An Energy Evolution: Alternative Fueled Vehicle Comparisons

Presented to the DOE EERE Office

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www.CleanCarOptions.com

Outline

- Main Results from 100-year simulation
  - Greenhouse Gas Emissions
  - Oil consumption
- Battery vs. Fuel Cell system comparison
- Capital investments (industry & Government) required for:
  - Hydrogen infrastructure
  - Electrical charging infrastructure
- Government Incentives required for:
  - BEVs
  - FCEVs
- Natural Gas Vehicle Comparisons

NHA Task Force Leader–
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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 presentation does not necessarily represent the views or individual commitments of individual members of the National Hydrogen Association. Some sections of this presentation, without the NHA logo, include work not yet reviewed by the NHA.

Two key options for reducing petroleum dependence and CO_2 pollution:

- Use oil, but less of it
- Switch to lower carbon or carbon-free fuels

Electricity | **Hydrogen**

What is best for society?

- Hybrid electric vehicles? (HEVs)
- Plug-in hybrids? (PHEVs)
- Biofuels?
- Fuel cell electric vehicles? (FCEVs)
- Battery Electric Vehicles (BEVs)

… .or all of the above!

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

What fuels?

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

Renewable Fuels

How do we choose?

National Hydrogen Association Process:

- Develop 100-year vehicle simulation computer program
- Use only peer-reviewed data
- Compare all alternative vehicle/fuel combinations over the century in terms of four societal attributes →

Simulation Outputs:

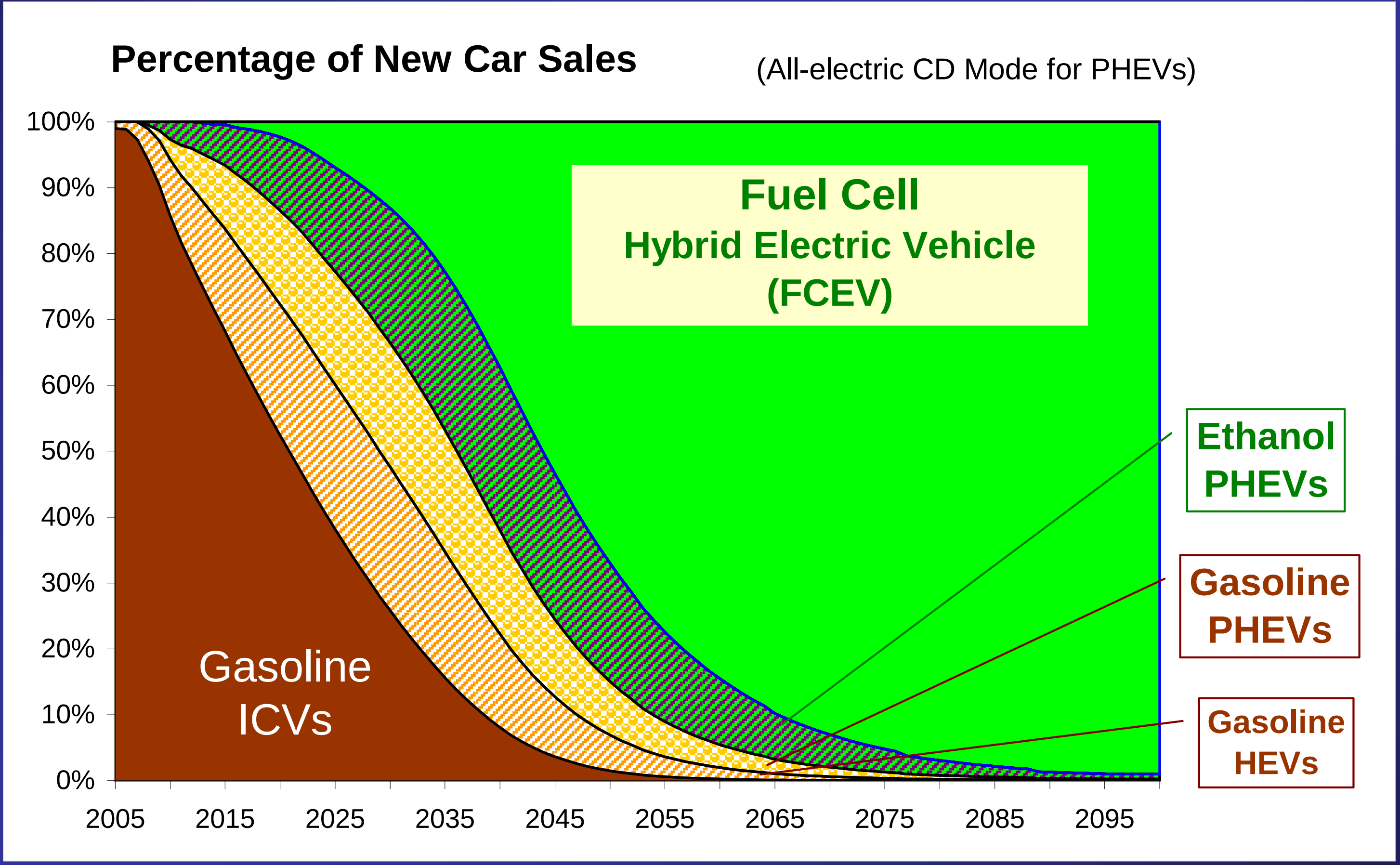
- Greenhouse Gas Emissions
- Oil Consumption
- Urban Air Pollution

Total Societal Costs

Key Assumptions

- Assume success for all options
  - Technical success
  - All Vehicles are affordable
- Assume stringent climate change constraints
  - Hydrogen production becomes green over time
  - Electricity production becomes green over time

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

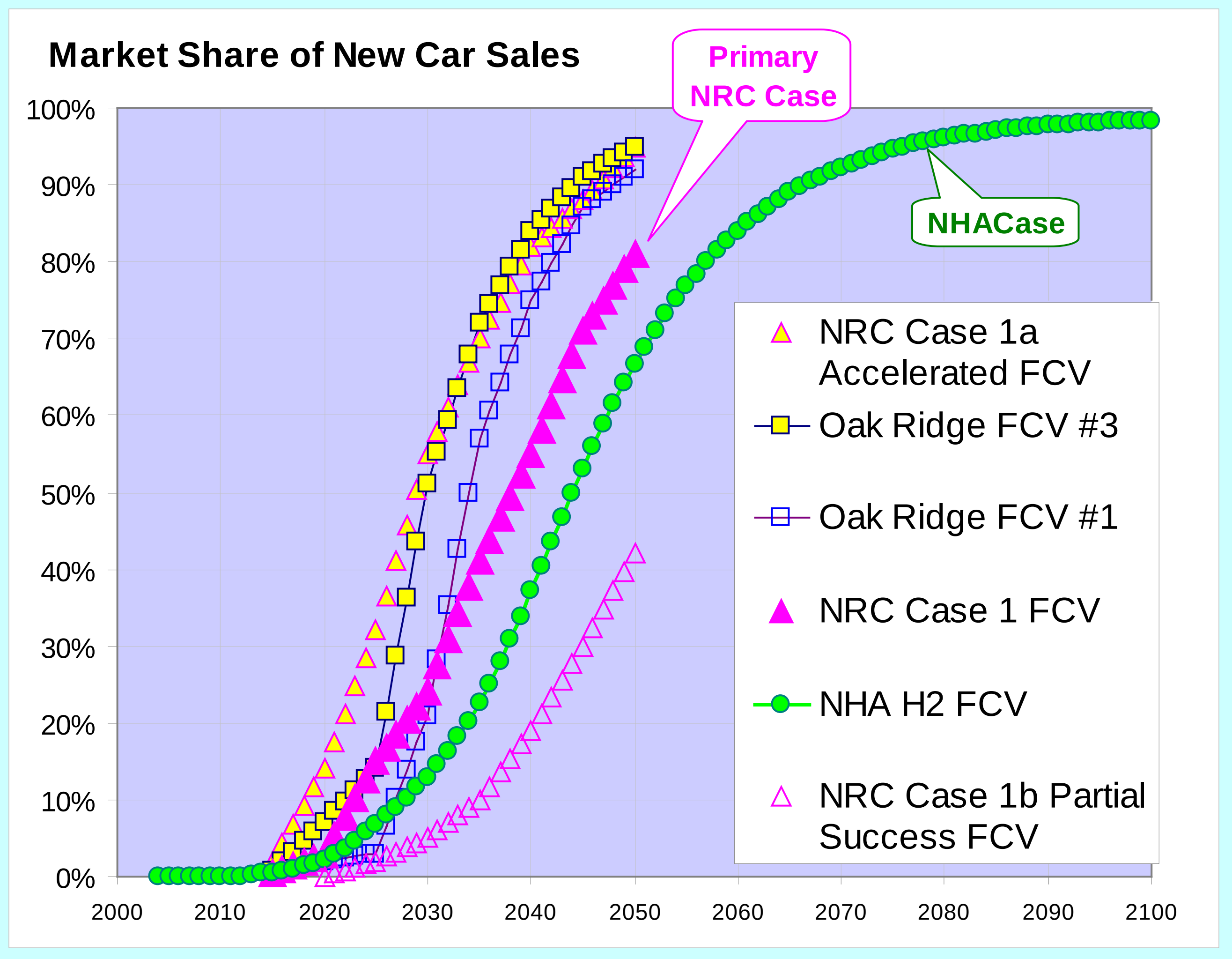


Story Simultaneous.XLS; Tab 'Graphs'; ED 30 2/16 /2009

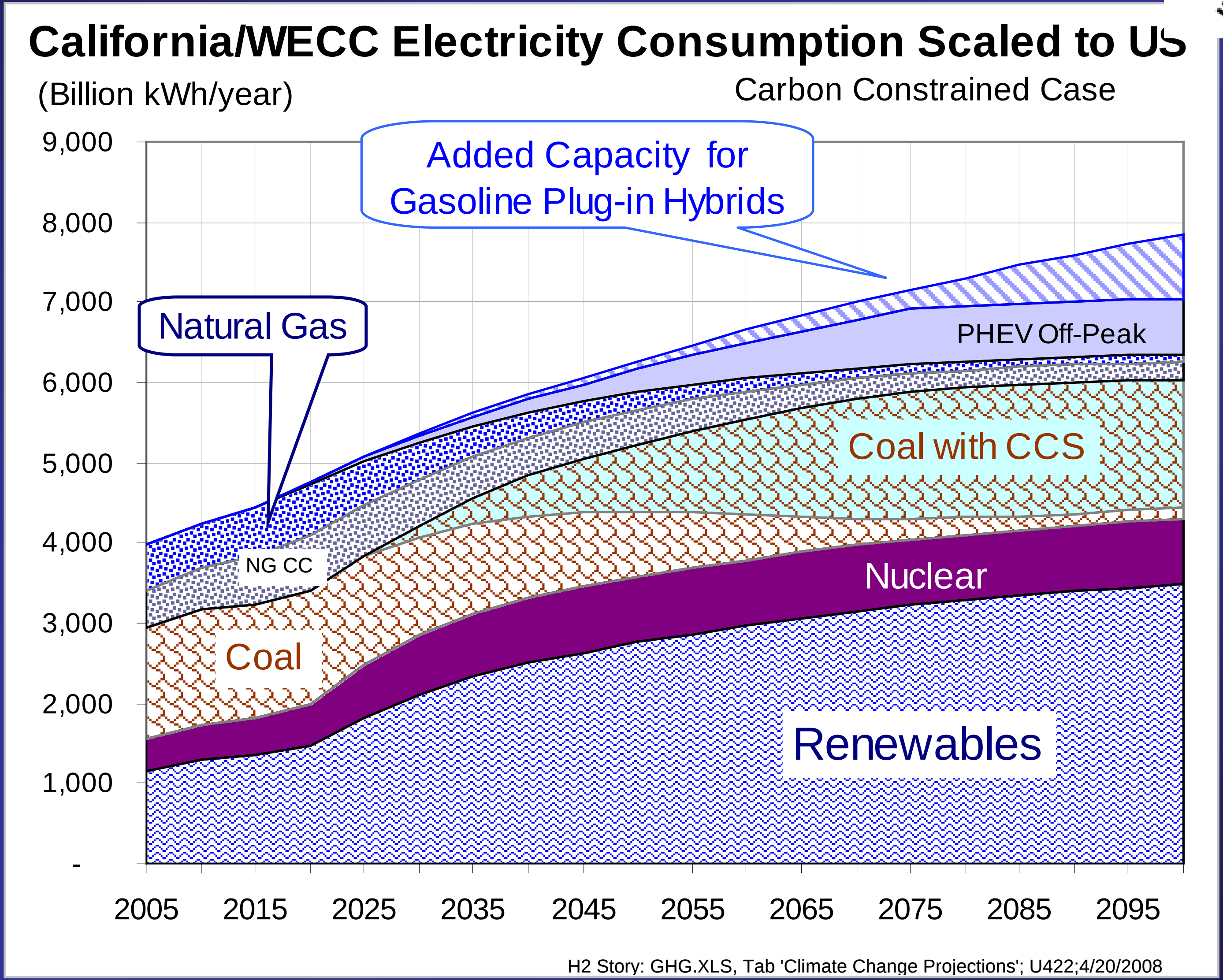
(50% Market Share Potential by 2035)

Fuel Cell Vehicle Market Penetration

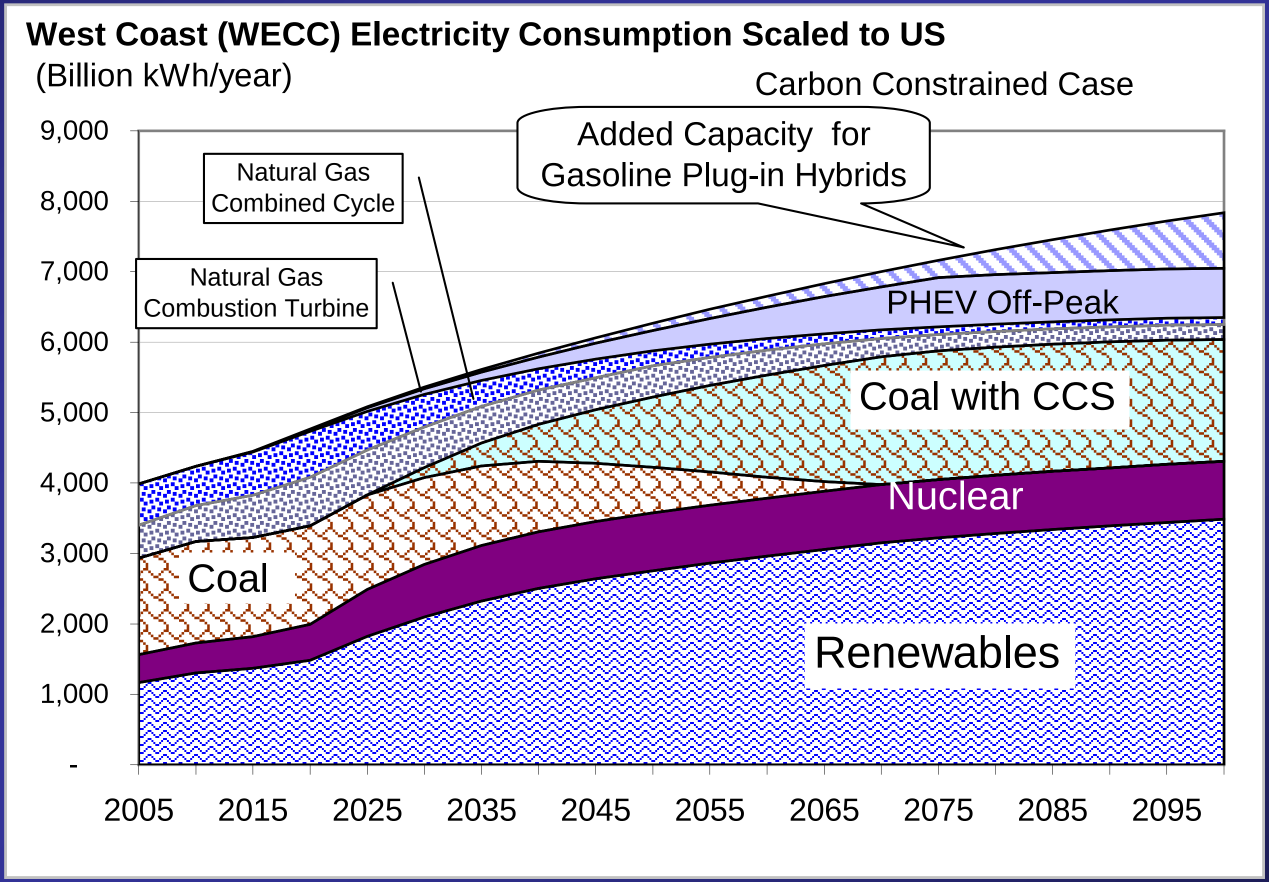
(Compared to 2008 National Research Council/ National Academy of Engineering Hydrogen Report & Oak Ridge Hydrogen Report)



