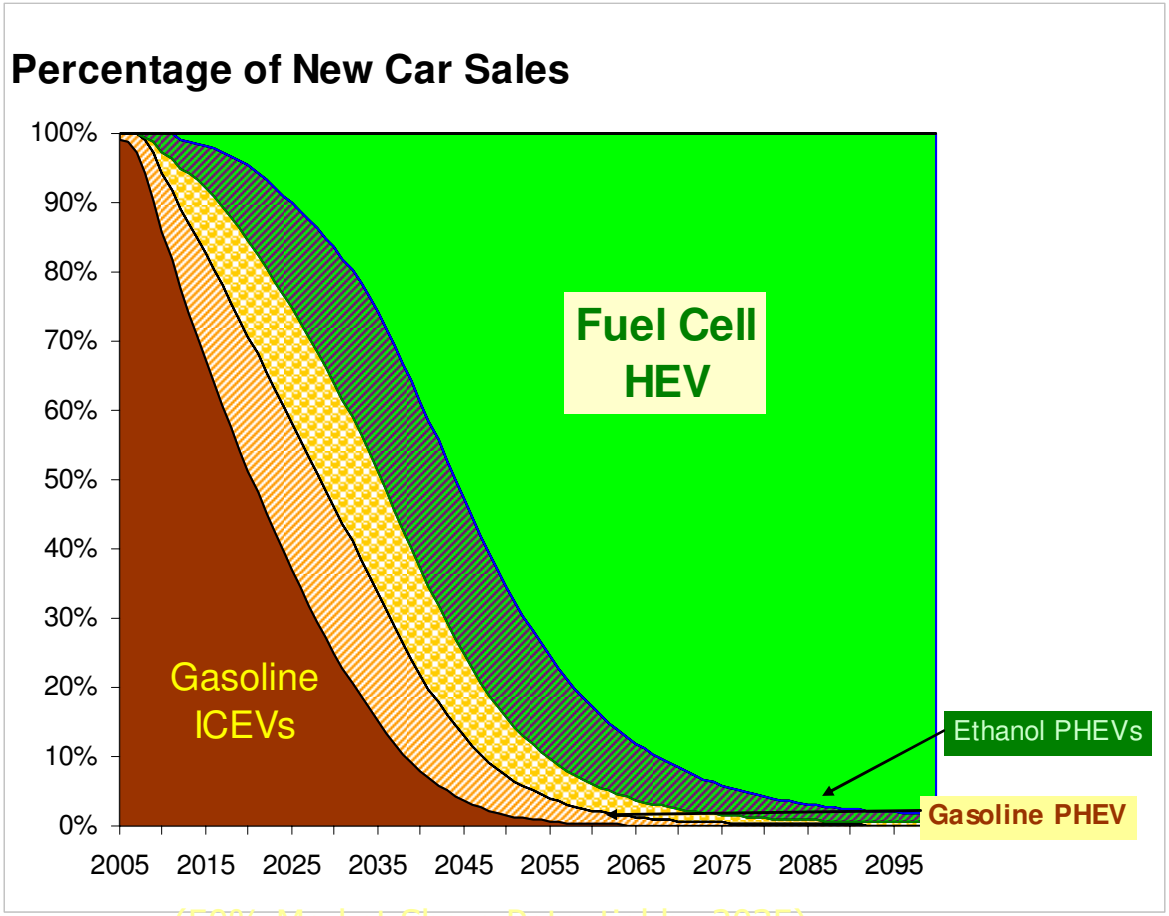
(50% market share potential by 2031; 75% plug-in potential; 12 to 52 mile all-electric range; 18% to 65% energy from grid)

Ethanol Plug-In Hybrid Scenario Market Shares



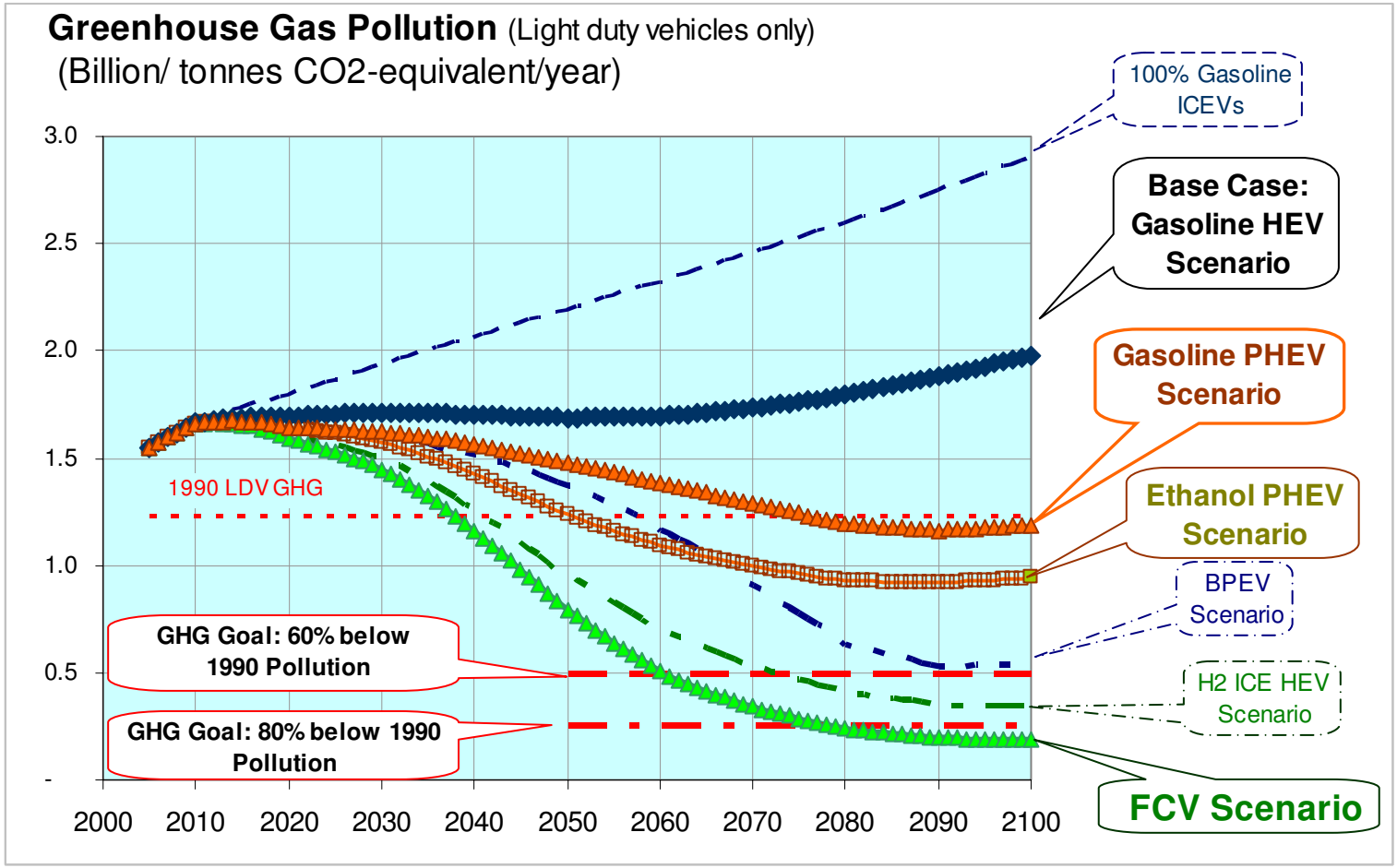
[50% market share potential by 2031, 75% plug-in potential, and 120 billion gallon/year ethanol production cap (vs. 7 B/yr now)]

Fuel Cell Vehicle
(& BEV, H2 ICE HEV)
Scenario Market Shares

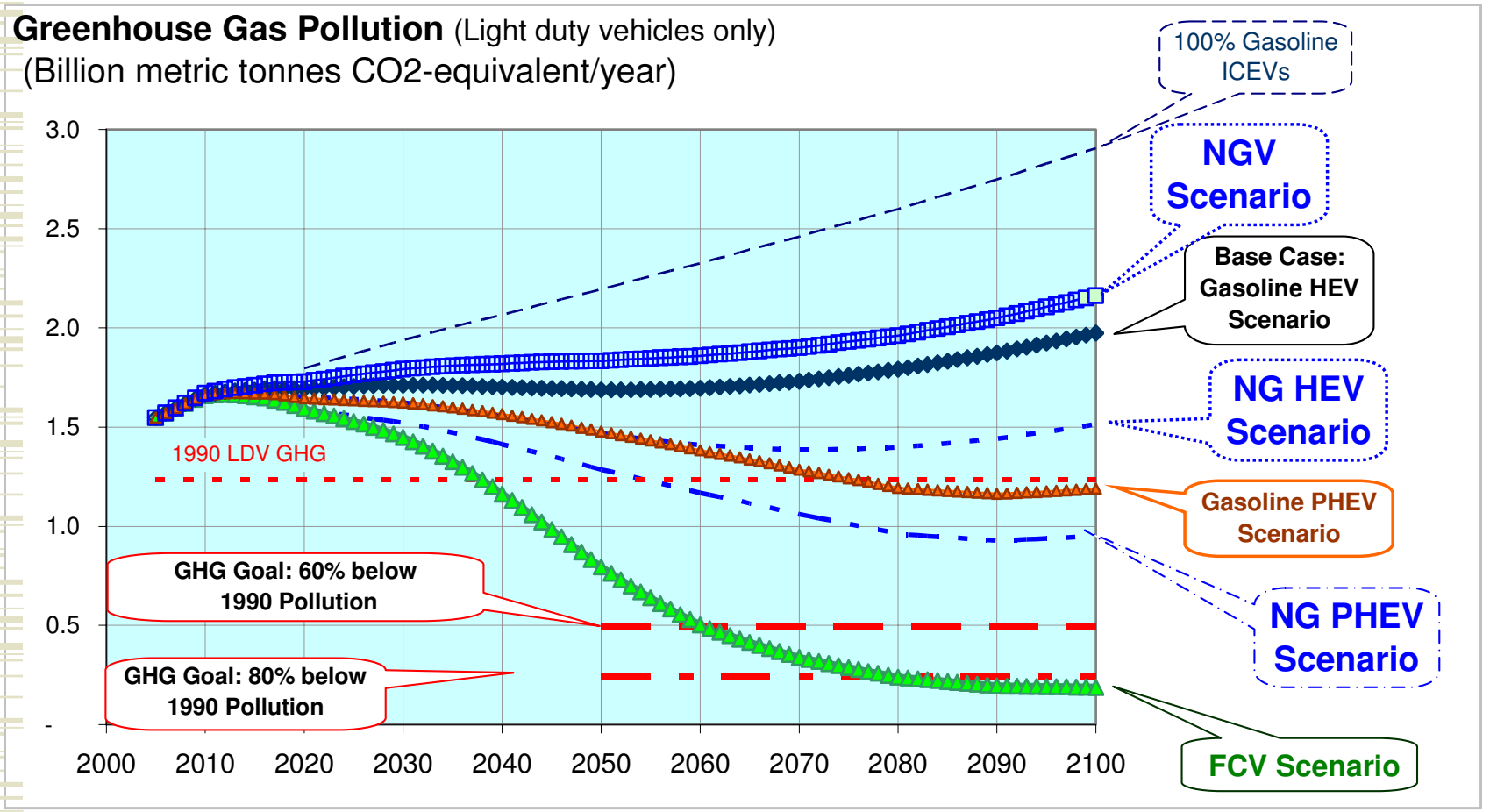


(50% Market Share Potential by 2035)