Greening of the Grid

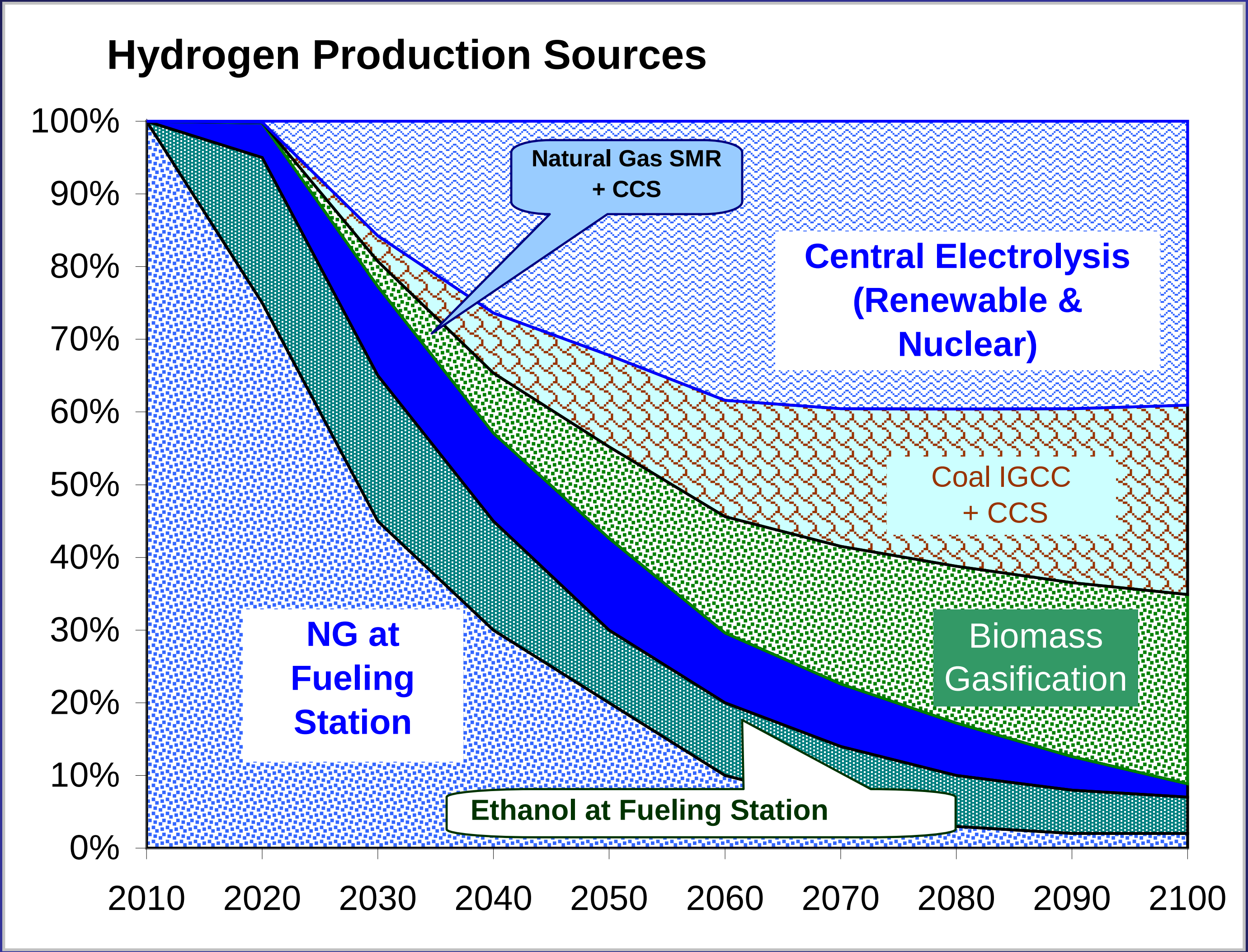


Revised Grid Mix after DOE inputs



H2 Gen: GHG.XLS, Tab 'Climate Change Projections'; U421;3/18/2010

Greening of Hydrogen



NG = Natural gas

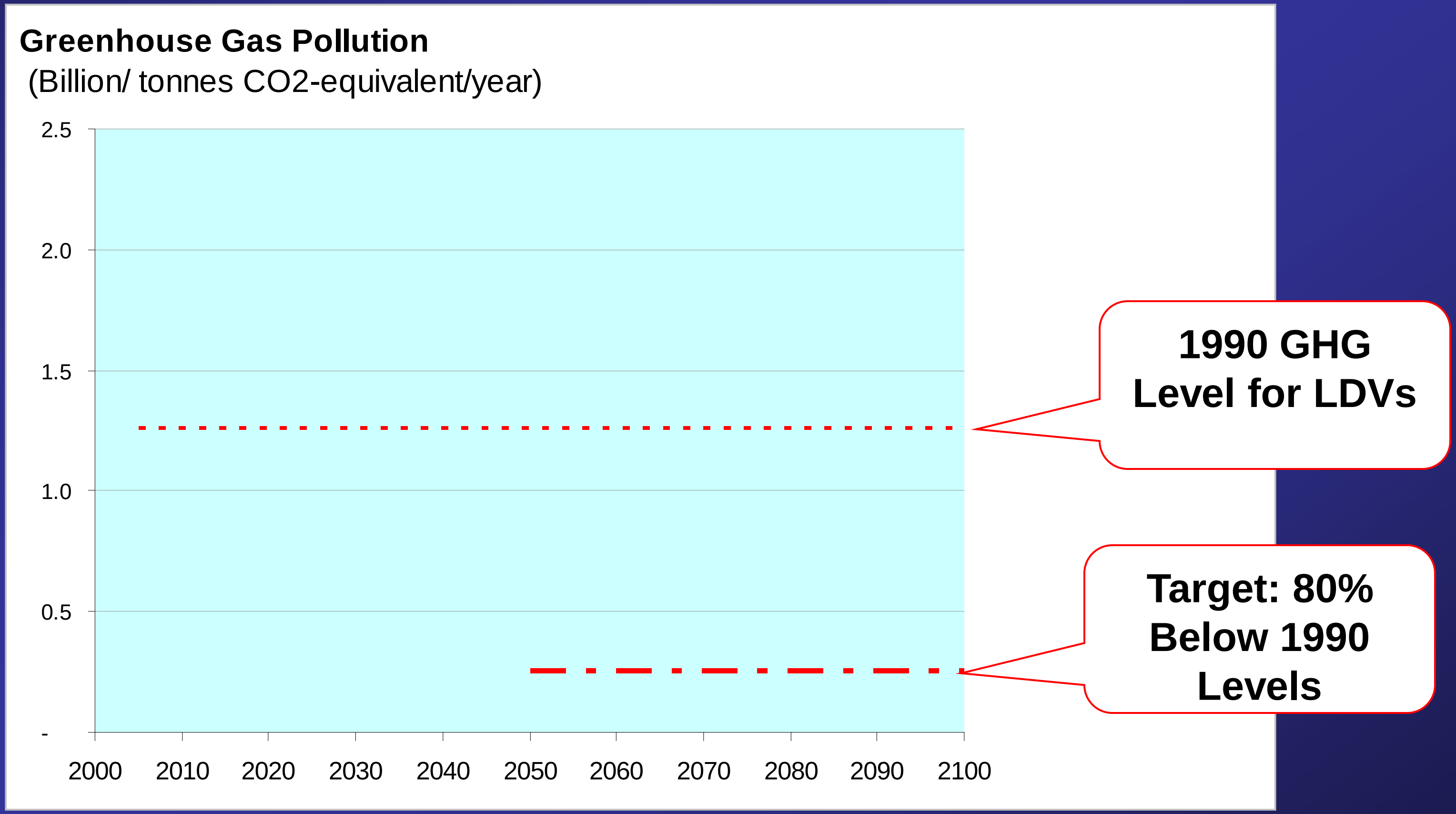
SMR = steam methane reformer (hydrogen from natural gas)

CCS = carbon capture and storage

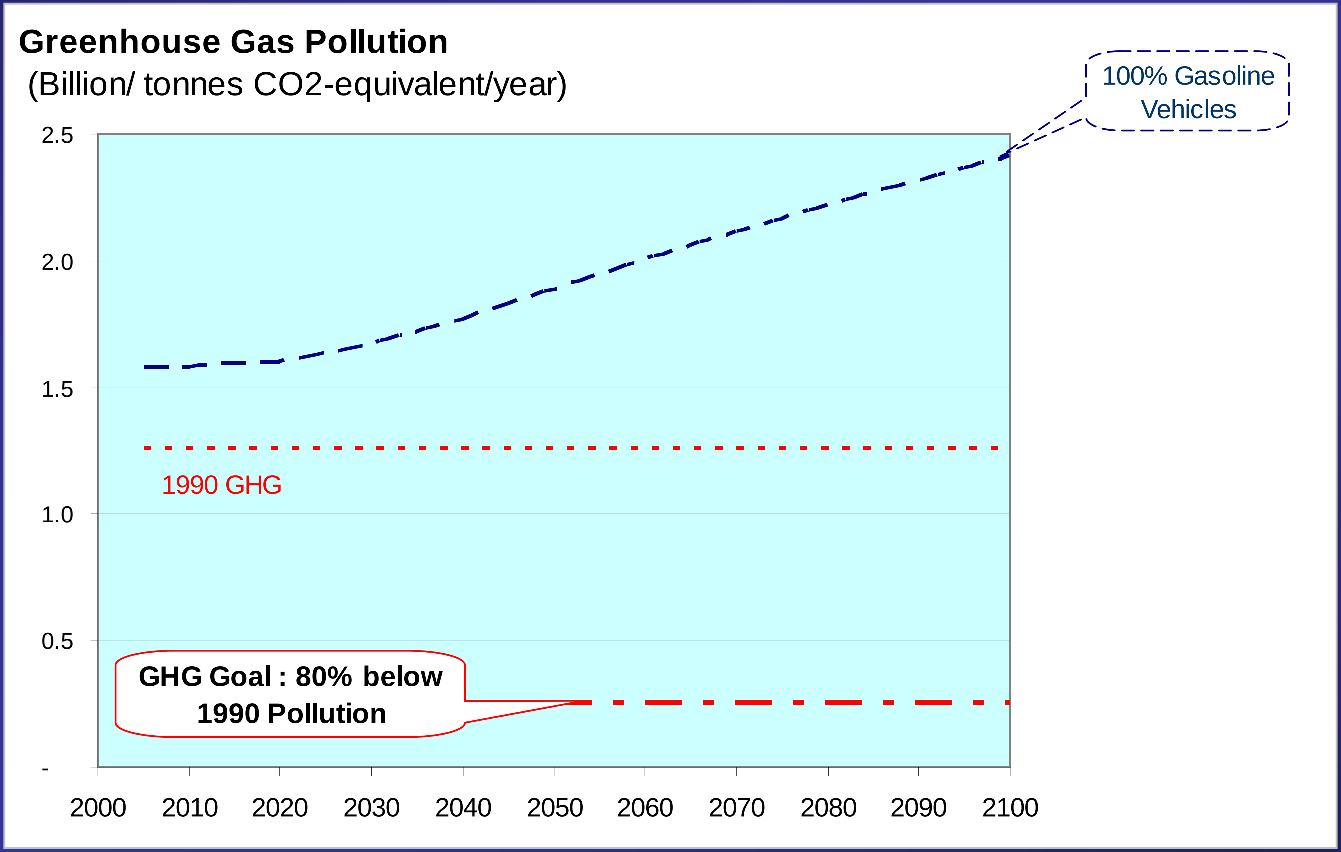
IGCC = integrated (coal) gasification combined cycle

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

1990 Baseline Transportation Greenhouse Gas (GHG) Emissions

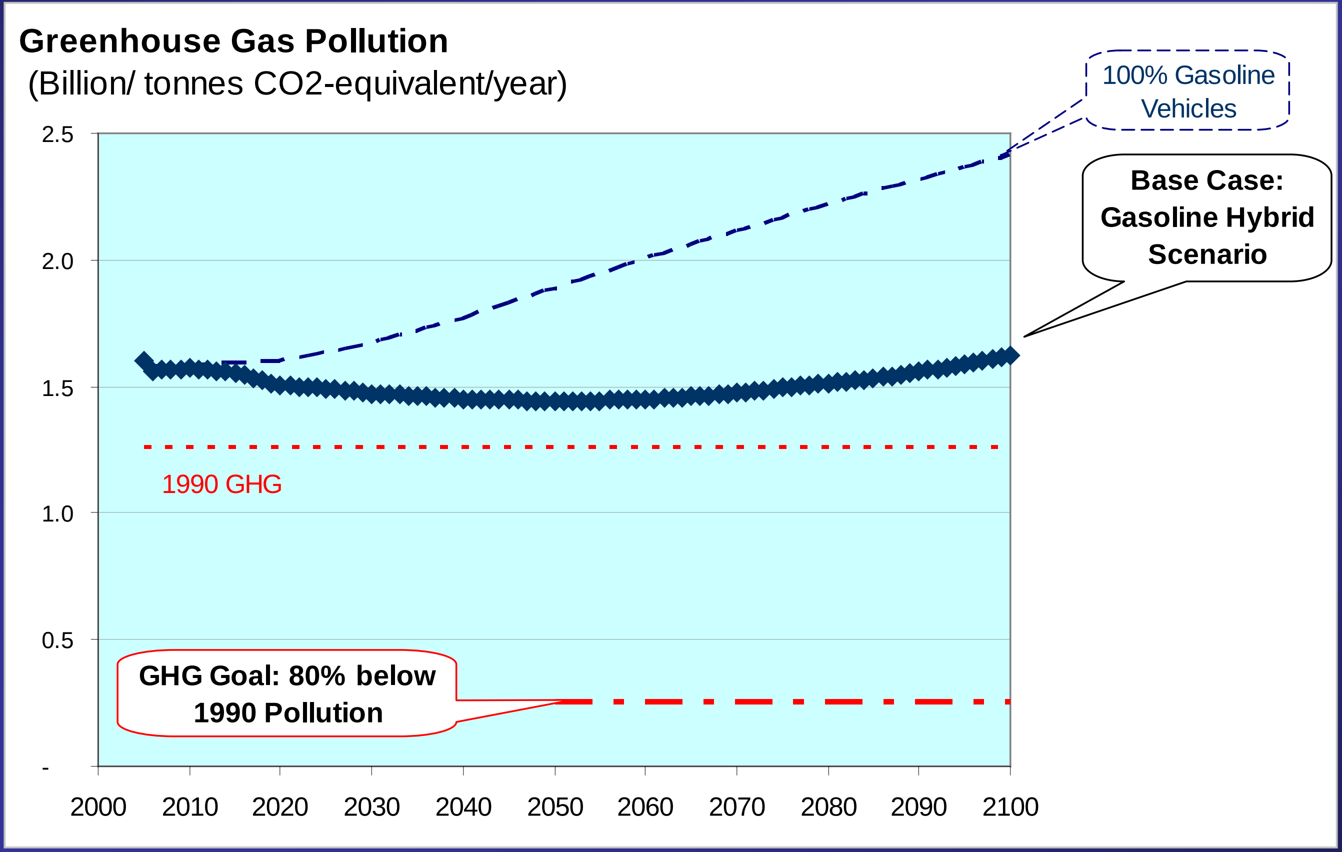


GHG Reference Case: 100% Gasoline Cars



Sources: Argonne National Laboratory GREET 1.8a & AEO 2010 Projections for VMT thru 2035