Greenhouse Gas Emissions

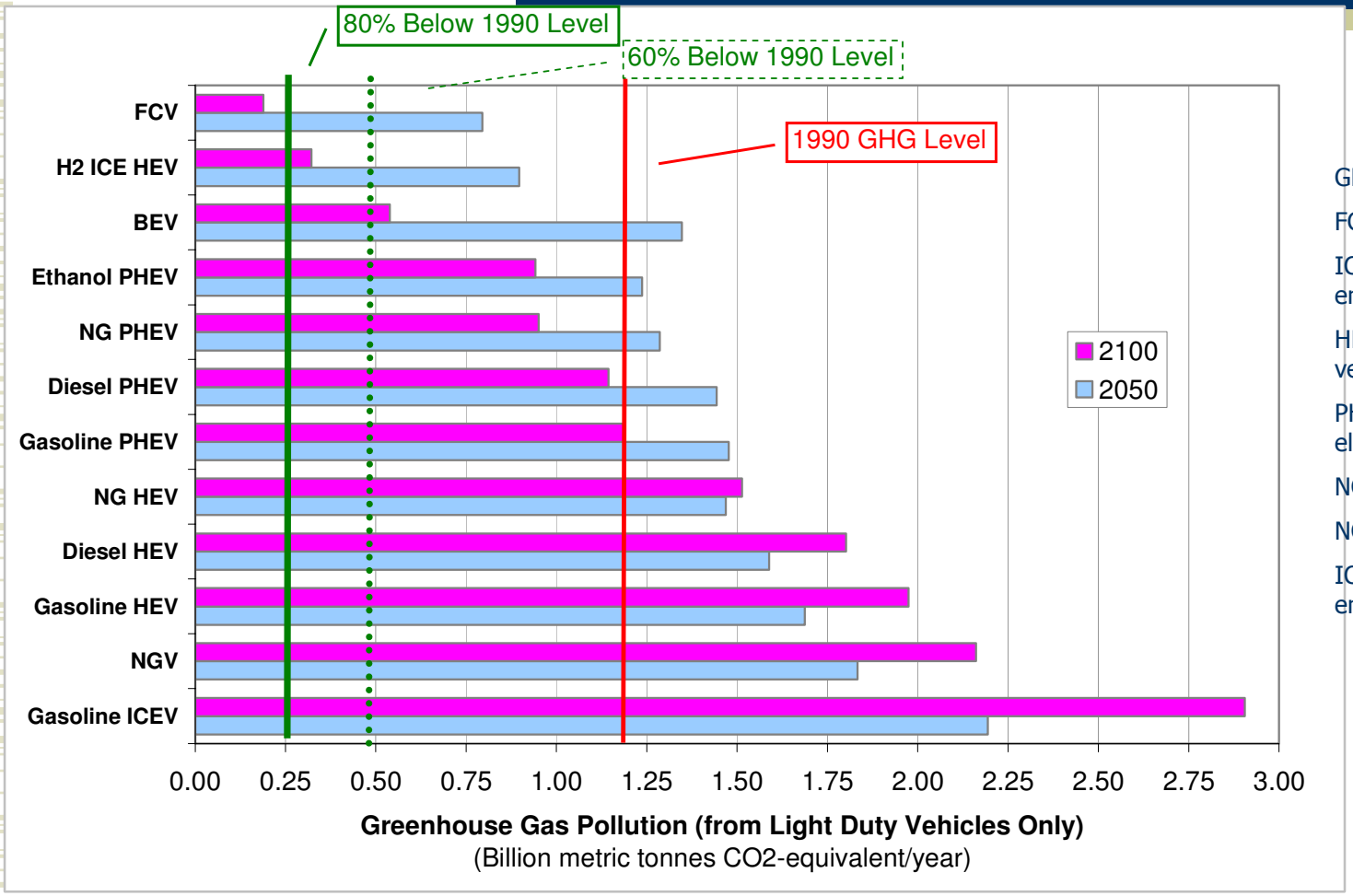


Greenhouse Gases with Natural Gas Vehicles



Story Simultaneous.XLS; Tab 'Graphs'; BC 495 9/8 /2008

Greenhouse Gas Pollution Comparisons (2050 & 2100)



GHG = greenhouse gases

FCV = fuel cell vehicle

ICE = internal combustion engine

HEV = hybrid electric vehicle

PHEV = plug=in hybrid electric vehicle

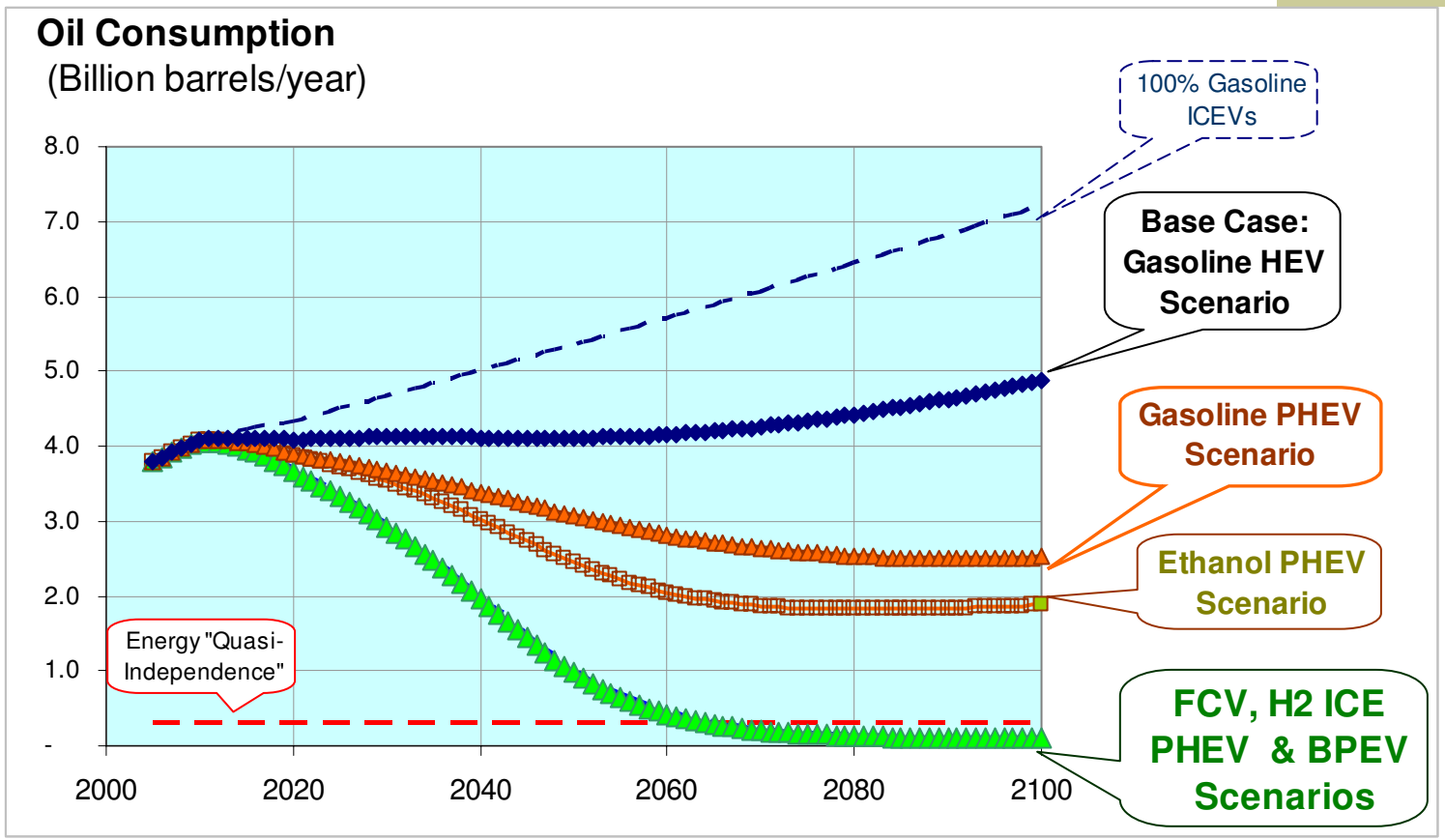
NG = natural gas

NGV = natural gas vehicle

ICEV = internal combustion engine vehicle

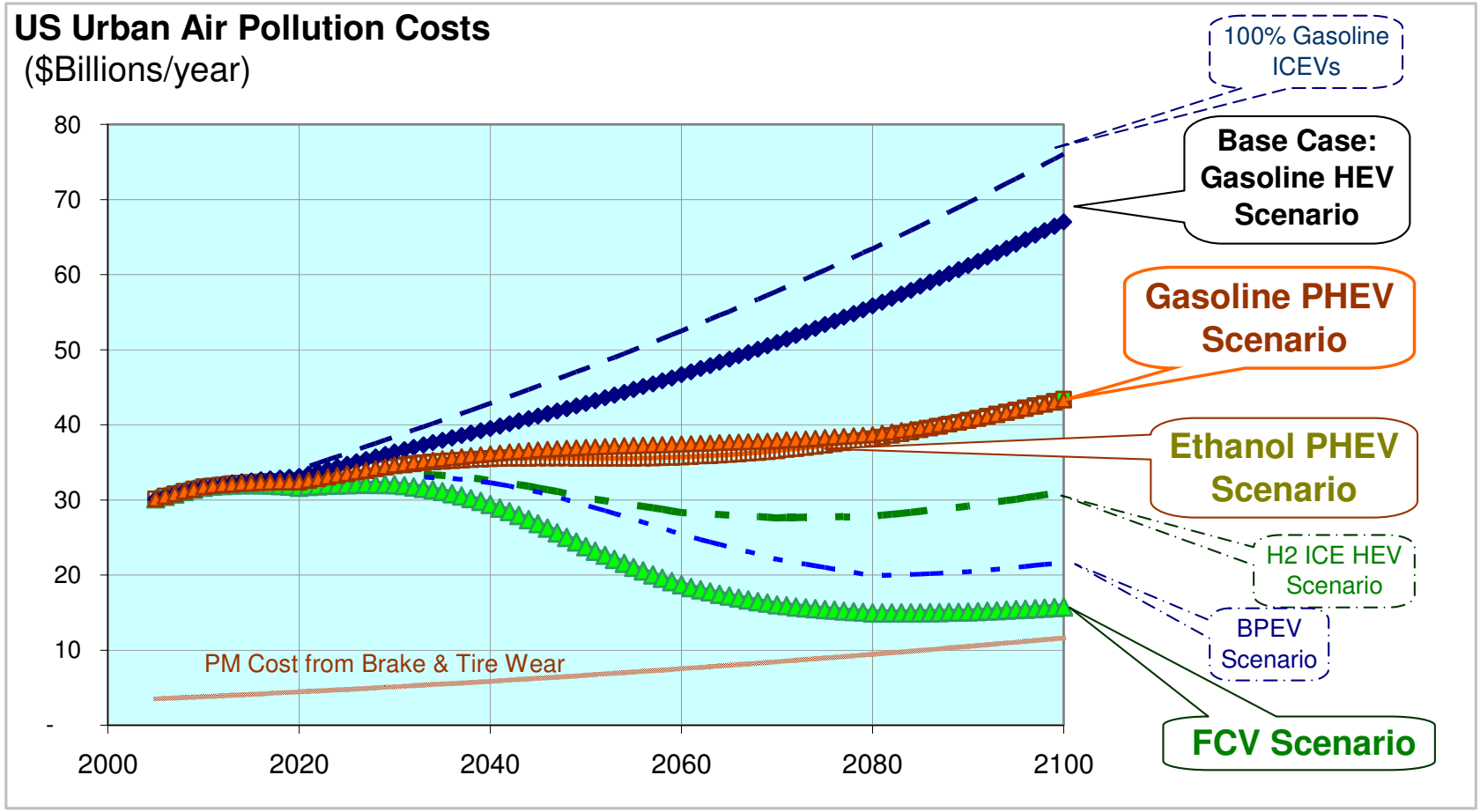
Story Simultaneous.XLS; Tab 'Graphs'; BJ 464 9/8 /2008

Oil Consumption (US)



US 2030 oil production = 2.72 B bbl/yr (14.3 Quads); US 2006 non-transportation consumption = 2.25 B bbl/year (6.16 M bbl/day) [Ref: AEO 2008]