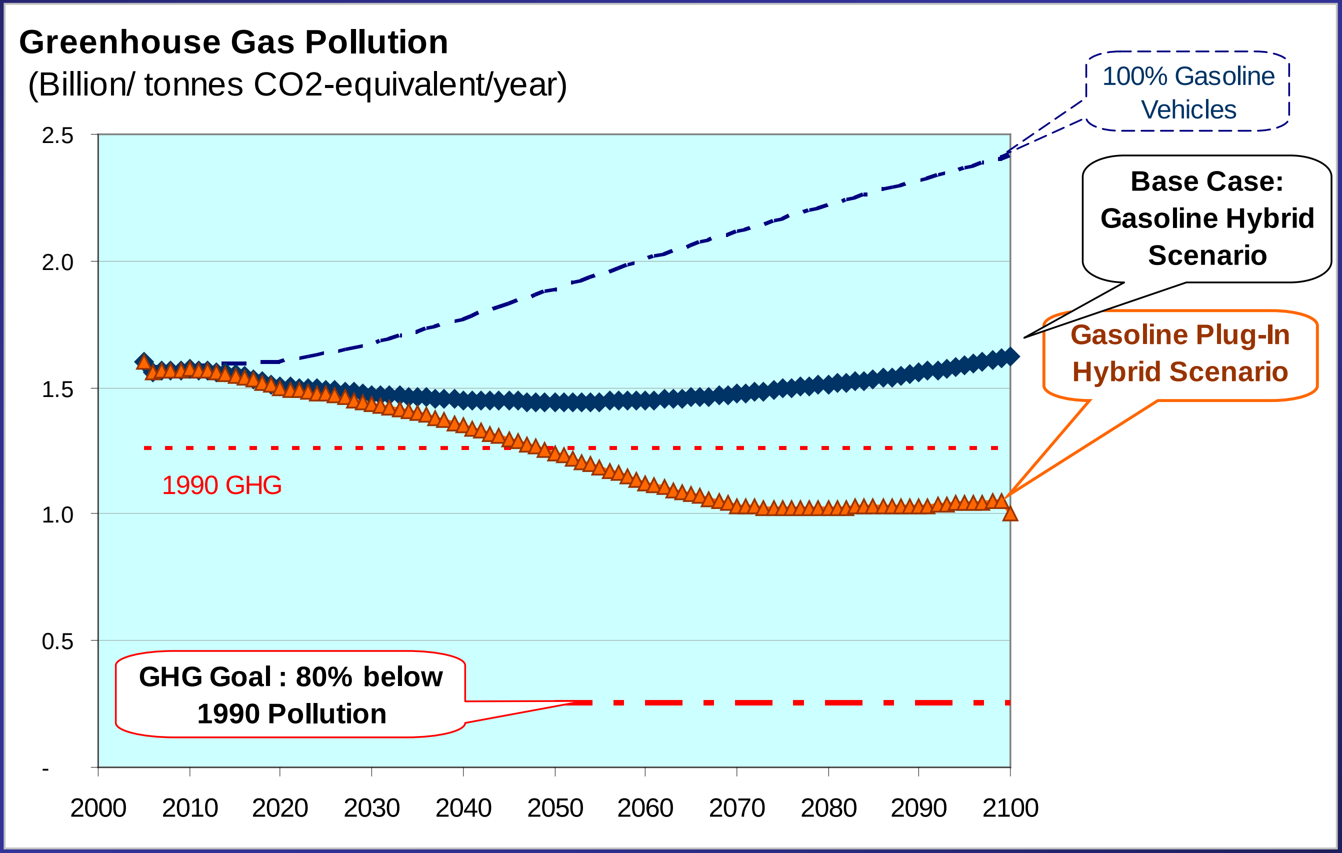
GHG Base Case: Gasoline Hybrid Electric Vehicles (HEVs)



Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

GHG: Gasoline Plug-in Hybrids

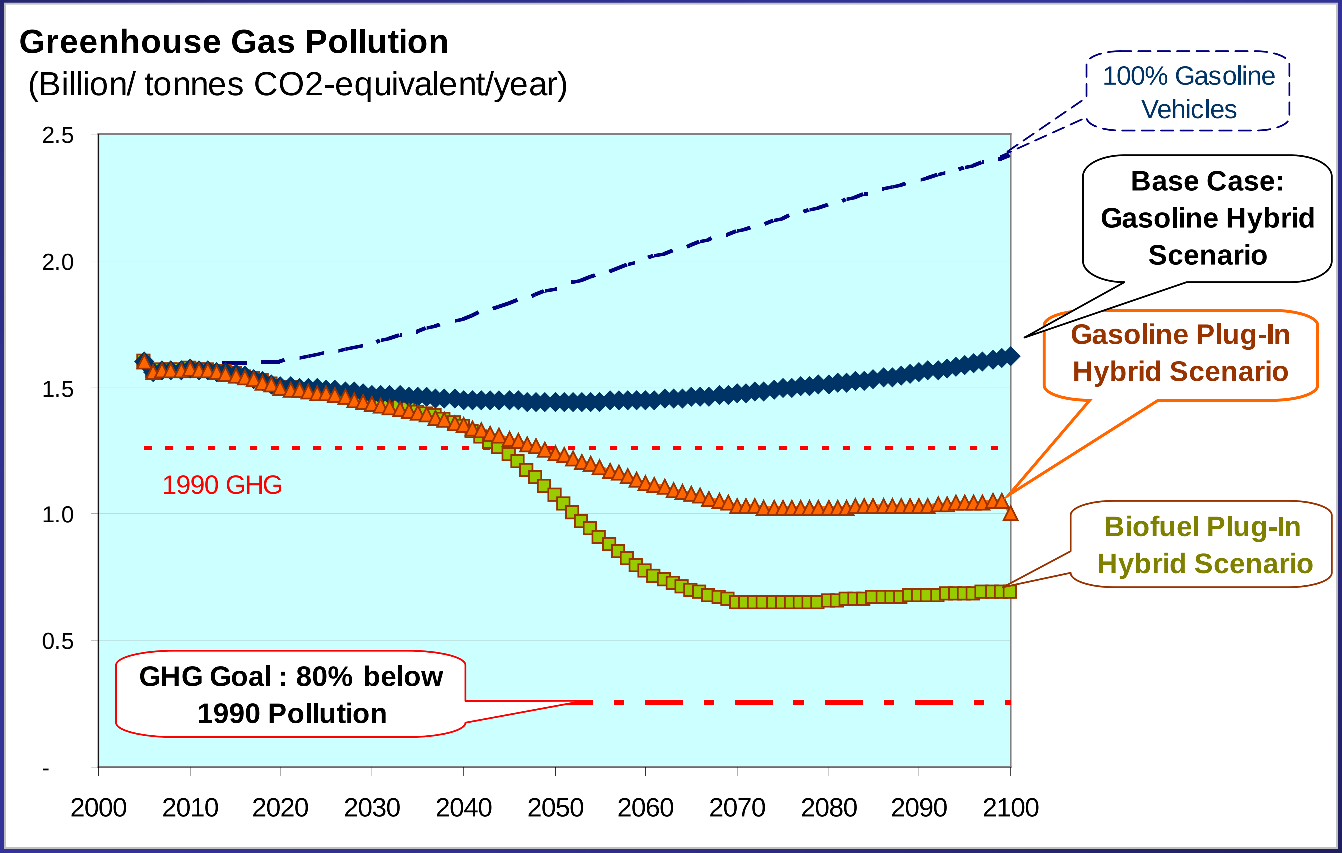
(PHEVs limited to 75% due to availability of charging outlets)



Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

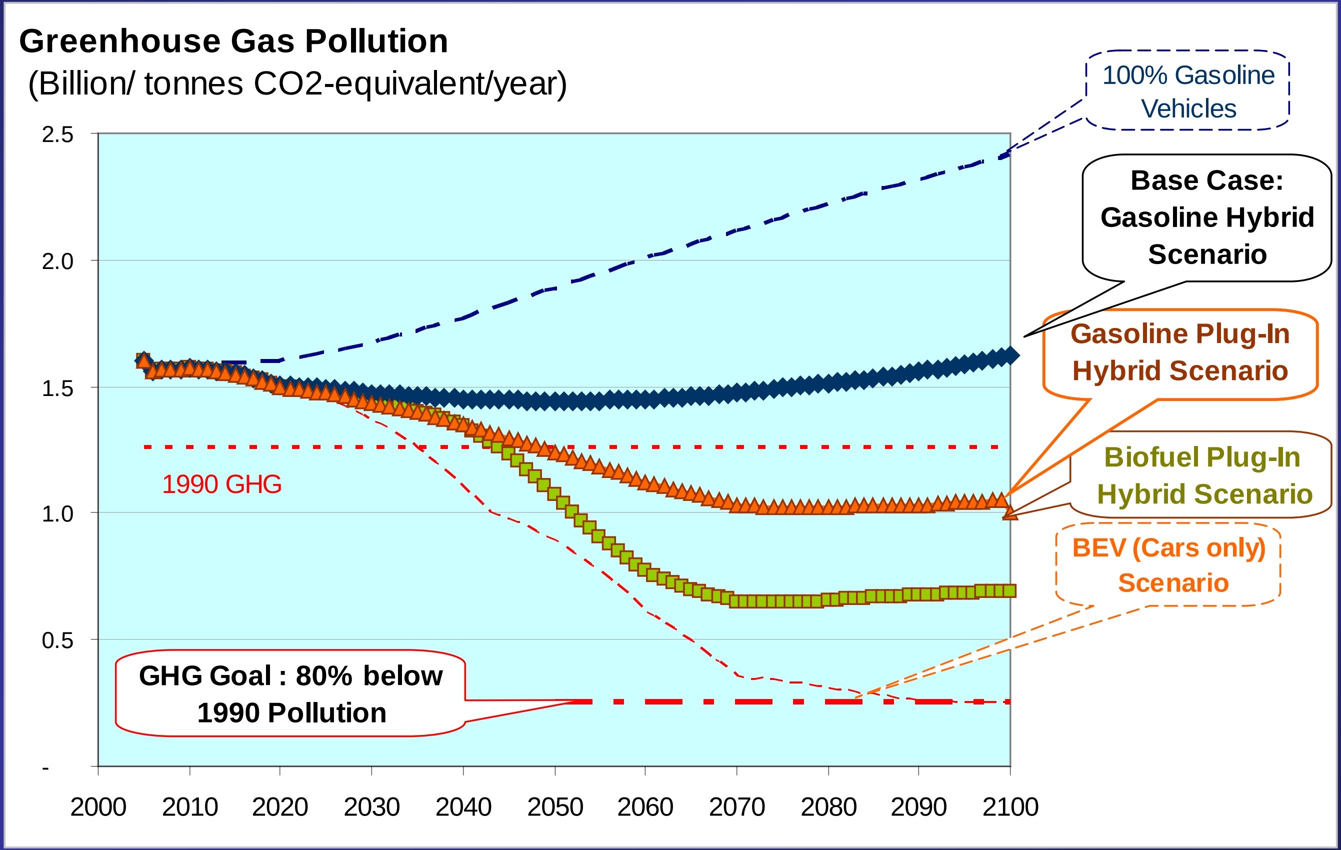
GHG: Ethanol Plug-In Hybrids

(90 Billion gallons/year* Cellulosic Ethanol & 75% PHEV limit)



*Sandia-Livermore estimates 90 B gallons/yr potential; NRC uses 60 B gallons/yr maximum

GHG: Battery Electric Vehicles (BEVs)- Passenger Vehicles only (no Battery-powered SUVs, pick-up trucks or vans)



Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

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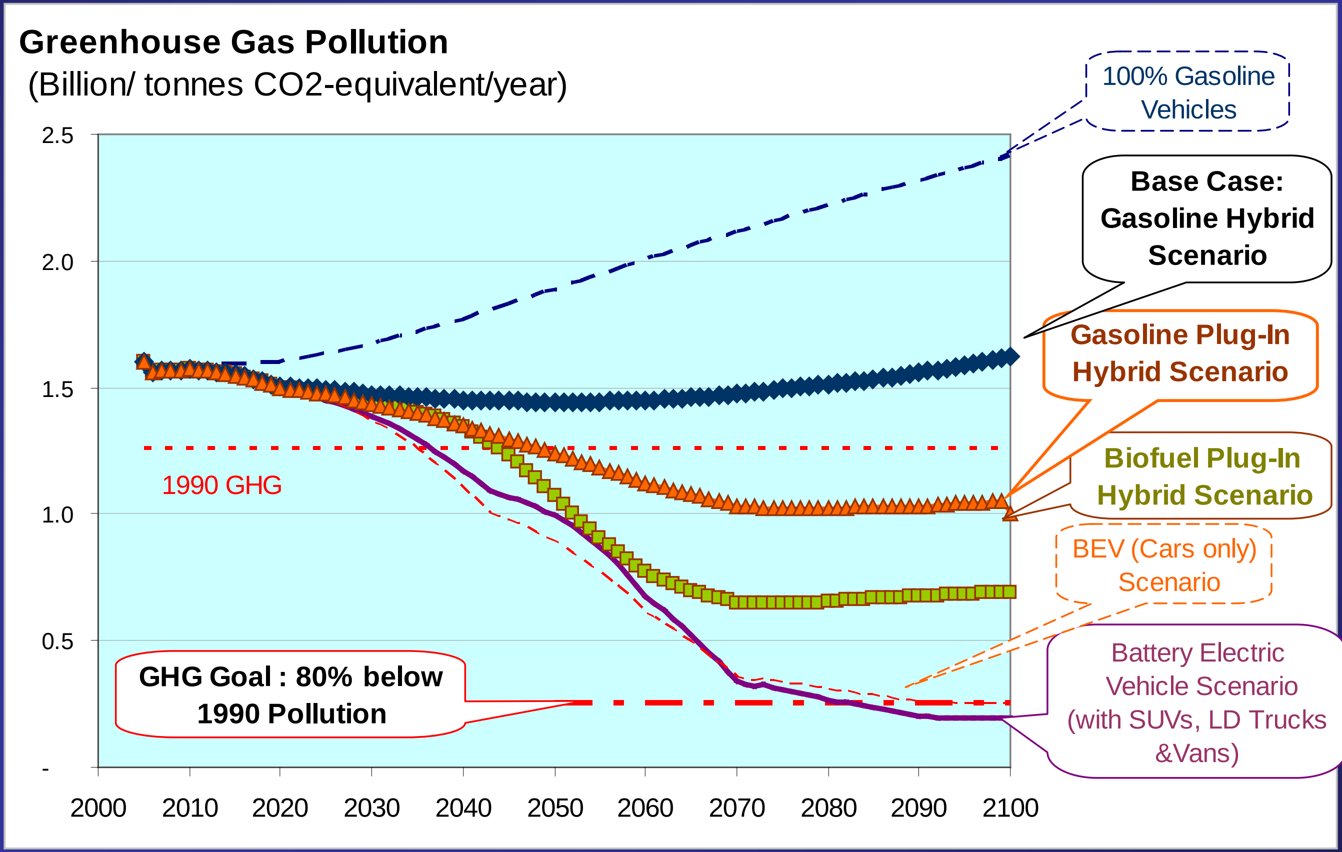
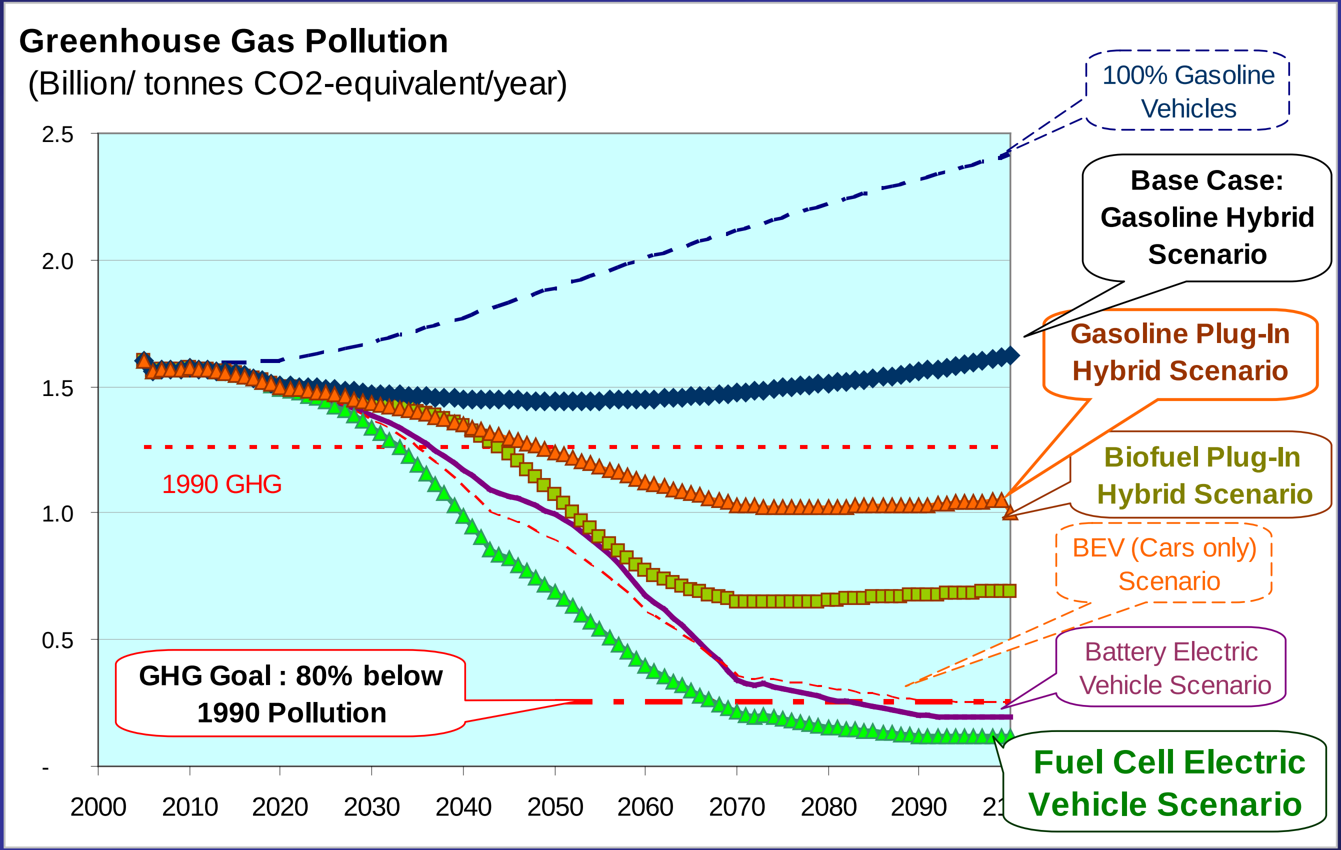


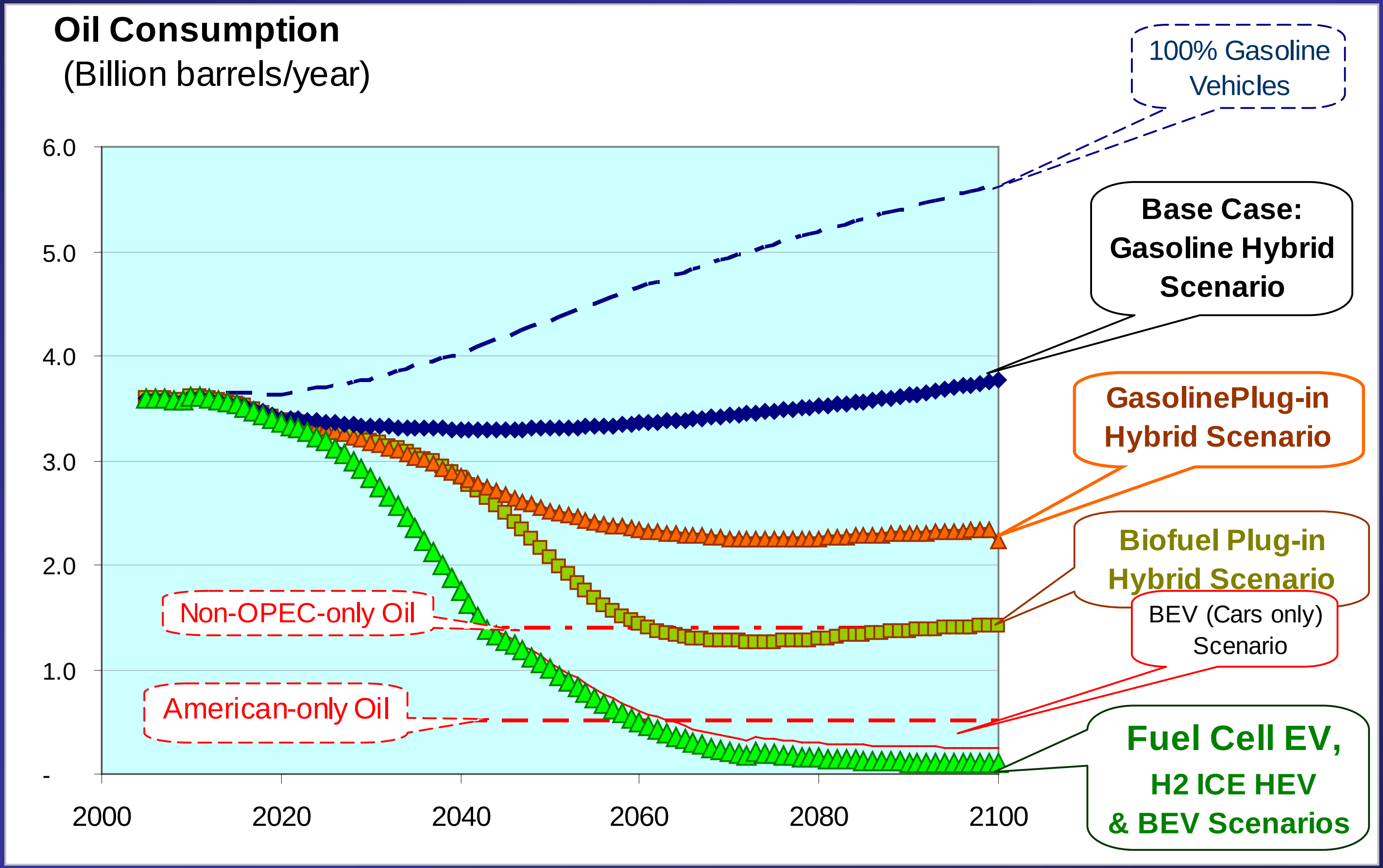
Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

GHG: Fuel Cell Electric Vehicle Scenario



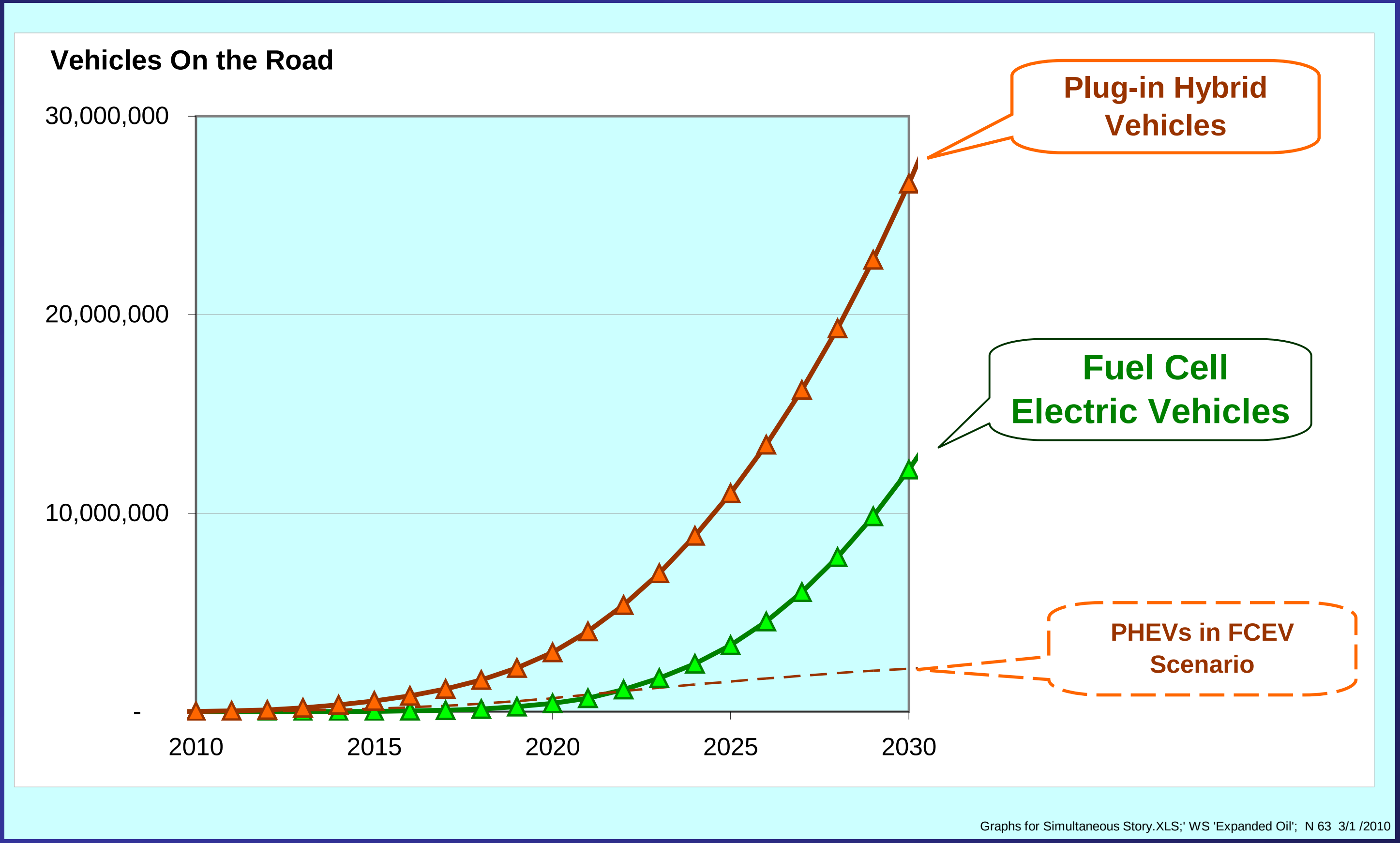
Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

Oil Consumption (US)

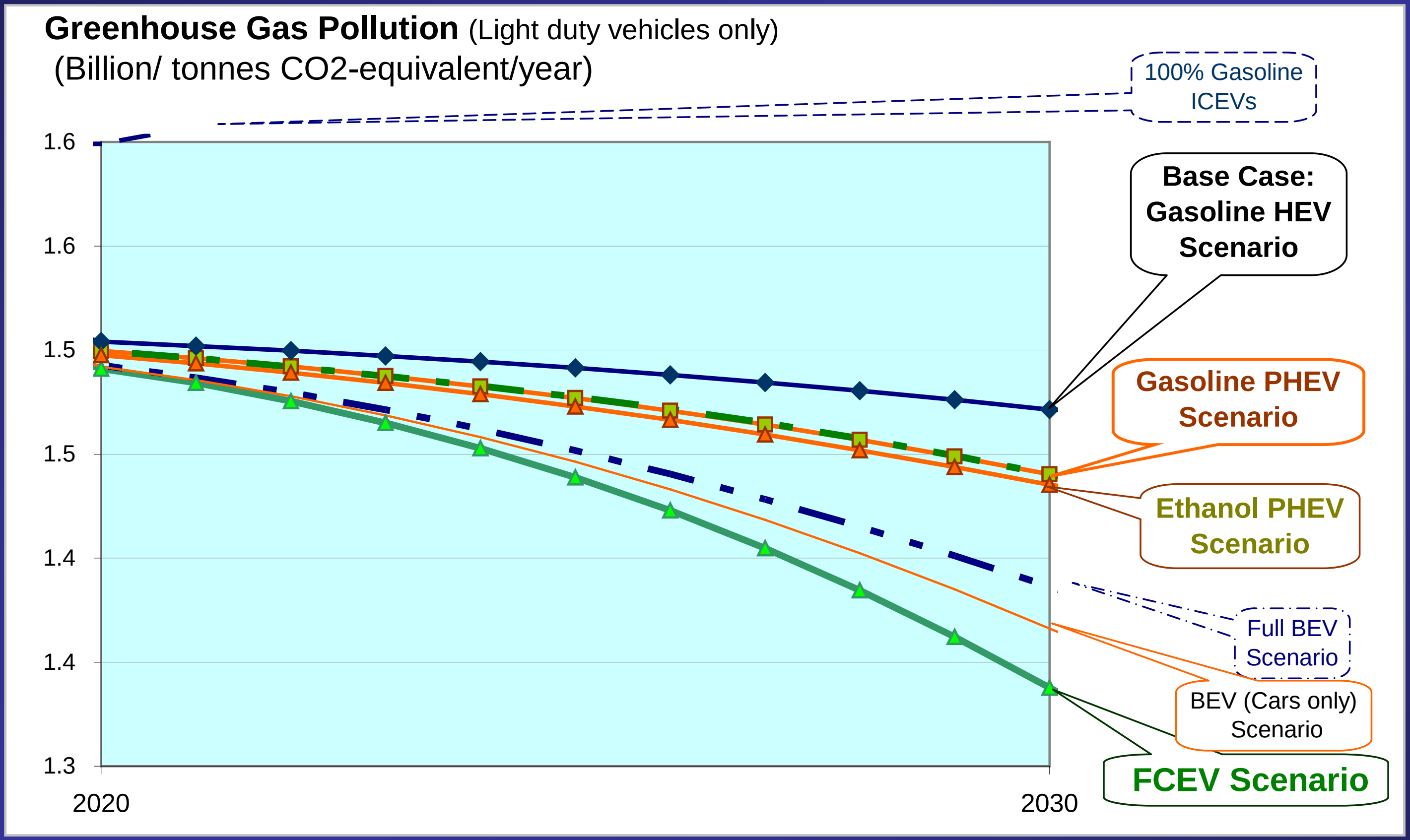


Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

PHEVs enter 5 years before FCEVs



Despite their earlier entry, PHEVs cut GHGs less than FCEVs by 2030



Story Simultaneous.XLS; Tab 'Graphs'; AD 346 7/20 /2010

PHEVs cut GHGs by 2% in 2030 compared to HEVs-only; While FCEVs cut GHGs by 8.8% relative to HEVs; or 4.3 times greater reduction in 2030

PHEV GHGs (Kromer & Heywood, MIT, May 2007)