Urban Air Pollution Costs
(with H2 ICE HEVs and BEVs)



Source: Argonne National Laboratory GREET 1.8a

Story Simultaneous.XLS; Tab 'Graphs'; CQ 102 5/25 /2008

Environmental & Oil Import Conclusions

- Hydrogen-powered fuel cell vehicles are the only option that could, in conjunction with biofuels, HEVs and PHEVs, *simultaneously*:
  - **Reduce GHG's to 80% below 1990 levels**
  - **Achieve petroleum energy quasi-independence***
  - **Nearly eliminate urban air pollution****

*Hydrogen ICE Vehicles and battery EVs could also achieve petroleum energy quasi-independence

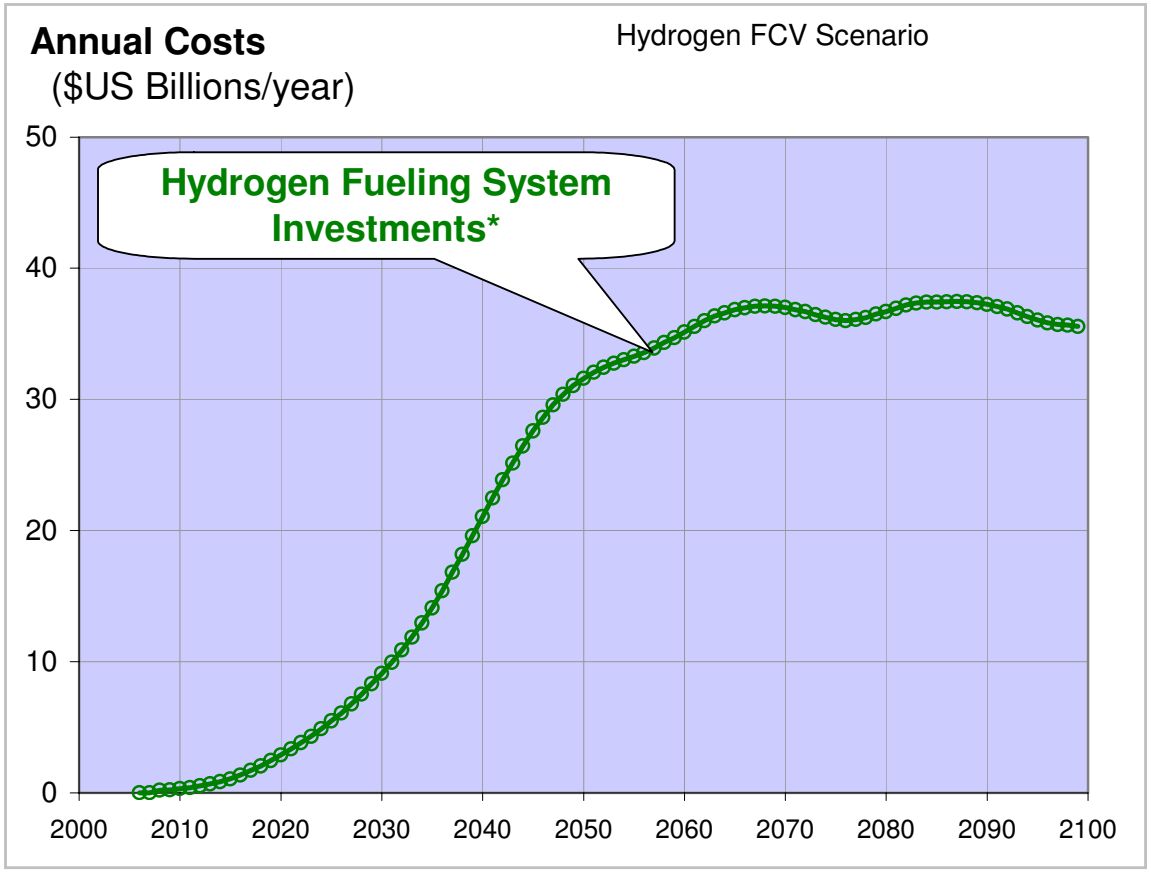
** With the exception of particulates from brake & tire wear

Hydrogen Infrastructure Costs

- 100-Year H2 Infrastructure Cost Estimates
- Comparison with:
  - Green Electricity Costs
  - Oil & Gas Investments
  - Societal Savings
  - other Government Projects

Hydrogen Infrastructure Costs (US)

(Distributed Hydrogen Generators at Fueling Stations)

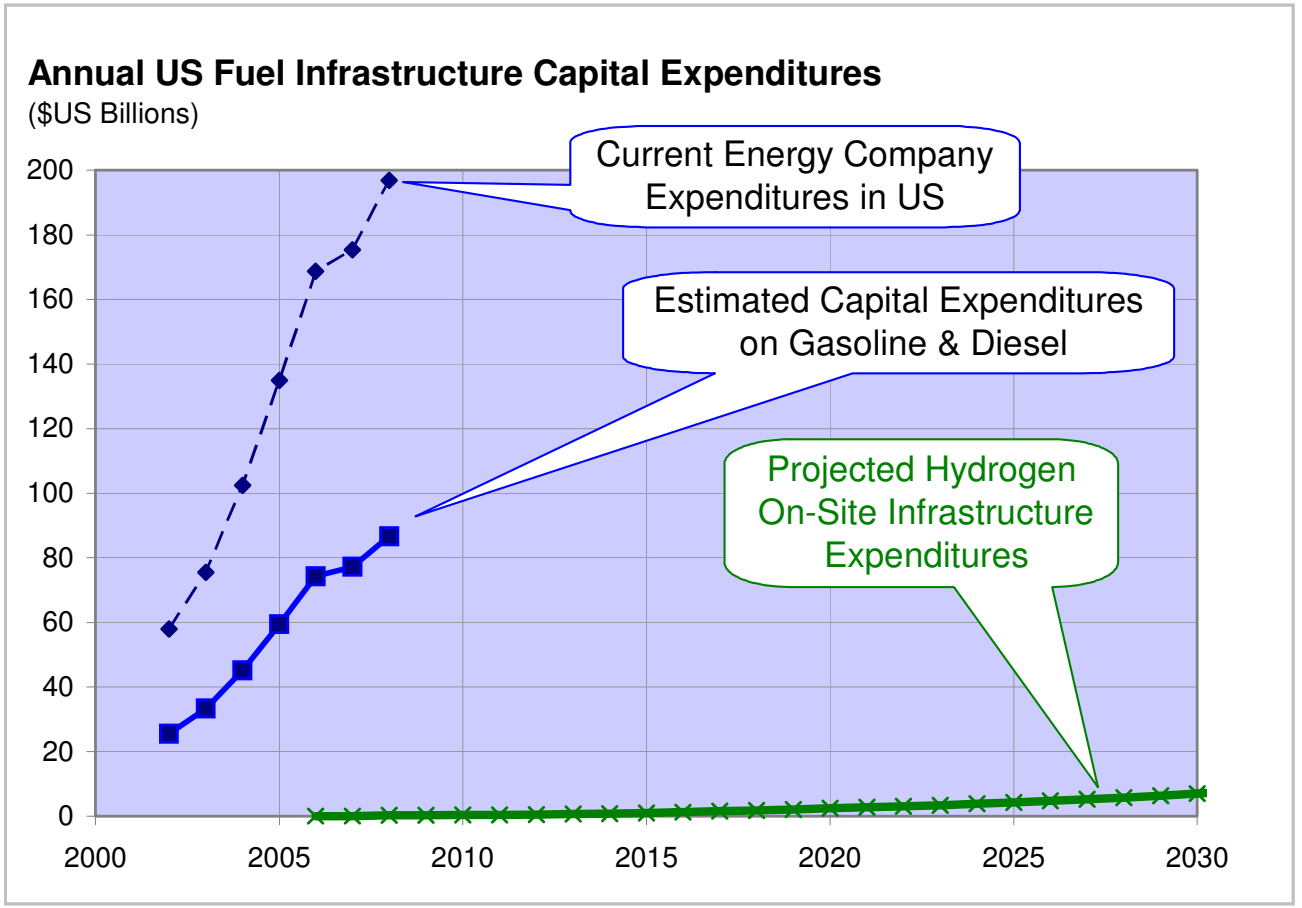


* Includes NG Capex share

H2 Energy Story.XLS; Tab 'Annual Sales';DK 23 5/11 /2008

Source: U.S. DOE H2A Model

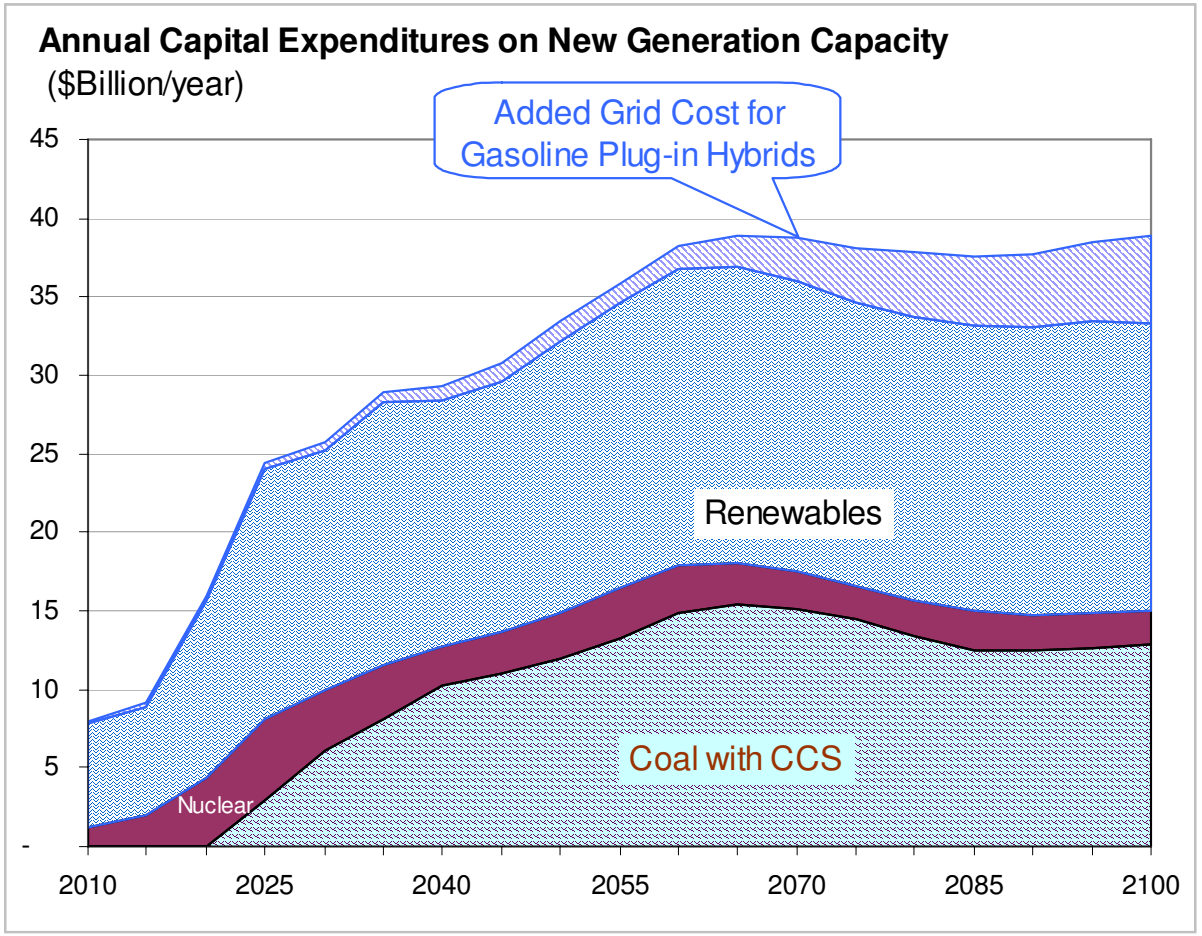
Comparison with Gasoline & Diesel Infrastructure Capital Costs



Source: Oil & Gas Journal

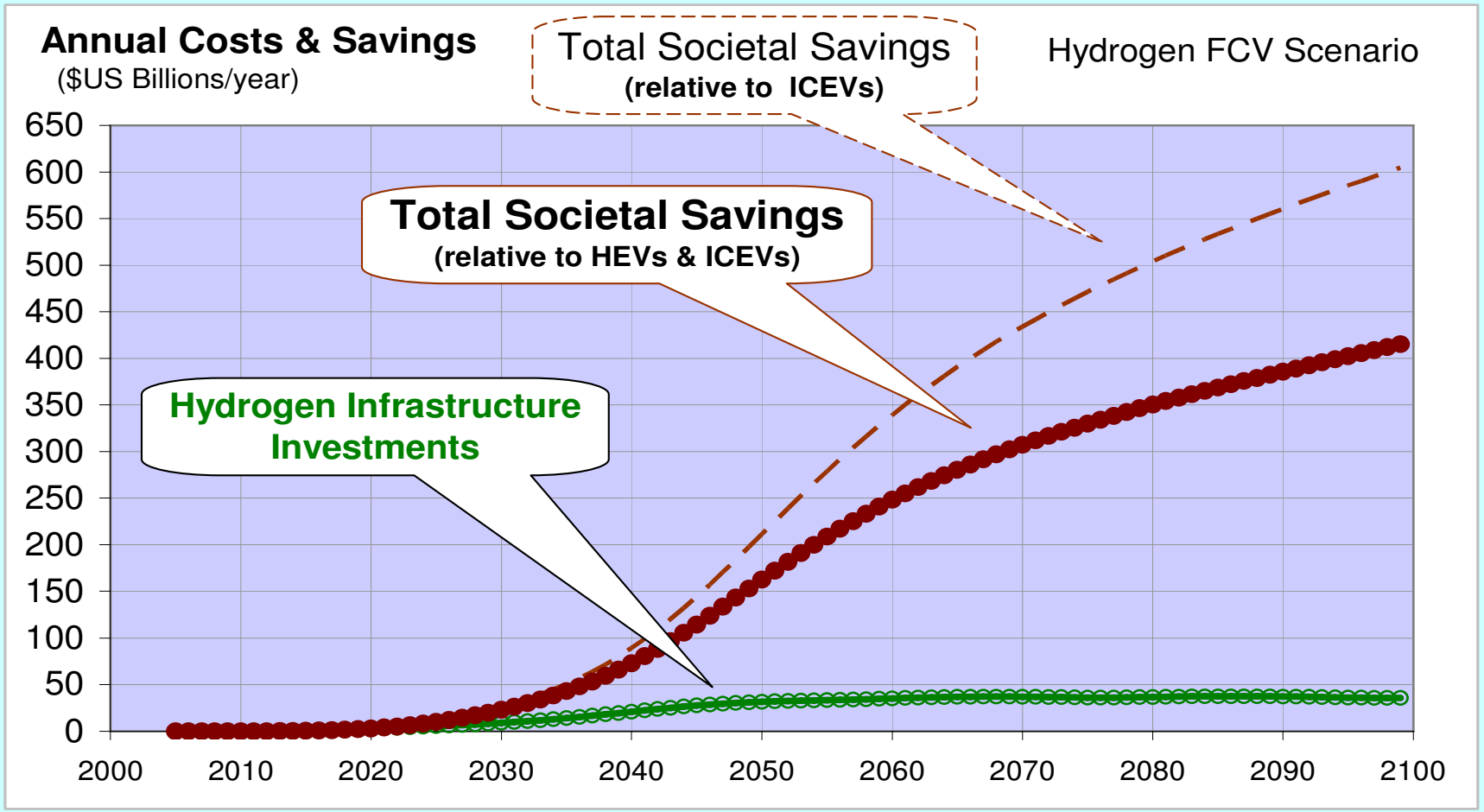
H2 Energy Story.XLS; Tab 'Annual Sales';ID 146 5/5 /2008

Cost to Reduce Grid Carbon Footprint



Source: EPRI for generator capital costs and capacity factors

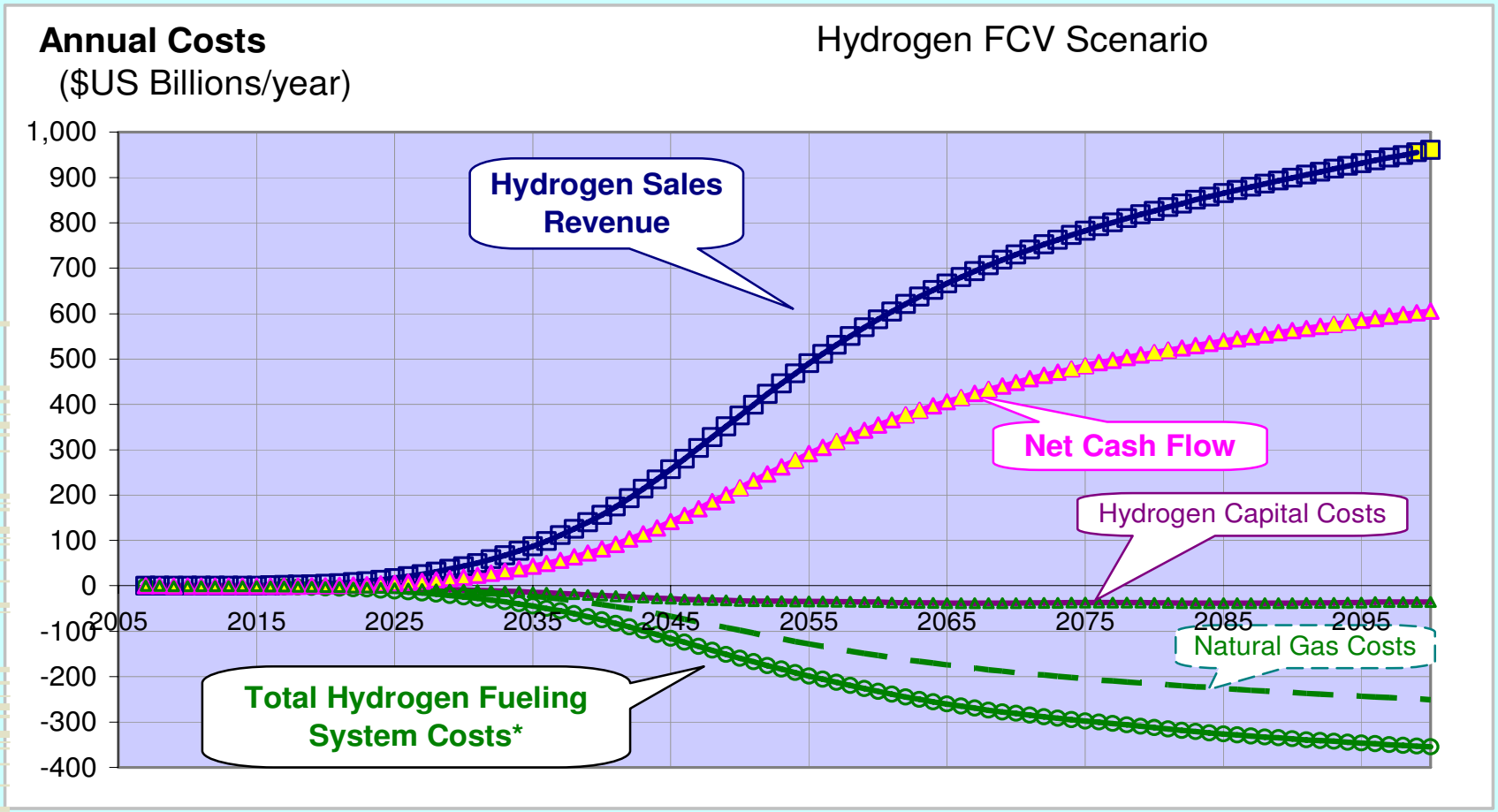
Hydrogen Costs vs. Societal Savings



	PM-10	PM-2.5	SOx	VOC	CO	NOx	CO2
Costs of Pollution:	1,608	134,041	29,743	6,592	1,276	13,844	25 to 50
($/metric tonne)		**Crude Oil Economic Cost**		**$60/bbl**			

H2 Energy Story.XLS; Tab 'Annual Sales';FL 26 5/25 /2008

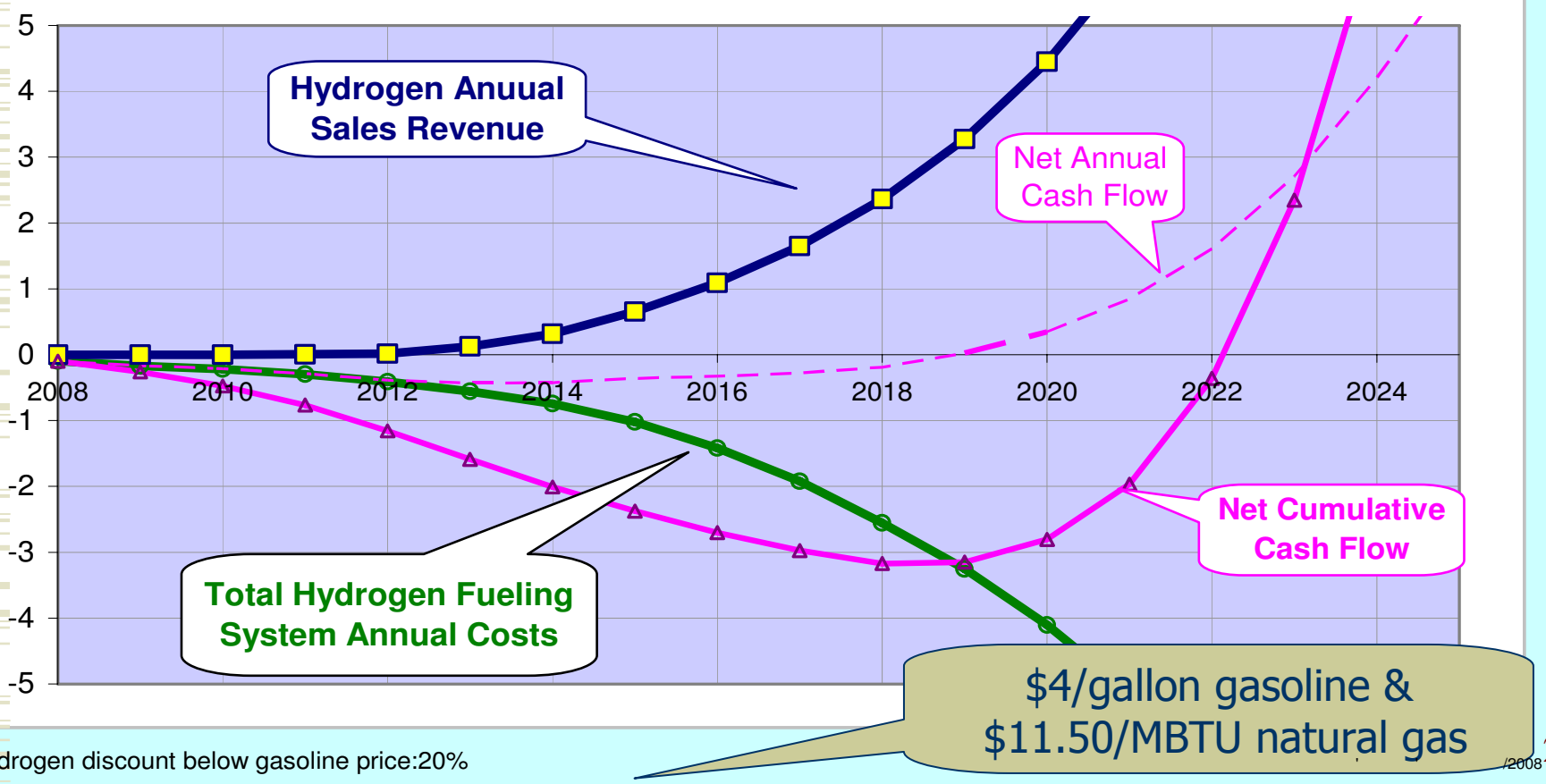
Commercial Perspective:
Hydrogen Fuel Industry Costs & Revenues



* Total hydrogen costs include all capital expenditures, natural gas @ $11.5/MBTU, electricity @$ 0.08/kWh, water, operation & maintenance, etc.