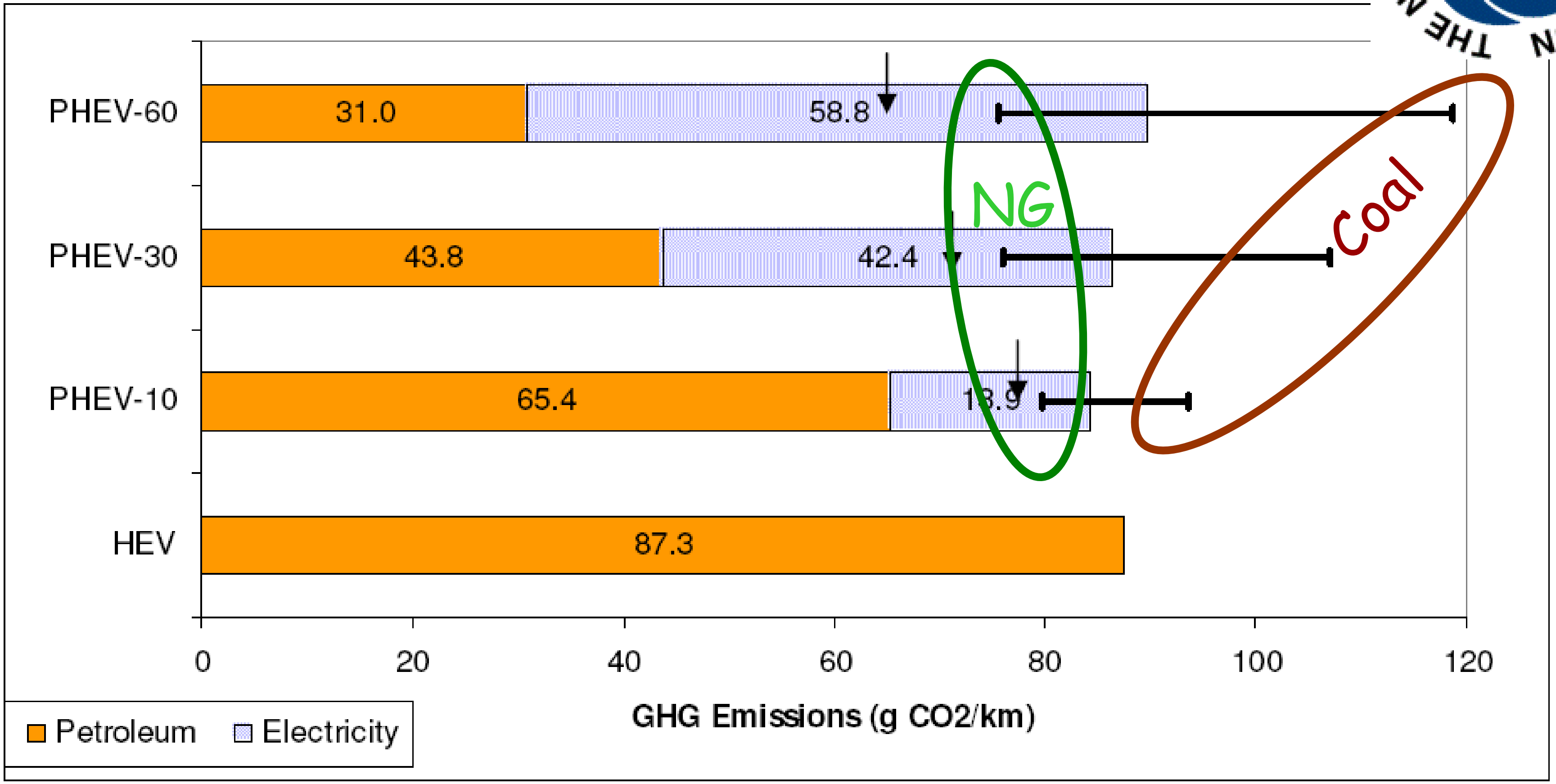
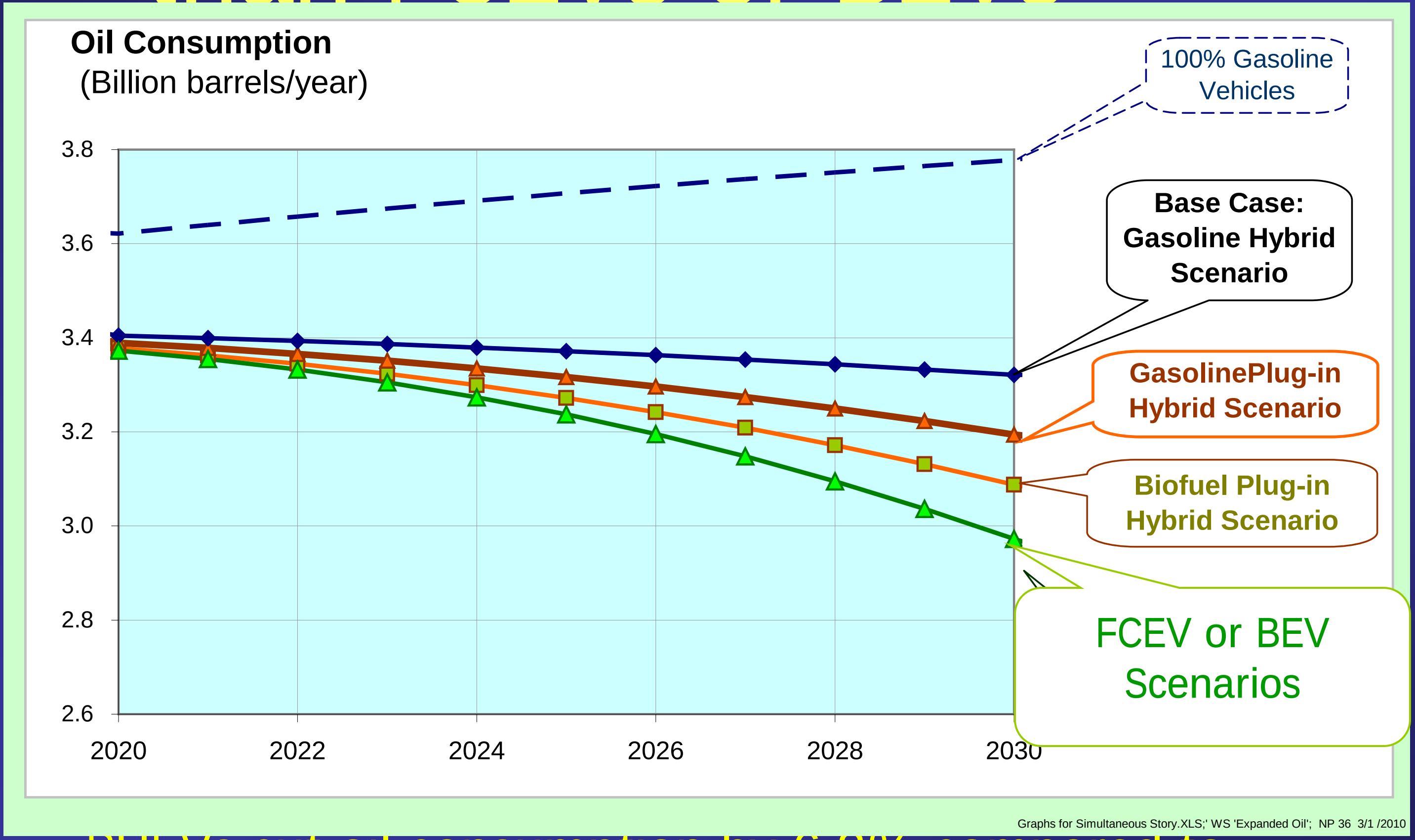


Figure 38: Breakdown of GHG emissions for the hybrid vehicle and plug-in hybrids with varying range. The low-end of the uncertainty bar corresponds to natural gas generation; the high-end corresponds to coal; and the base case corresponds to the average grid. The arrows indicate the emissions rate of the clean grid mix identified in section 5.7.4.

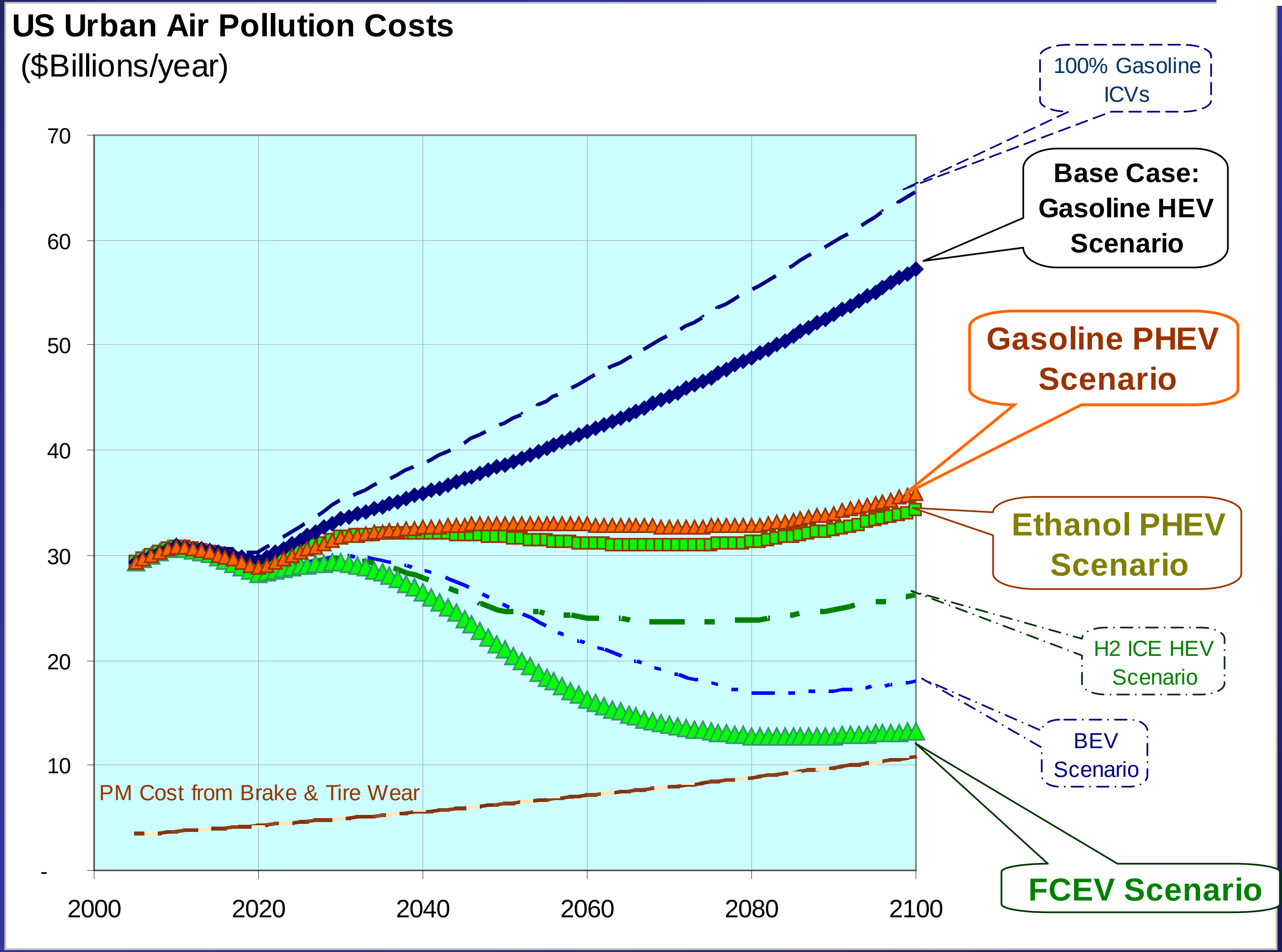
"Clean Grid" = 50% nuclear + renewables; 15% advanced NG CC & 35% advanced coal

Despite their earlier entry, PHEVs cut oil consumption less than FCEVs or BEVs



PHEVs cut oil consumption by 6.3% compared to HEVs-only, While FCEVs cut GHGs by 14.7% relative to HEVs; or 2.3 times greater reduction in 2030

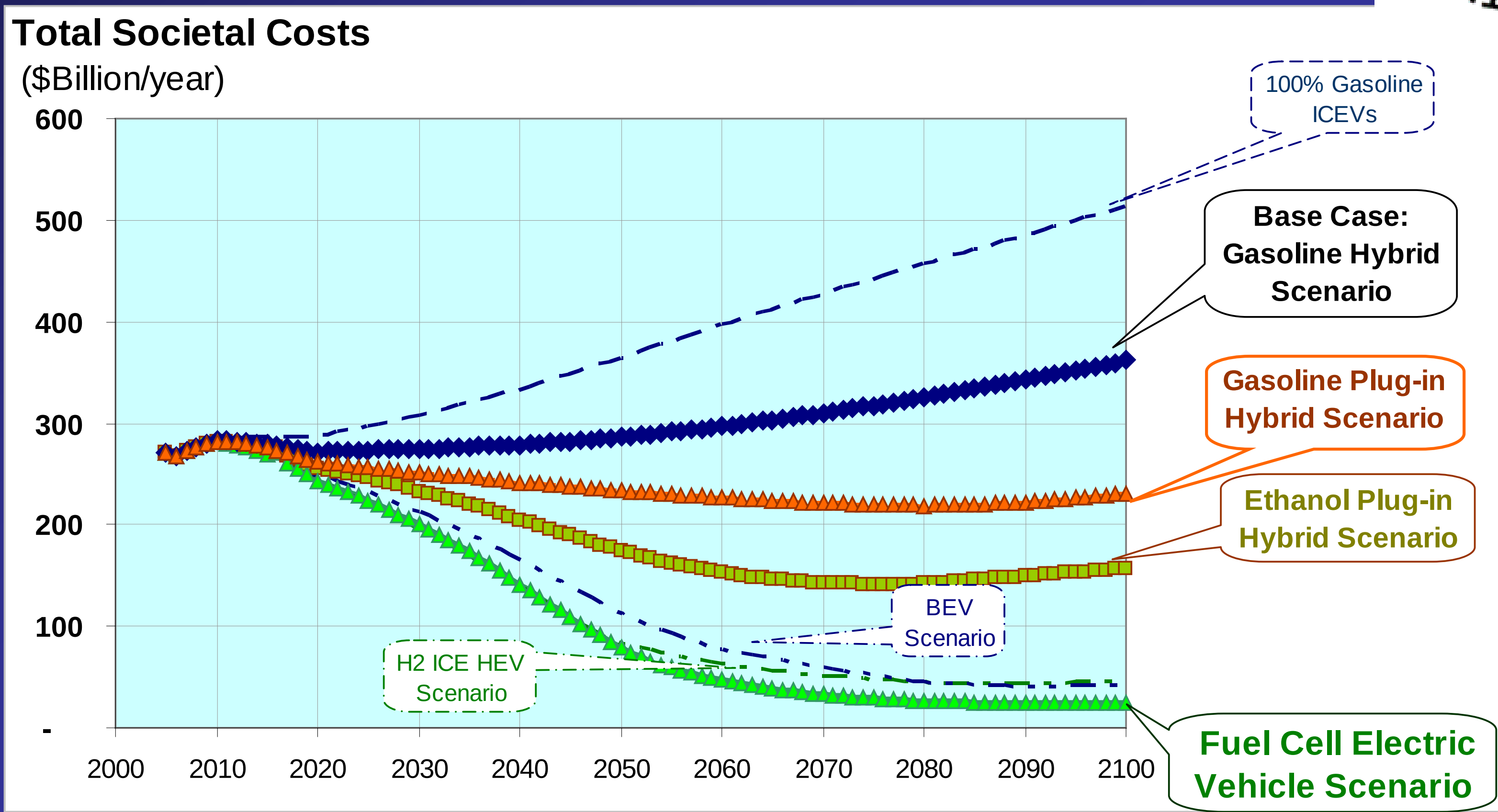
Urban Air Pollution Costs



Sources: Argonne National Laboratory GREET 1.8a, AEO 2009 & NHA models

Societal Costs

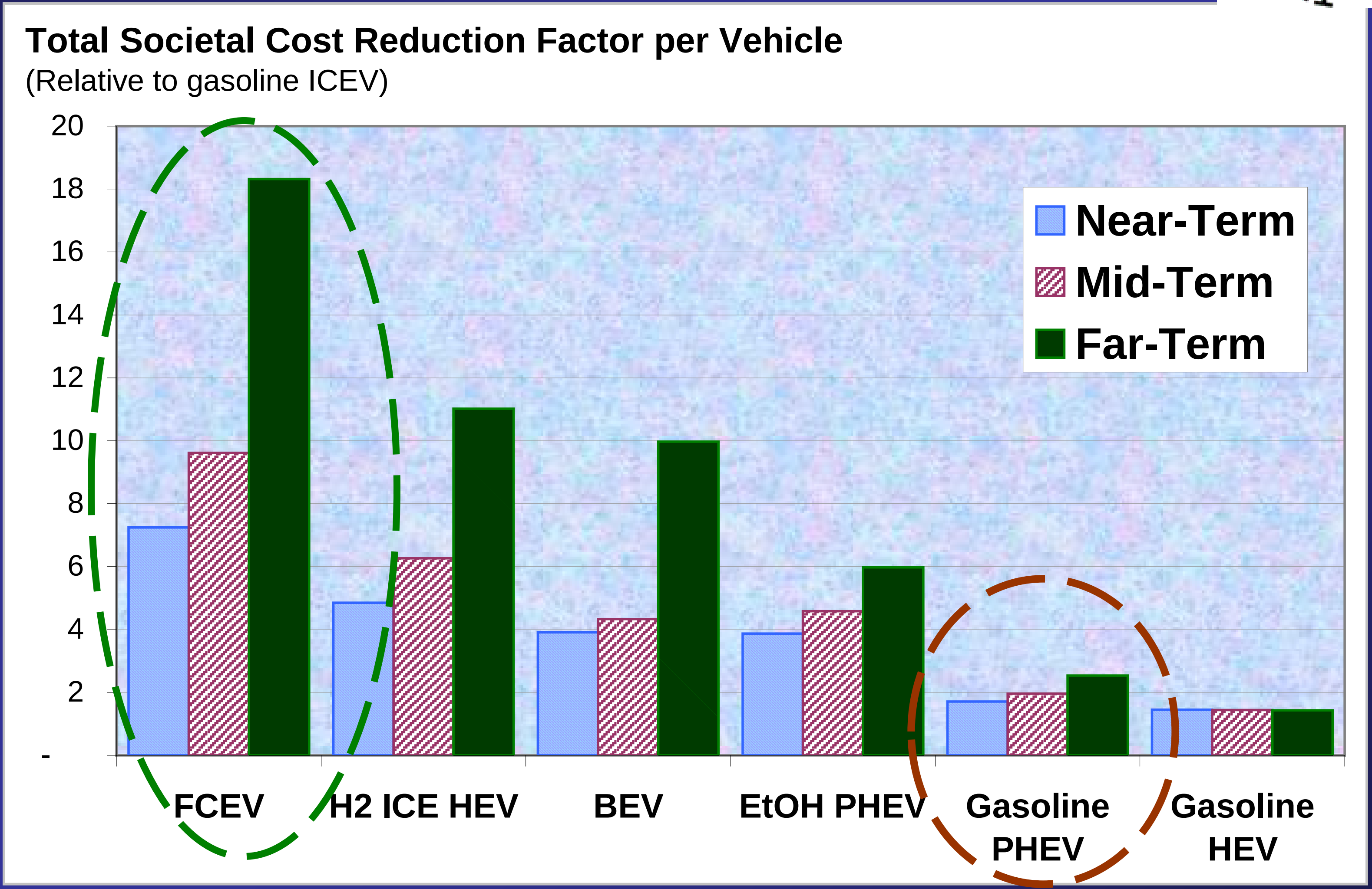
(of greenhouse gases, oil imports and urban air pollution)



	PM-10	PM-2.5	SOx	VOC	CO	NOx	CO2
Costs of Pollution:	**1,608**	**118,552**	**21,873**	**7,510**	**1,677**	**13,297**	**25 to 50**
($/metric tonne)		**Crude Oil Economic Cost**		**$60/bbl**		H2 Energy Story.XLS; Tab 'Annual Sales';FD 26 7/19 /2010	

(See Int. J. of hydrogen Energy, 34, 9274-9296, 2009).

Societal Cost Reduction Factors



Summary Greet 1.8a XLS; Tab 'Summary'; AG 200 3/14 /2009

Near-term = now to 2020; Mid-term = 2021 to 2050; Far-Term = 2051 to 2100

Primary Conclusion

- Achieving GHG and Oil reduction targets will require all-electric vehicles
- Three choices:
  - Battery EVs
  - Fuel Cell EVs

  Batteries AND Fuel Cells
- Next slides will compare:
  - Weight
  - Volume
  - Greenhouse Gases
  - Cost

Outline

- Main Results from 100-year simulation
  - Greenhouse Gas Emissions
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- Battery vs. Fuel Cell system comparison
- Capital investments (industry & Government) required for:
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- Government Incentives required for:
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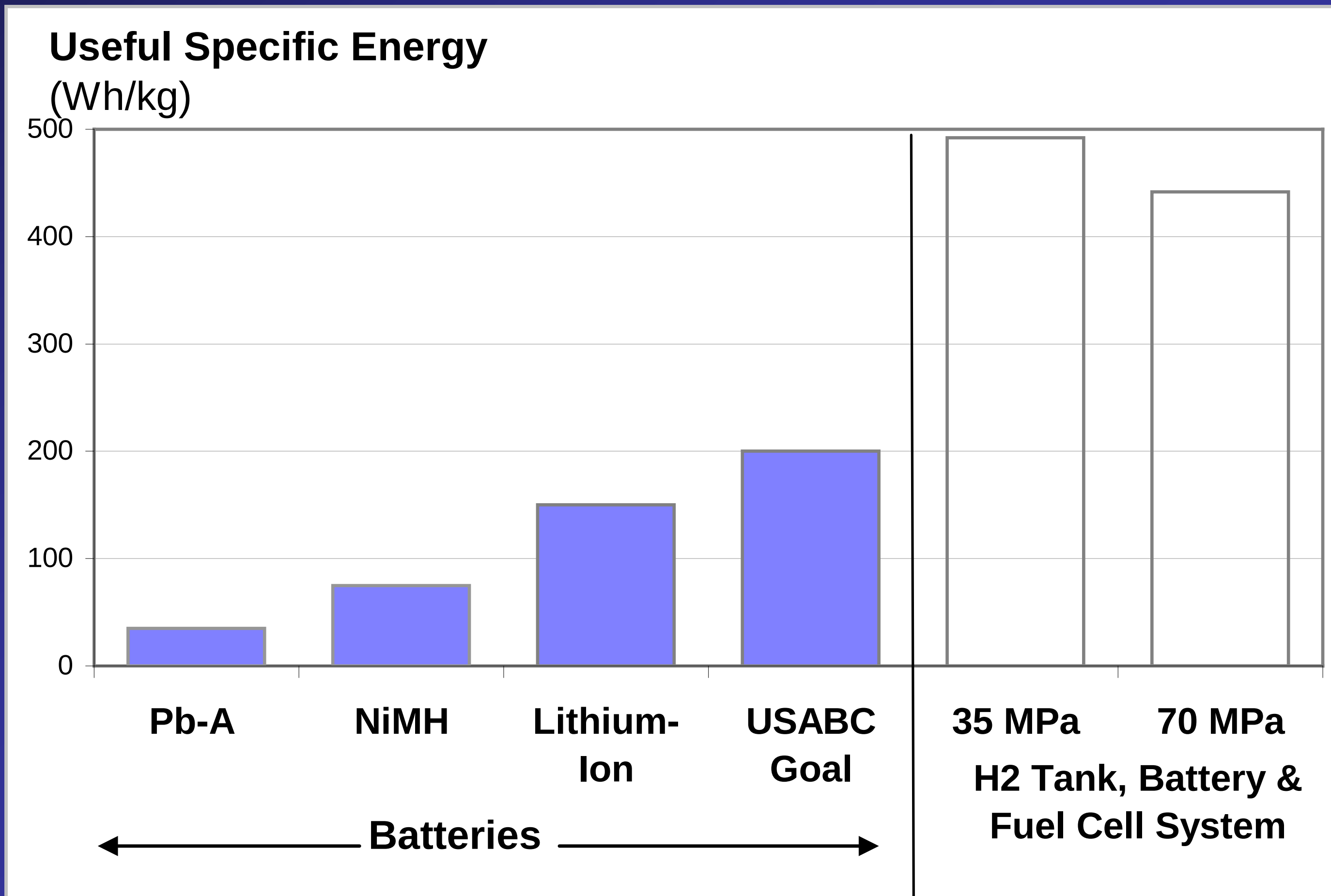
  - FCEVs
- Natural Gas Vehicle Comparisons

Specific Energy Comparison



H2Gen: Wt_Vol_Cost.XLS; Tab 'Battery'; S60 - 7 / 14 / 2010

Note: The Chevy Volt Li-ion battery has 44.1 kWh/kg of <u>useful</u> specific energy. (although PHEVs require much less energy than BEVs…see slide 35)

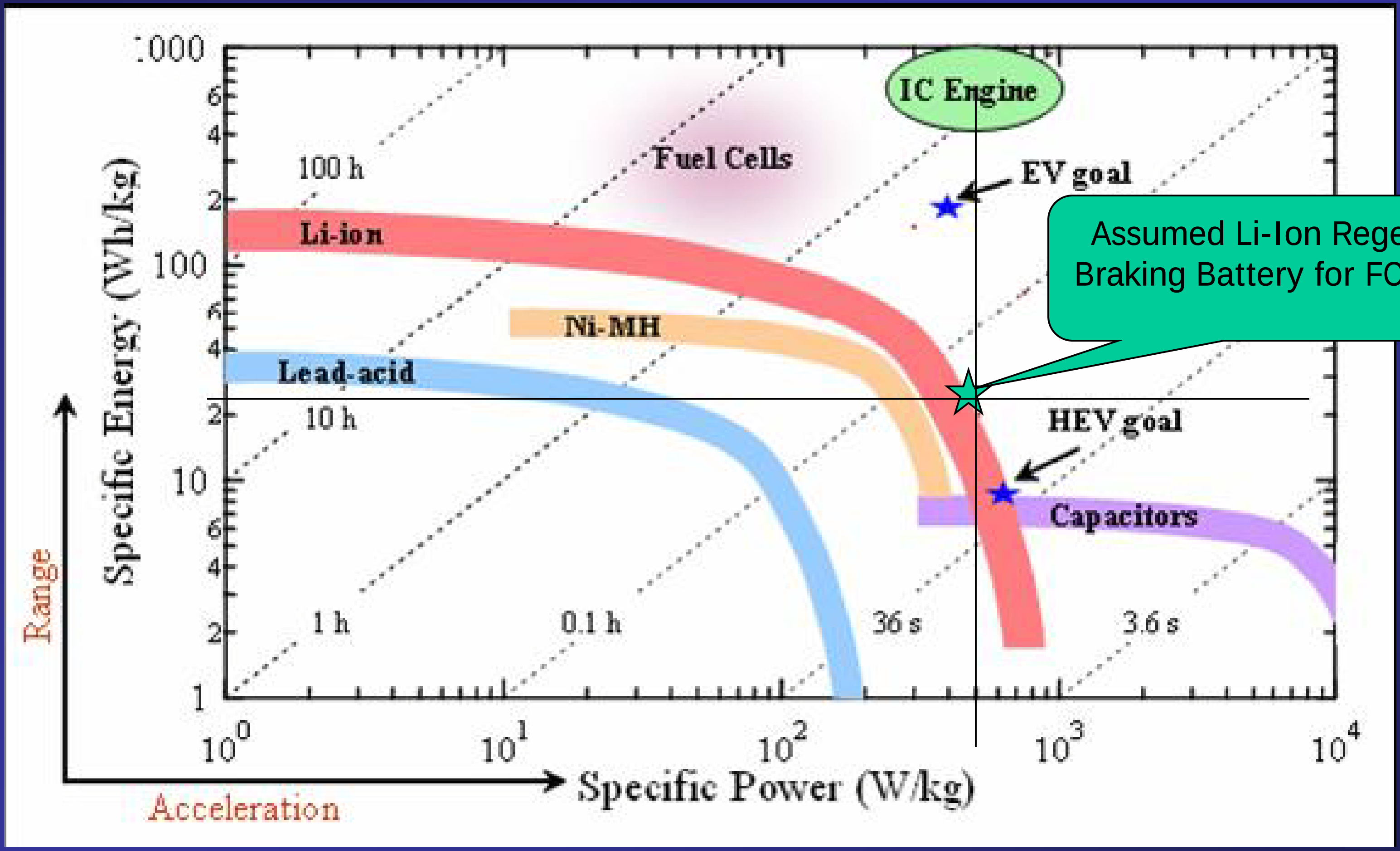
Vehicle & Battery Characteristics

Vehicle Characteristics						
Glider: Ford AIV (Aluminum Intensive Vehicle) Sable						
Curb Weight (kg)		1269				
Cross Section (m^2)		2.127				
Drag Coefficient		0.33				
Rolling Resistance		0.0092				
Acceleration		Seconds:	Power (kW):		FC	
	0 to 60 mph	10	77.9	→	59.6	kW
	5 to 20 mph	1.9	71.9		Battery	
	40 to 60 mph	7	76	→	18.3	kW
	55 to 65 mph	6	62.3			
Regen/Peak Power (Li-Ion) Battery Characteristics						
Specific Power (W/kg)		500	} (See Next Chart)			
Specific Energy (Wh/kg)		25				
Power Density (W/liter)		200				
RT Battery Efficiency		84.60%				
Energy Capacity (kWh)		0.917				
Useable Energy (kWh)		0.776				
Regen Braking Recovery		70%				
Regen Braking Energy (FUDS)		0.399	kWh			
Regen Braking Energy (HYWY))		0.107	kWh			
Fuel Cell System Characteristics			DOE 2015 Goals			
FC Specific Power (W/kg)		0.94	2.0			
FC Power Density (W/liter)		1.91	2.0			
FC Peak Power (kW)		59.6	80			

On 1.25X EPA combined cycle

Vehicles/Batteries/Battery & H2Tank Wt_Vol_Cost.XLS; Tab 'Spec shart'; G34 - 7 / 14 / 2010

Battery Power vs. Energy Trade-off



Ref: Kromer, Matthew & J.B. Heywood, "Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet," Sloan Automotive Laboratory, Massachusetts Institute of Technology, Publication Number LFEE 2007-03 RP, May 2007

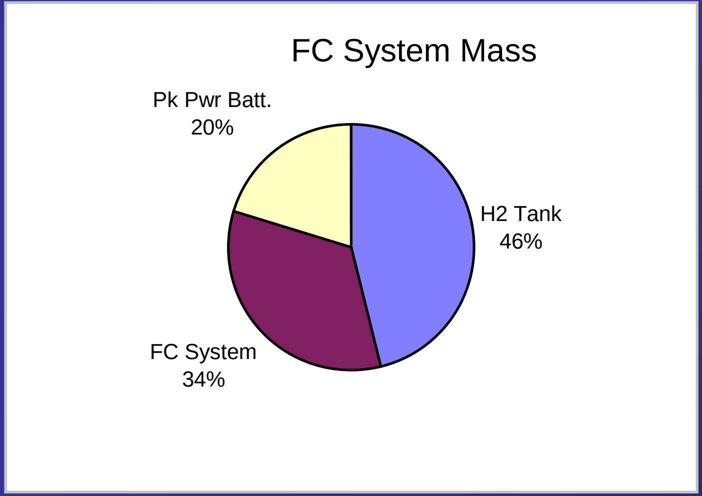
FC & H2 weight & volume

Stored Hydrogen (kg)	5.13	for 350 miles range
H2 Energy (kWh)	170.90	
Average FC Eff. Over cycle	54%	(1.25X accelerated EPA Combined Cycle)
FC output Energy (kWh)	92.3	