Story Simultaneous.XLS; Tab 'H2 Cost'; Z 96 6/6 /2008

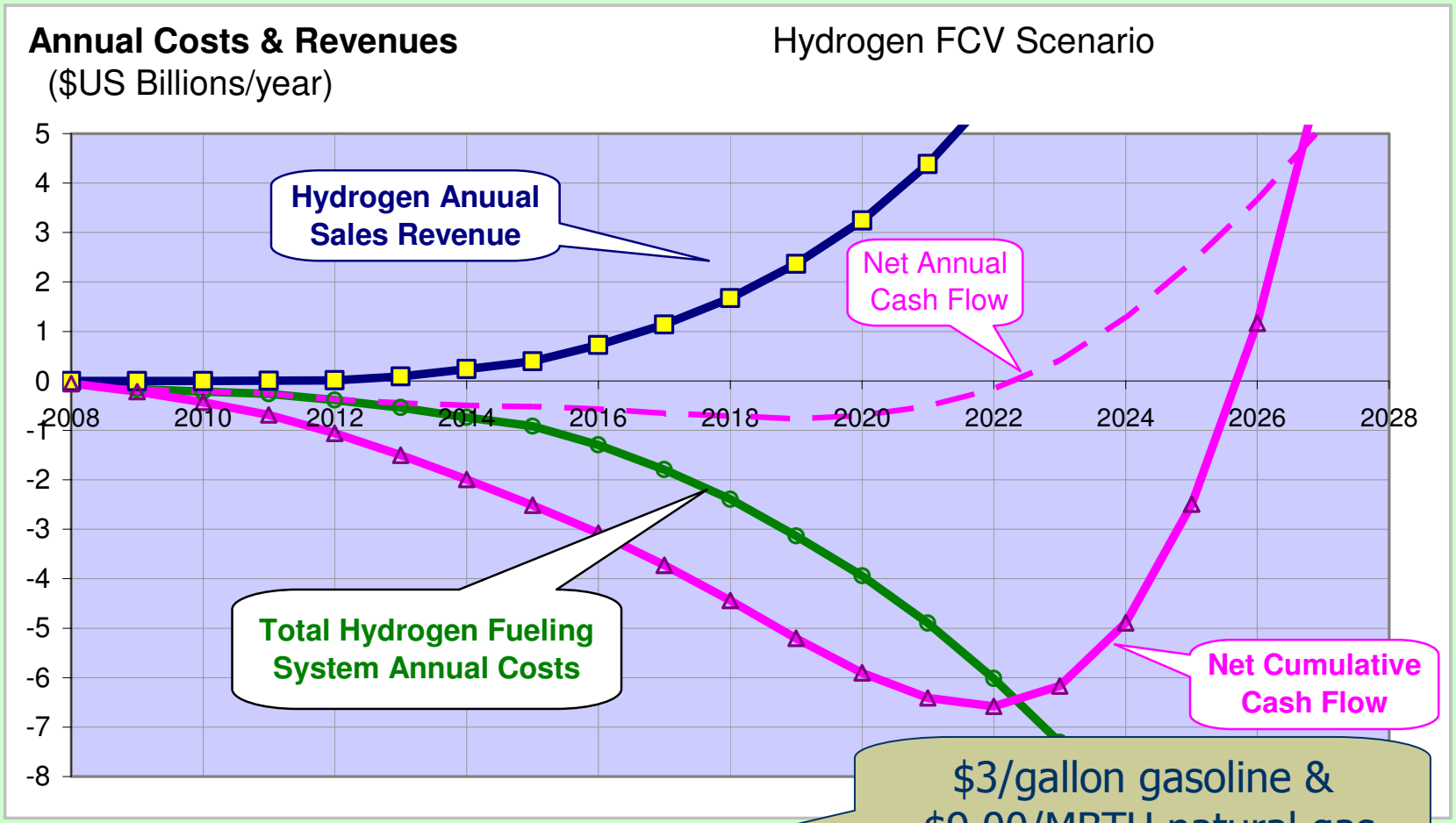
Near-term Hydrogen Industry Cash Flow



Hydrogen discount below gasoline price:20%

Gasoline price: $4/gallon; Natural gas price: $11.5 /MBTU

Near-term Hydrogen Industry Cash Flow



Hydrogen discount below gasoline price:20%

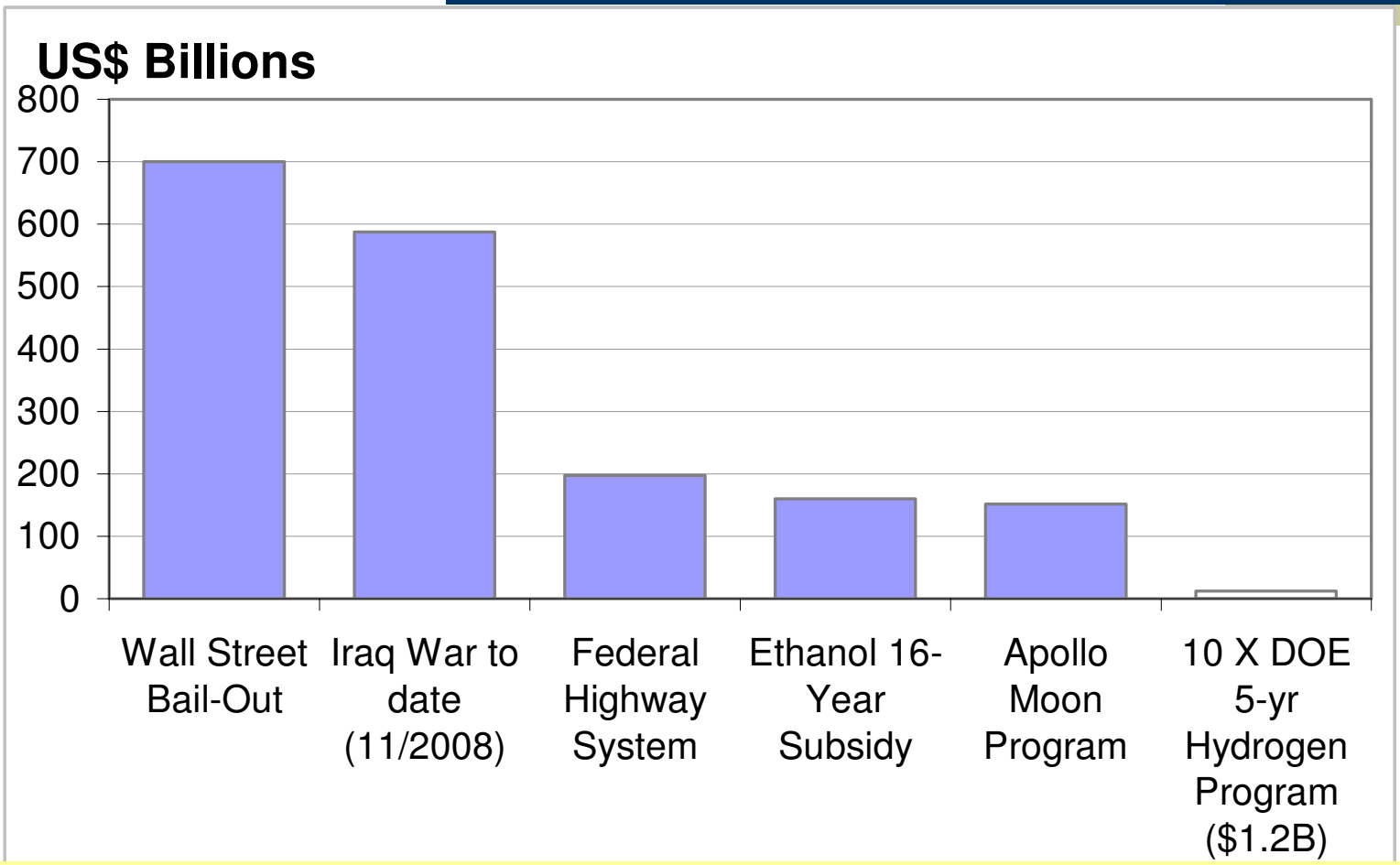
Gasoline price: $3/gallon; Natural gas price: $9 /MBTU

Initial Hydrogen Fueling Incentives Required

(for National Hydrogen Infrastructure)

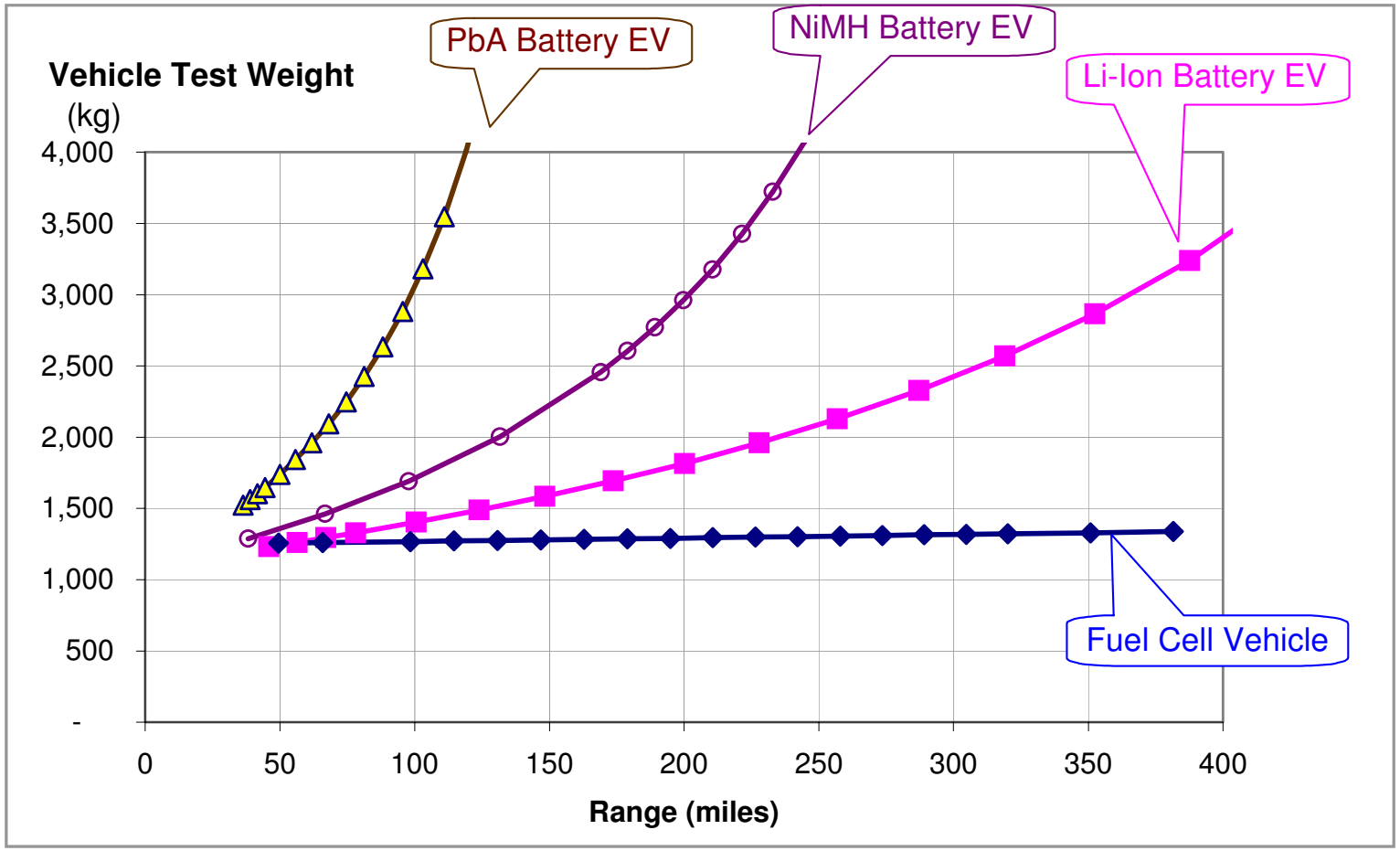
- $3 to $7 billion cumulative over 8 to 10 years for hydrogen fueling systems (Less than $450 to $775 million/year)
- Could be in the form of:
  - Private investors
  - Government incentives
  - Loan guarantees
  - Combinations of the above
  - [Feebates for FCVs]