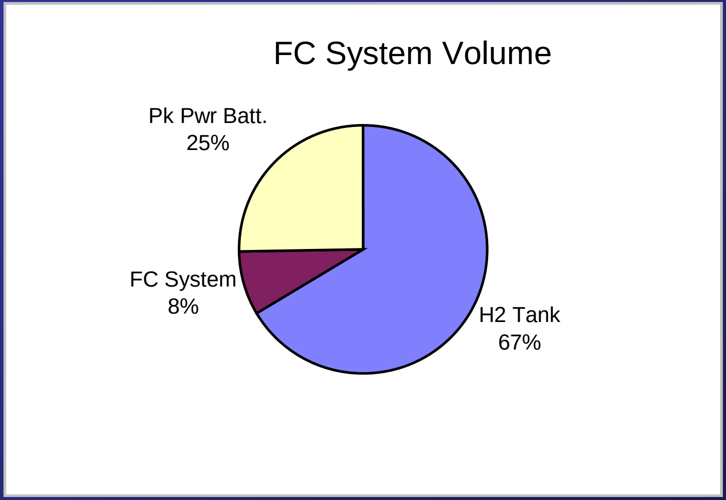
System Attributes

H2 Storage			FC System		Regen Battery		Total	Total	Energy	Specific
Volume	Wgt	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Density	Energy
liters	%	kg	liters	kg	liters	kg	liters	kg	Wh/l	Wh/kg
248.5	5.94%	86.2	31.2	63.4	94.43	37.77	374.2	187.4	246.6	492.5
162.4	4.76%	107.7	31.2	63.4	94.43	37.77	288.1	208.9	320.4	441.8

Vehicles/Batteries/Battery & H2Tank Wt_Vol_Cost.XLS; Tab 'H2 Stroage'; X20 - 7 / 15 / 2010



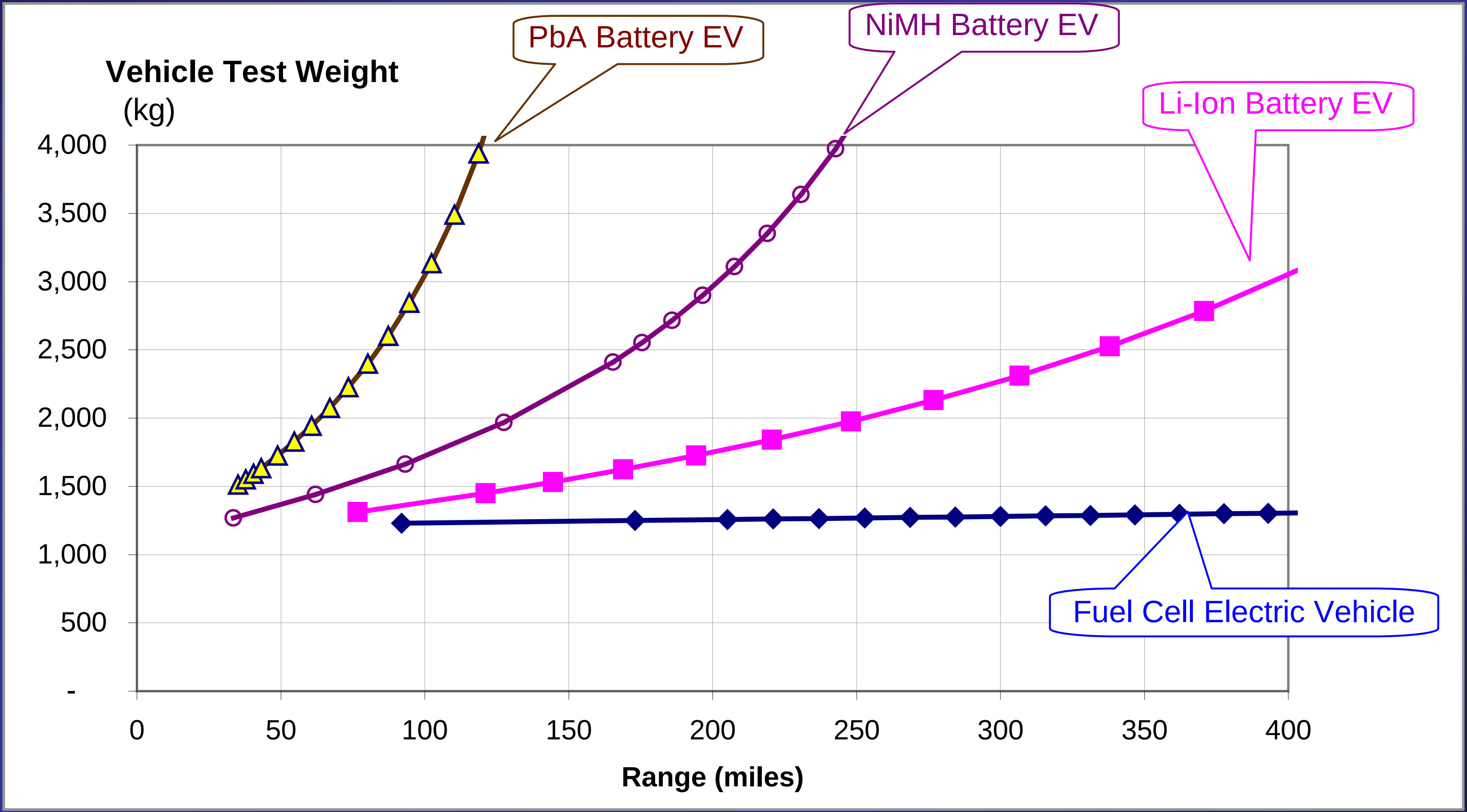
Vehicles/Batteries/Battery & H2Tank Wt_Vol_Cost.XLS; Tab 'H2 Stroage'; AD83 - 7 / 14 / 2010



Vehicles/Batteries/Battery & H2Tank Wt_Vol_Cost.XLS; Tab 'H2 Stroage'; AD66 - 7 / 14 / 2010

Batteries Weigh More than Fuel Cells

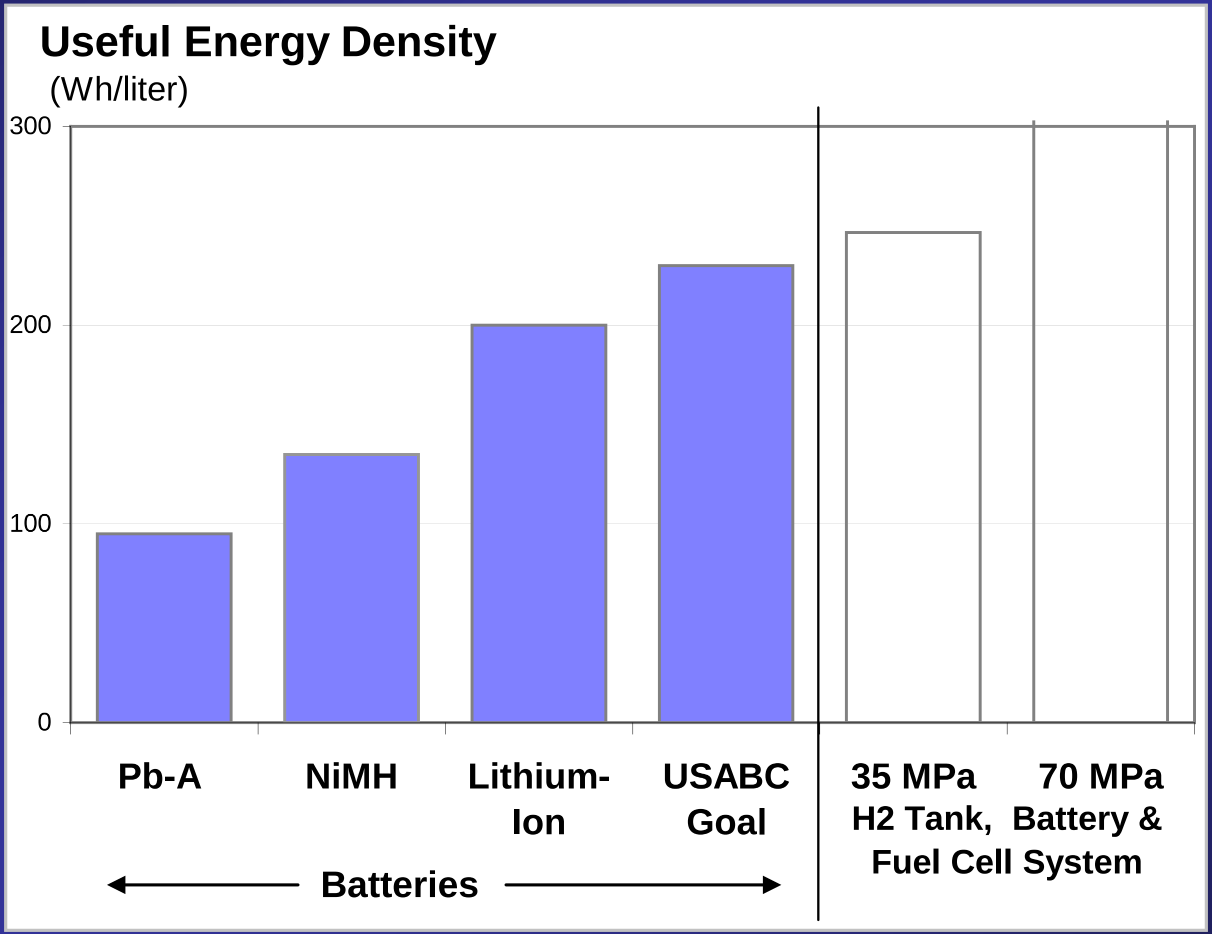
(Effects of mass compounding, equal performance)