Hydrogen Infrastructure Costs Compared to Other Projects



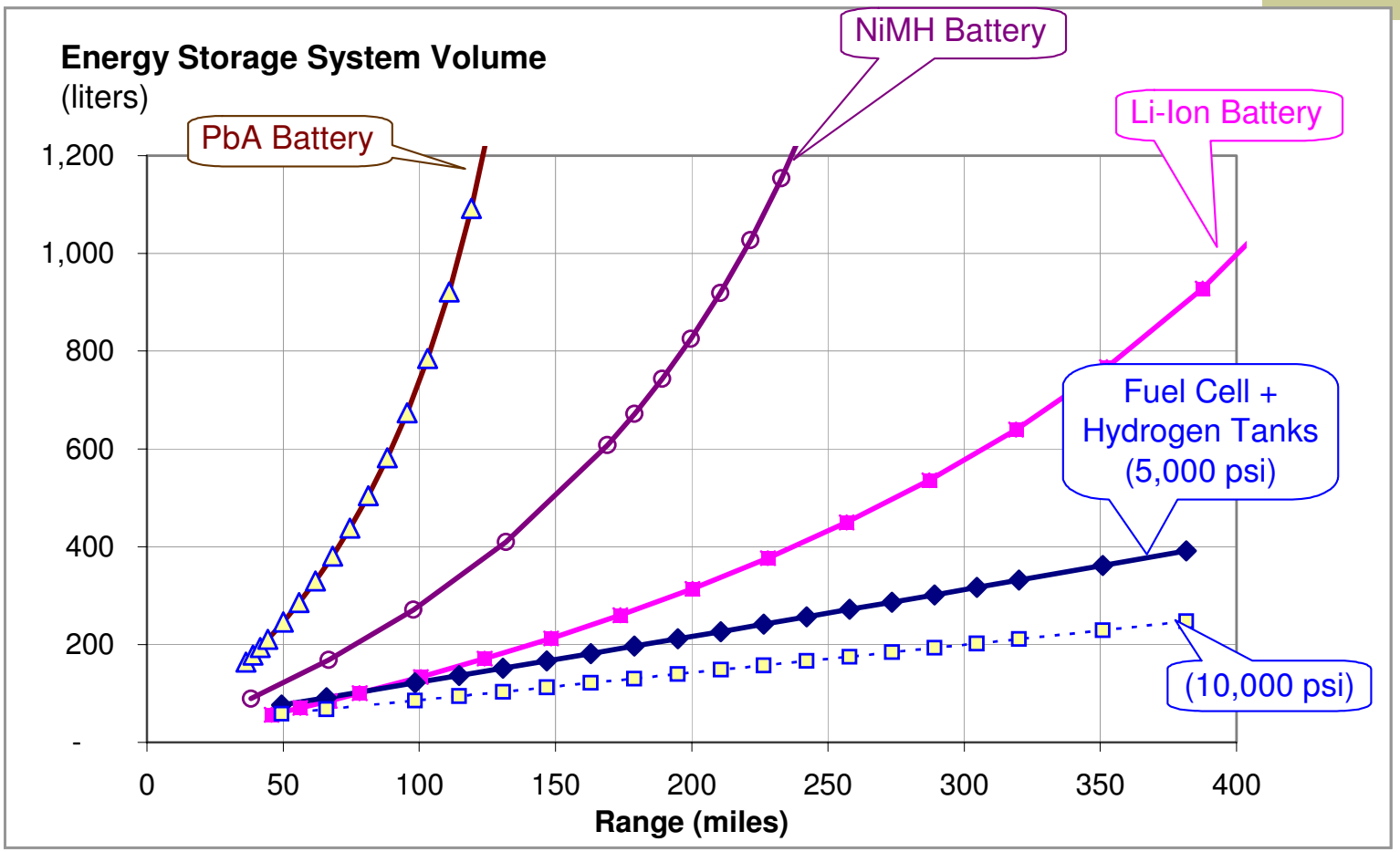
DOE annual hydrogen program $ = 1.45 days of Iraq War $

Vehicle Weight Compounding (Batteries vs. Hydrogen)



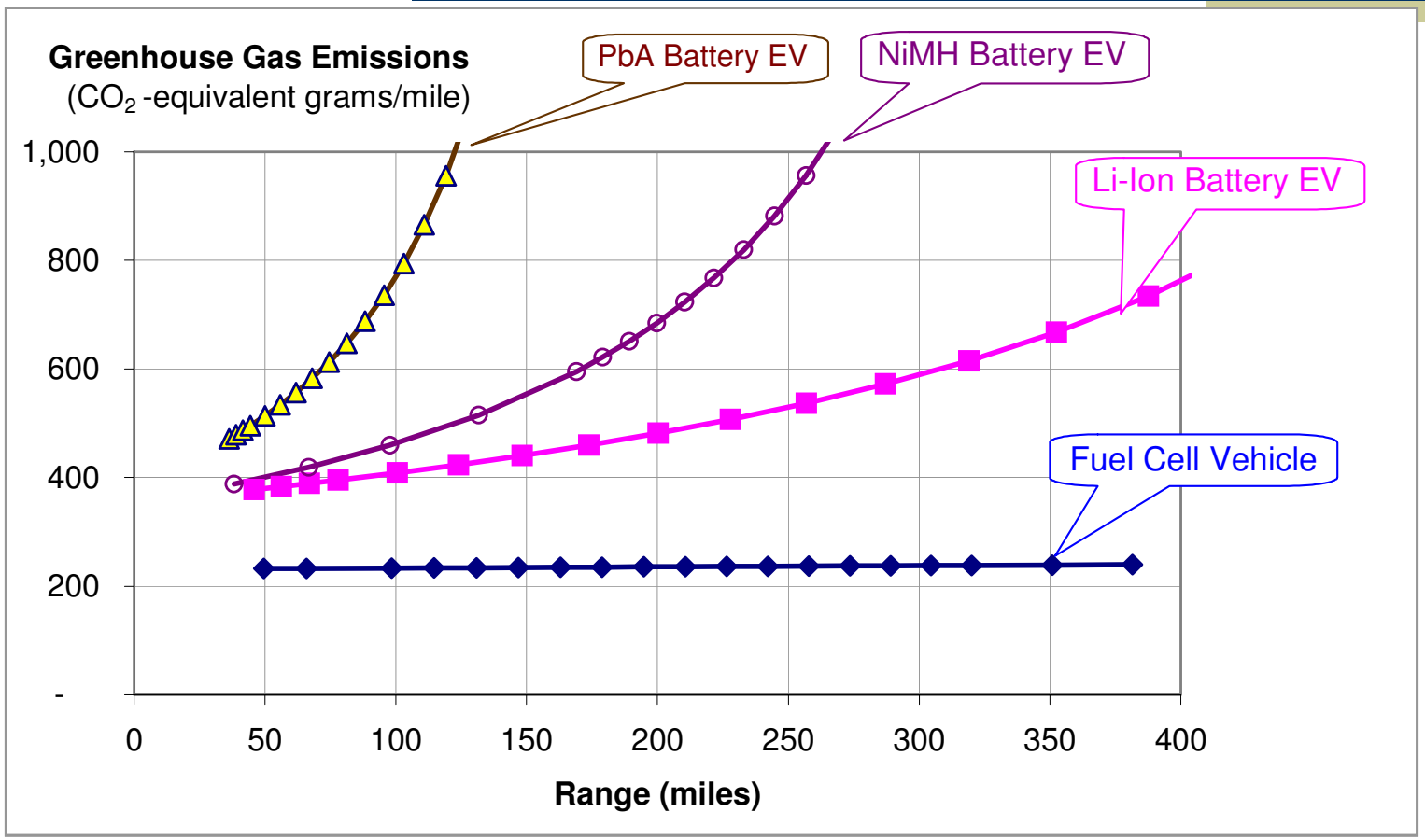
H2Gen: BPEV.XLS; WS 'Compound' AF137 8/26 /2006

Storage Volume
(Batteries vs. Hydrogen)



H2Gen: BPEV.XLS; WS 'Compound' AF108 8/26 /2006

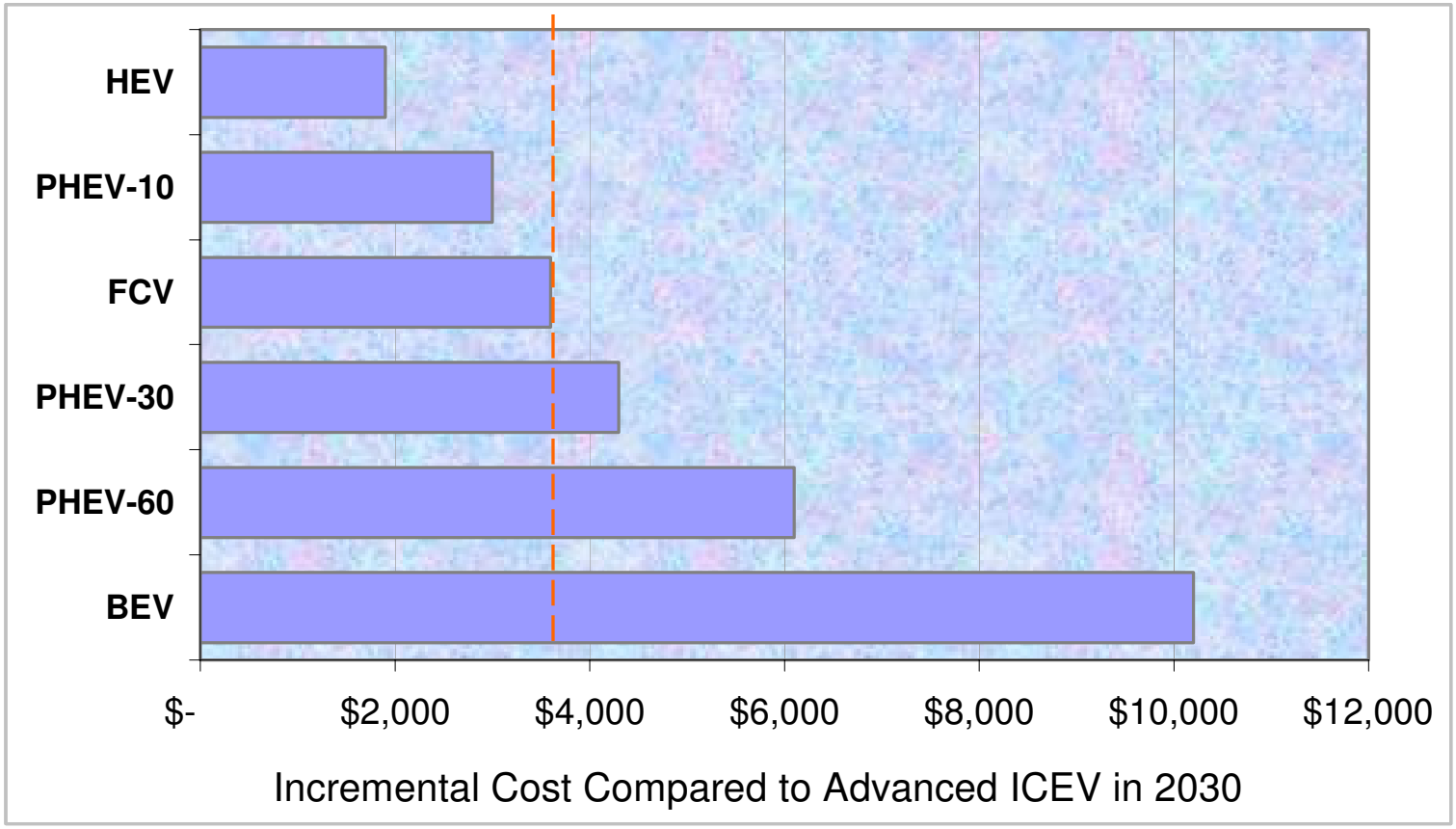
Current Greenhouse Gases*
(Batteries vs. Hydrogen)



*Assumes hydrogen made on-site from natural gas, and average marginal US electrical grid mix for charging EV batteries

H2Gen: BPEV.XLS; WS 'Compound' AF164 8/26 /2006

Incremental Cost of Alternative Vehicles (2030 MIT Estimates)



Ref: Kromer & Heywood, "Electric Powertrains: Opportunities & Challenges in the U.S. Light-Duty Vehicle Fleet Report # LFEE 2007-03RP, MIT, May, 2007, Table 53

Story Simultaneous.XLS; Tab 'AFV Cost'; N 26 9/22 /2008

NRC/NHA Topics Analyzed

Plug-In Hybrids

NGVs

Battery EVs

	NRC Assessment	NHA Assessment
Alternative Vehicles Compared:		
Gasoline ICEVs	Yes	Yes
Advanced ICEVs	Yes	Not separately
Gasoline HEVs	Yes	Yes
Gasoline PHEVs	NO	Yes
Ethanol HEVs	Yes ?	Yes
Ethanol PHEVs	NO	Yes
Diesel HEVs	NO	Yes
Diesel PHEVs	NO	Yes
NGVs	NO	Yes
NG HEVs	NO	Yes
NG PHEVs	NO	Yes
H2 ICE HEVs	NO	Yes
H2 ICE PHEVs	NO	Yes
H2 FCV HEVs	Yes ?	Yes
BEVs	NO	Yes
Societal Attributes Compared:		
Oil Consumption	Yes	Yes
Greenhouse Gases	Yes	Yes
Urban Air Pollution	NO	Yes
Total Societal Cost	NO	Yes
Added Vehicle Cost	Yes	NO
Time Horizon	To 2050	To 2100
Cellulosic Ethanol Production	45 to 60 billion gallons/year	120 billion gallons/year

Source: NRC NHA Comparisons (MS Word)

NRC Press Headlines

NRC Study: Supporting a Transition to Hydrogen Fuel Cell Vehicles in the US Will Require About $200B Over Next 16 Years
17 July 2008 (Green Car Congress)

Renouncing oil for hydrogen will cost US at least $200 billion (Energy Efficiency News)

We Need a $200 Million Hydrogen Fundraiser (Planet Green)

Well, it looks like hydrogen fuel is in the need for a fund raiser in order to get it up to snuff in order to compete with gasoline. A **$200 Billion** dollar fund raiser to be exact.

Paving the Hydrogen Highway Will Cost $200 Billion (KBB Green)

NRC Study says up to 25 million hydrogen vehicles by 2030, $200 billion needed (Hydrogen Forecast)

TABLE S.1 Summary of Cumulative Budget Roadmap Costs for Transition to Hydrogen Fuel Cell Vehicles (maximum practicable number of vehicles by 2020)

Cost Elements	Total Cumulative Cost, 2008-2023	Average Cost per HFCV on Road 2008-2023[a]
"Base vehicle" cost of conventional vehicles	$128 billion	$23,000[b]
Incremental fuel cell vehicle cost relative to conventional gasoline vehicles	$40 billion	$7,000[c]
Total purchase cost of fuel cell vehicles	$168 billion	$30,000
Infrastructure capital cost for hydrogen supply	$8 billion	$1,500
Total operating cost for hydrogen supply	$8 billion	$1,500
Total cost of hydrogen supply	$16 billion	$3,000
Total cost for vehicles and hydrogen fuel supply	$184 billion	$33,000
Estimated government share of total vehicle and hydrogen fuel supply cost	$50 billion	$8,500
Government RD&D funding	$5 billion	$1,000
Private RD&D funding	$11 billion	$2,000
Total funding for government and private RD&D	$16 billion	$3,000
Total cost for vehicles, hydrogen, and all RD&D	$200 billion	$36,000
Estimated government share of total cost for vehicles, hydrogen, and RD&D	$55 billion	$9,500

[a] Rounded estimates based on 5.54 million HFCVs on the road in 2023.
[b] The final (learned-out) cost per vehicle in 2023 is $27,000.
[c] The final (learned-out) incremental cost per vehicle in 2023 is $3,600.

NOTE: All costs in constant 2005 U.S. dollars.

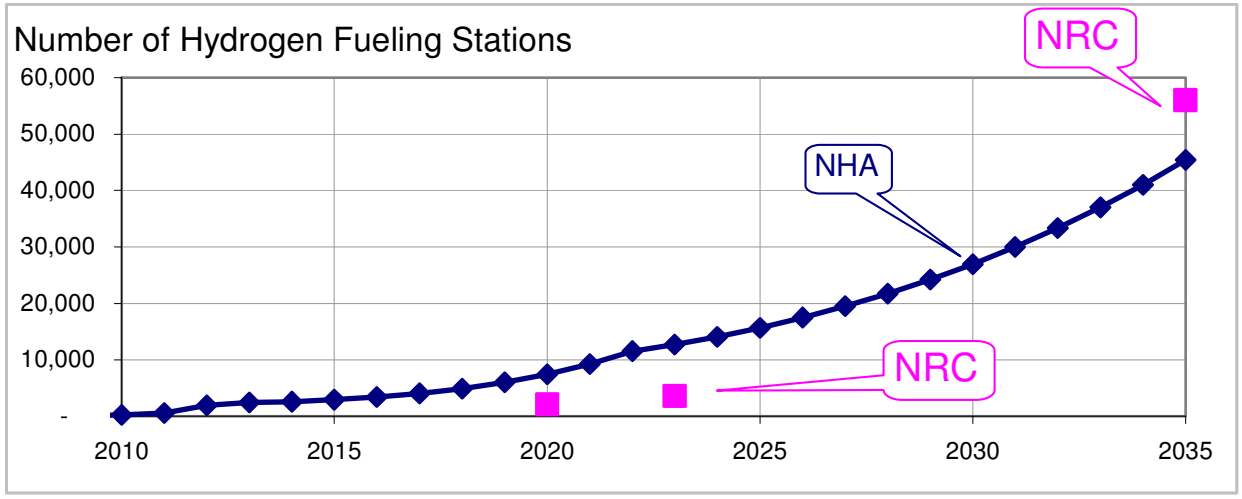
Main NRC Cost Table

$72 billion

Hydrogen Infrastructure Costs & Revenues to Station Owner (2010-2023)

	NRC Assessment	NHA Assessment
Capital cost (2008-2023)	$8 billion	$16.4 billion
Operating costs	$8 billion	$14.8 billion
Total cumulative costs	$16 billion	$31.2 billion
(Cumulative H2 Revenues)*	-	($37.1 billion)
Incentives Required:	$8 to $10 billion	$3.2 to $7 billion

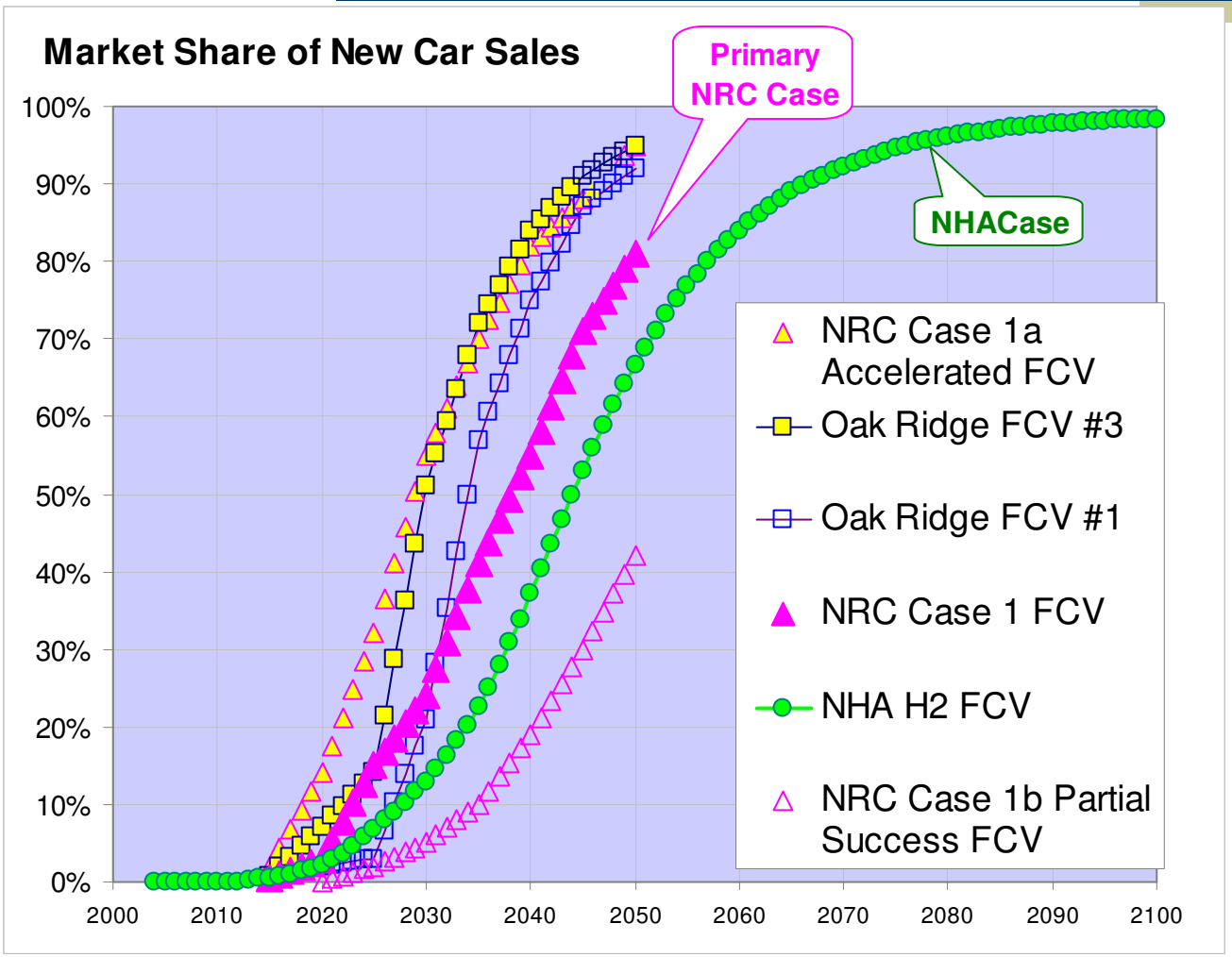
*Assumes hydrogen is sold at $3.20/gallon of gasoline on a range-equivalent basis



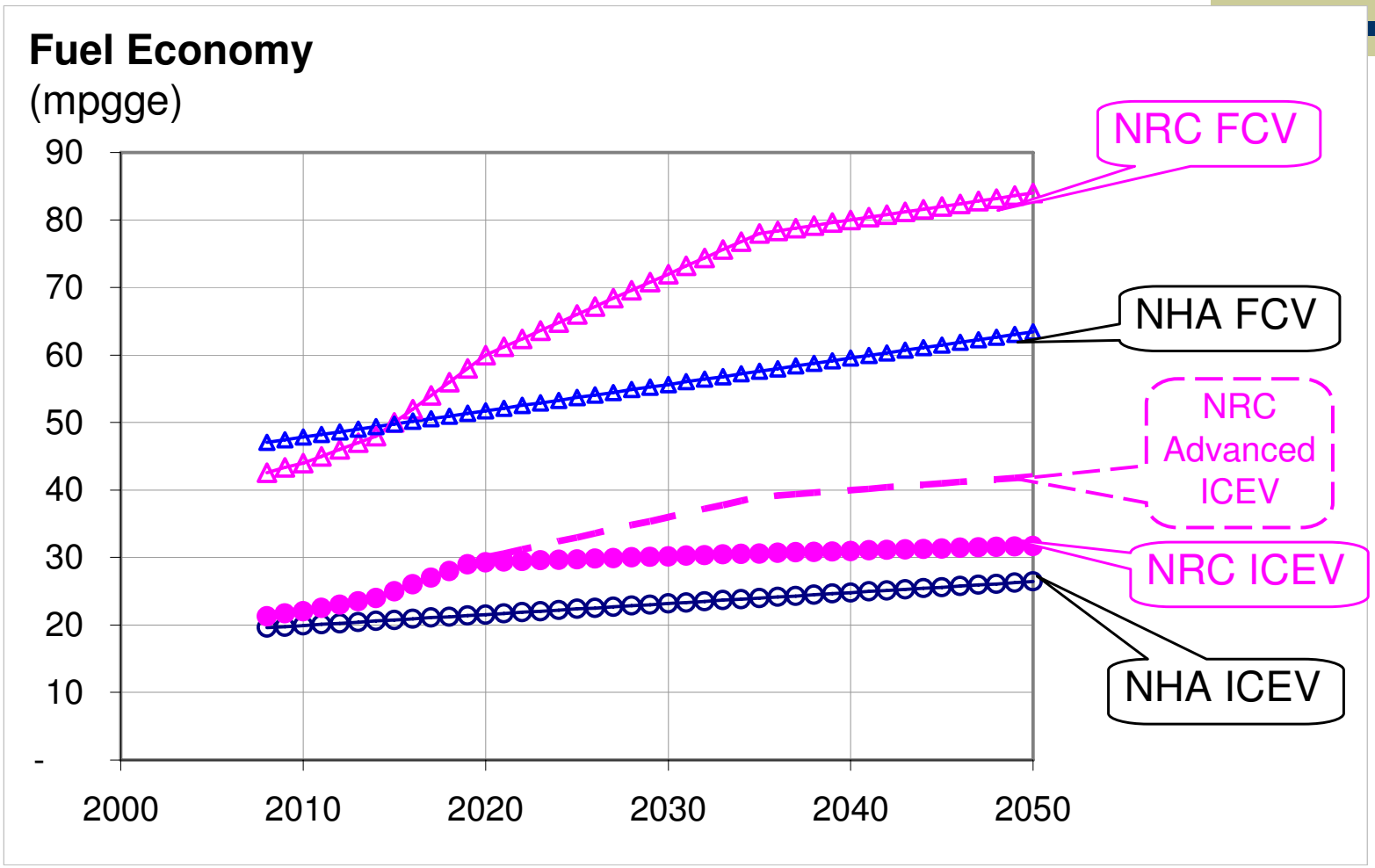
H2 Energy Story.XLS; Tab '#H2 Stations'; U 29 11/5 /2008

Fuel Cell Vehicle Market Penetration

(Compared to 2008 National Research Council/ National Academy of Engineering Hydrogen Report & Oak Ridge Hydrogen Report)

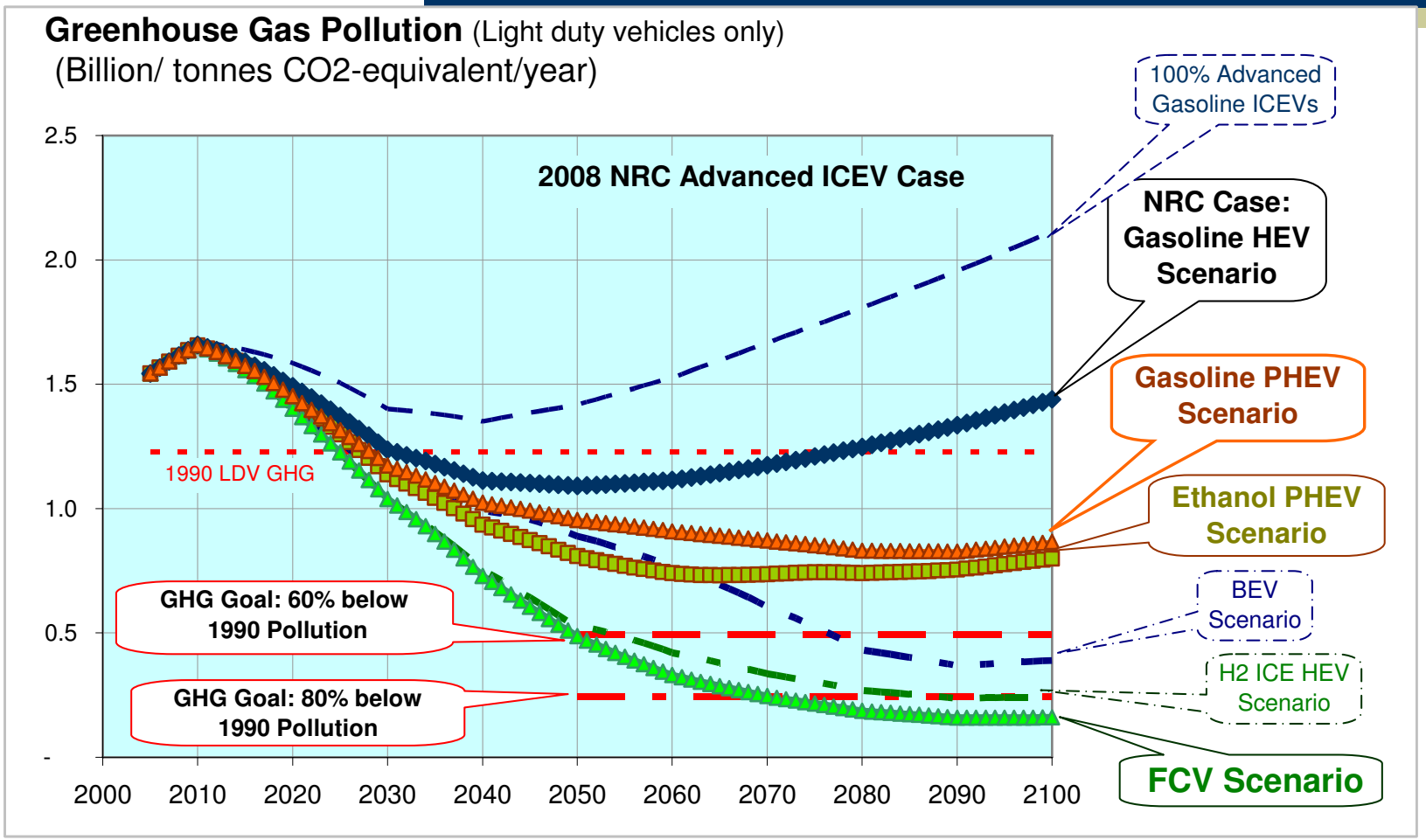


Fuel Economy (NRC vs. NHA)



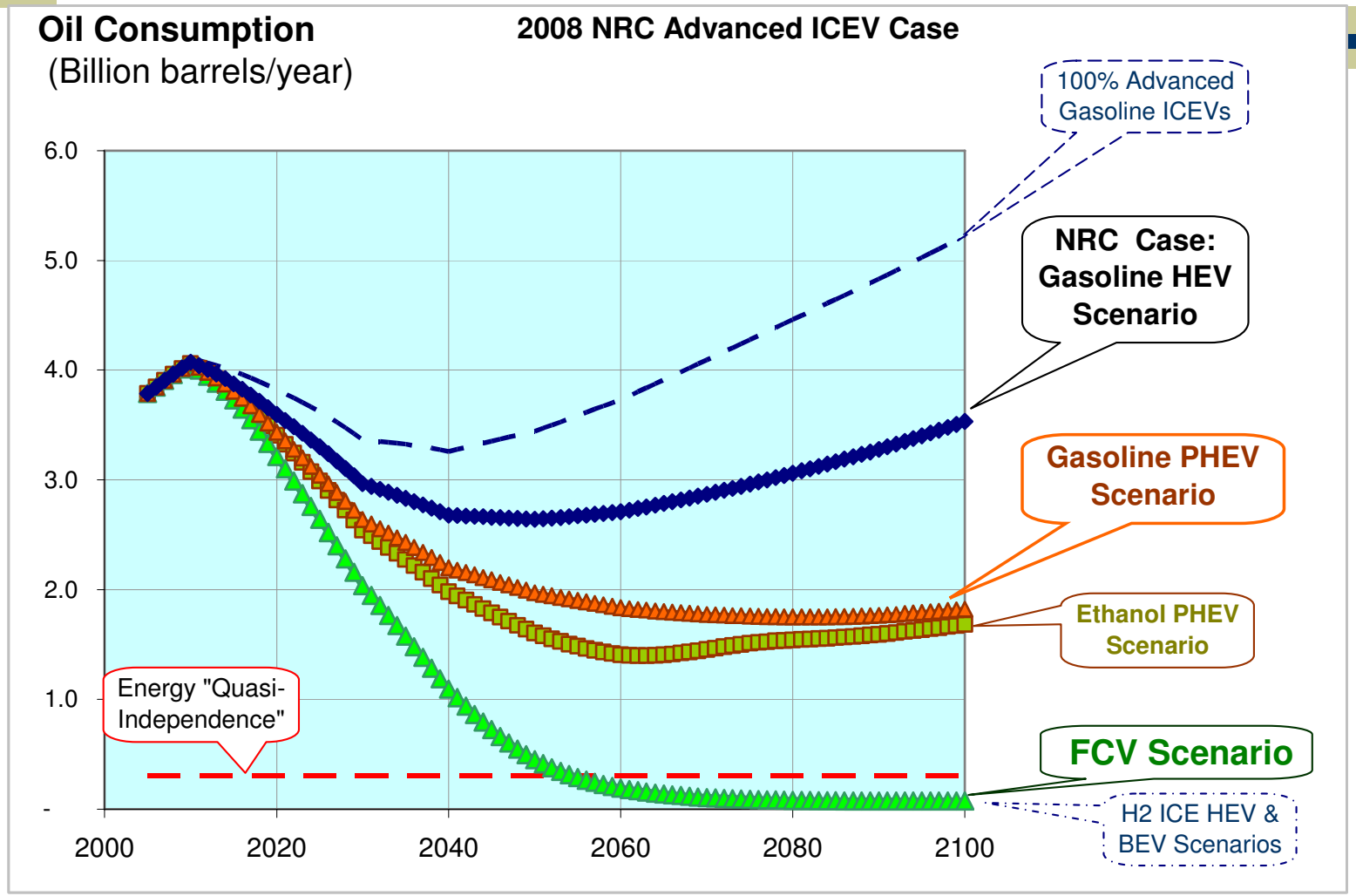
H2 Energy Story.XLS; Tab 'Fuel Economy';AF 71 7/20 /2008

GHG: NHA Model with NRC Input Data



Story Simultaneous.XLS; Tab 'NRC Tables'; AJ 157 8/19 /2008

Oil Consumption: NHA Model with NRC Input Data



Story Simultaneous.XLS; Tab 'NRC Tables'; W 158 8/19 /2008

Acknowledgments

- Frank Novachek & NHA Hydrogen Transportation Story Task Force
- Joan Ogden (1989 Solar Hydrogen Report)
- Bob Rose, US FC Council (for many helpful comments on Hydrogen Transportation Story drafts & guidance over the years)
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- US DOE (1994 Ford/DOE/DTI to present; H2A cost model, Steve Chalk, JoAnn Milliken, Sig Gronich et al.)
- Argonne National Lab (Michael Wang & GREET model)
- Barney Rush (CEO H_2Gen)

Thank-You!

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