BPEV.XLS; 'Compound' AF142 3/14 /2009

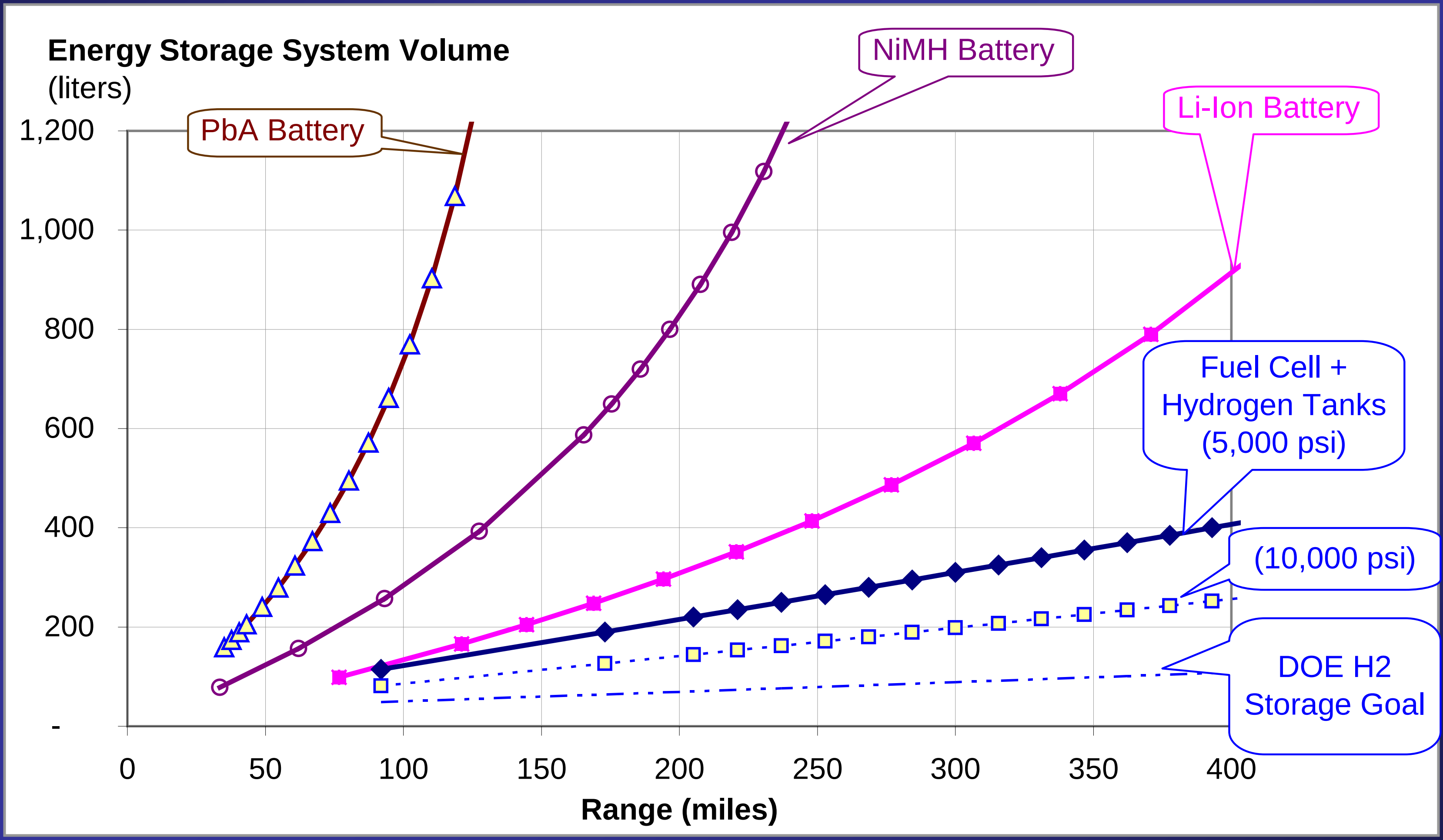
Structural weight addition: 15%

Useful Energy Density



Battery & H2 Tank Wt_Vol_Cost.XLS; Tab 'Battery'; S36 - 7 / 15 / 2010

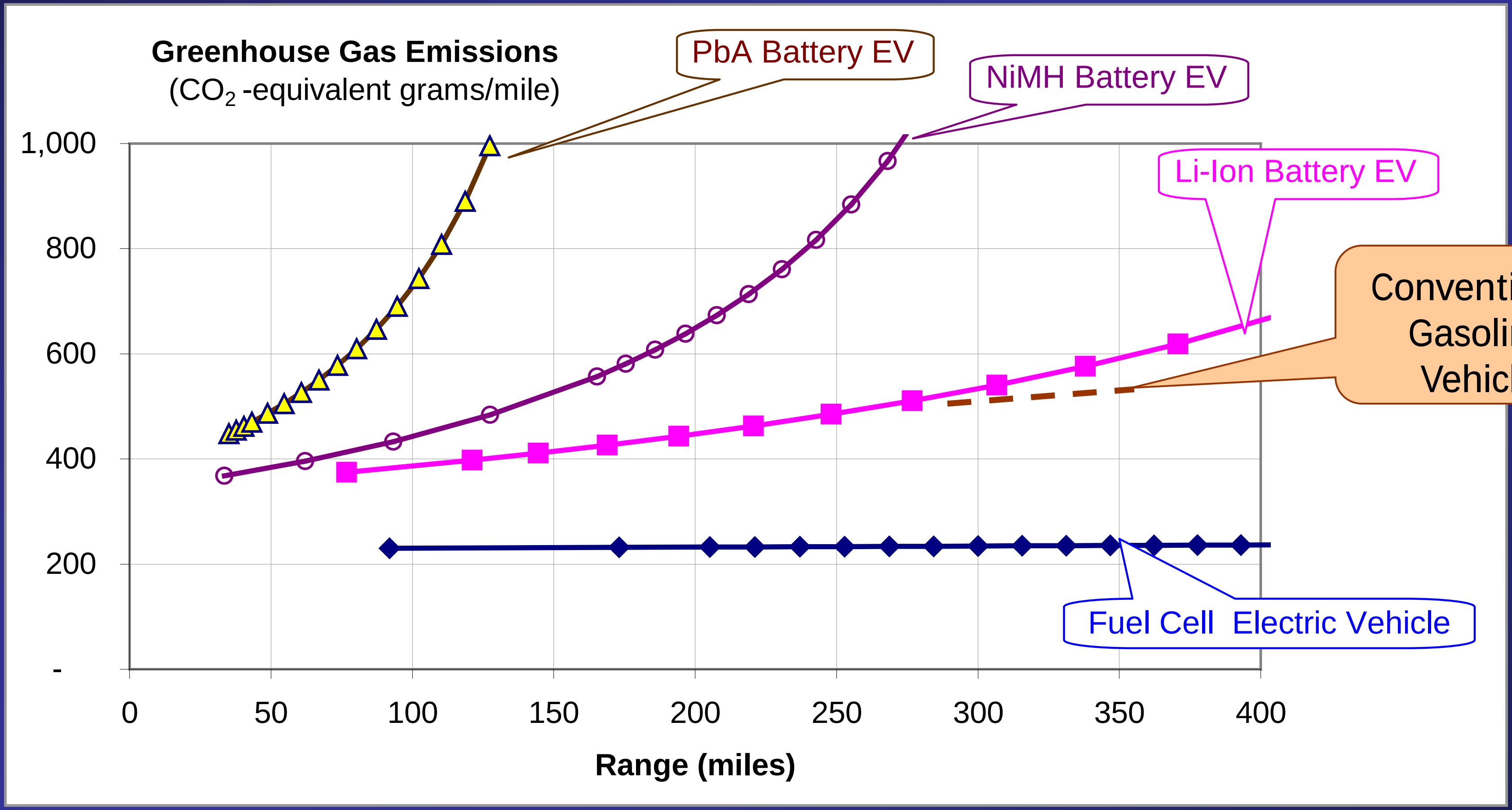
Batteries also take up more space:



DOE Storage Goal: 2.7 kWh/Liter

BPEV.XLS; 'Compound' AF114 3/14 /2009

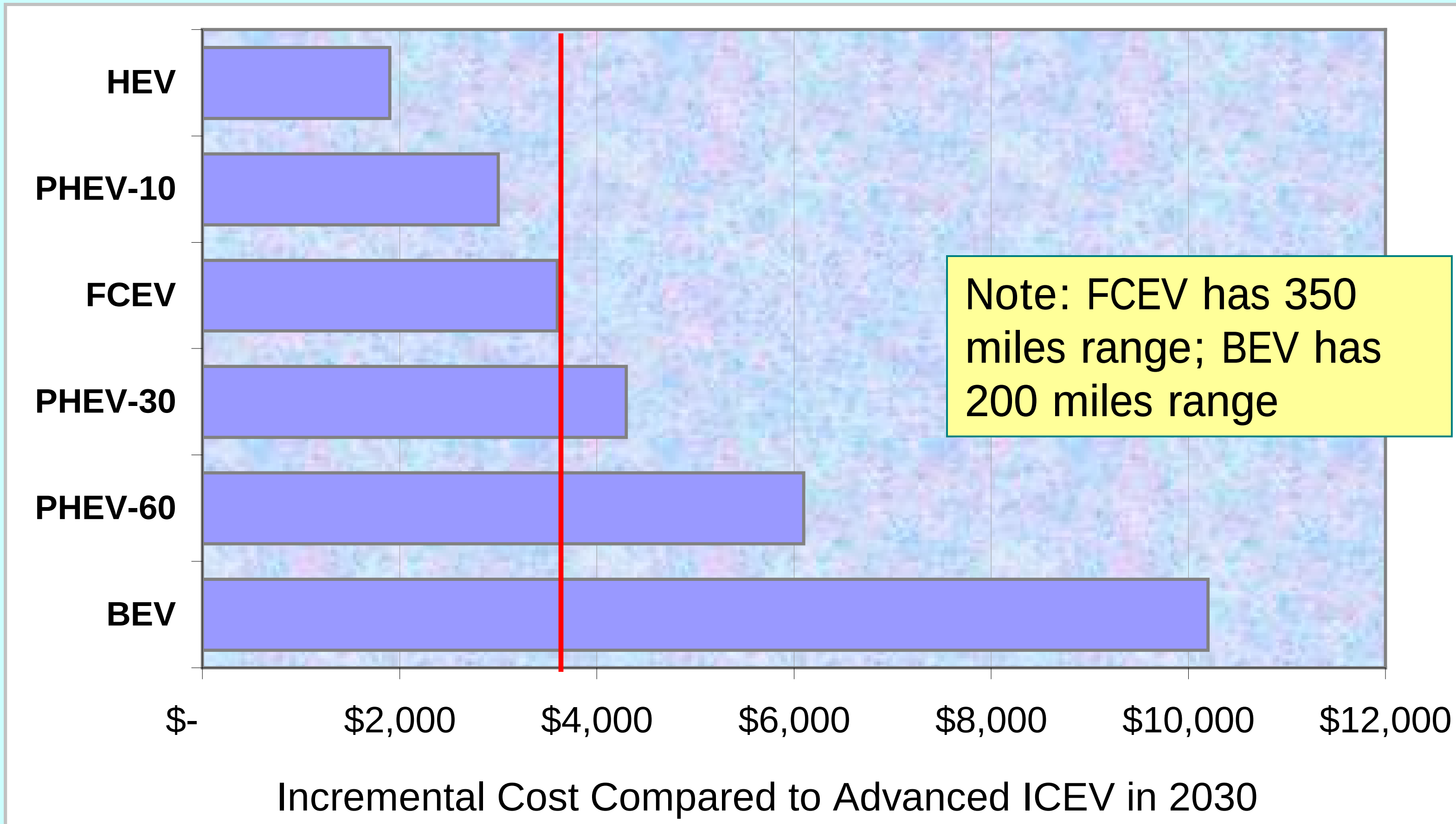
BEVs will initially have more Greenhouse Gases than FCEVs*



H2Gen: BPEV.XLS; WS 'Compound' AF169 3/14 /2009

*Assumes hydrogen made on-site from natural gas, and average marginal US electrical grid mix for charging EV batteries in 2020

...and BEVs are projected to cost more than FCEVs by MIT (2030)



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 3/15 /2009

Comparison of MIT Cost Assumptions & Old DOE Goals*

			DOE	DTI	DOE	MIT
			2010	2015	2015	2030
Fuel Cell System Cost		$/kW	45	39.45	30	50
Hydrogen Storage Cost		$/kWh	4	15	2	15
Hydrogen Storage Density		kWh/L	0.9	0.8	1.3	0.8

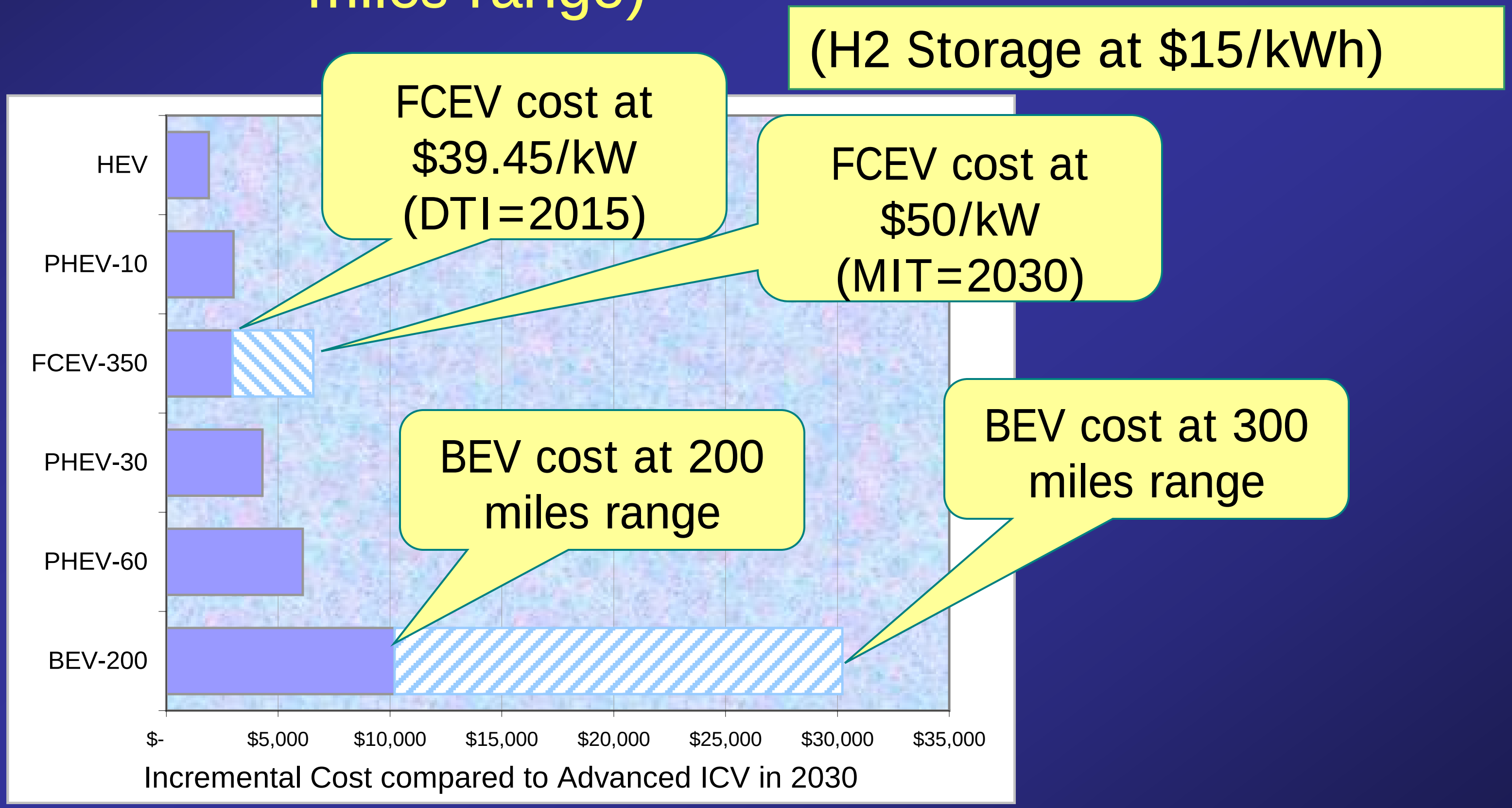
Story Simultaneous.XLS; Tab 'AFV Cost'; E 36 7/20 /2010

If the 2015 DOE goals were met, then the incremental cost for fuel cell electric vehicles would decrease from $3,600 estimated by MIT down to $840.

DTI estimates $39.45/kW using 2015 technology in mass production →

*DOE cost targets are currently being revised

AFV incremental cost estimates for 300 miles range (FCEV still at 350 miles range)



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Story Economics.XLS; Tab 'Vehicle Cost Deltas'; M 81 7/20 /2010

Incremental cost of a FCEV-350 is slightly less than that of a PHEV-10 with the new DTI FC system cost estimate ($2,967/kW vs $3,000/kW!!)

Fueling Time Analogy

- Pumping 14 gallons of gasoline in 3 minutes is equivalent to 10 Megawatts of power
- The average hydrogen power flow in more than 14,000 FCEV fueling events monitored by NREL was 1.61 MW
- A home 120V/20A circuit has a maximum power rating of 1.9 kW, which is 5,200 times slower than pumping gasoline and 850 times slower than pumping hydrogen

Ratio of Fueling Powers

			Fuel Power Flow (kW)	Ratio Gasoline to alternatives	Ratio Hydrogen to Alternatives
Gasoline	10	MW	10000		
H2	1.61	MW	1610	6	1
120V/20A circuit		kW	1.9	5,263	847
240V/40A circuit		kW	7.7	1,299	209

Graphs for Simultaneous Story.XLS;' WS 'Fuel Savings'; BV 62 3/1 /2010

Conclusion: it is easier, faster and more efficient to transfer molecules of gasoline or molecules of hydrogen than to move electrons though wires and terminals with finite resistance

Fuel Cell Advantages over Batteries:

- Less weight (56%)*
- Less space in vehicle (56%)*

  } Longer Range

- Lower greenhouse gases** (44%)
- A FCEV with 350 miles range has lower estimated mass production cost [$6,600 (MIT) to $7,380 (DTI)] than a BEV with 200 miles range.
- Shorter refuel time

*at 300 miles range

**for average marginal US grid mix

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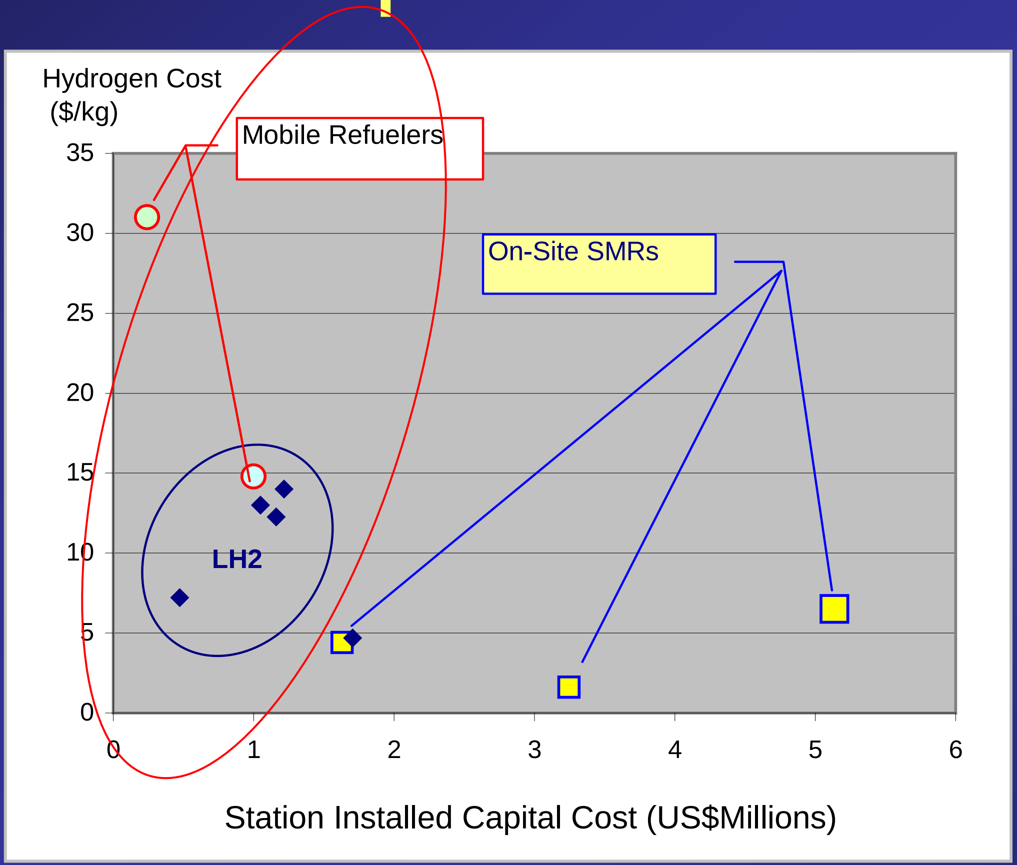
Previous Hydrogen Infrastructure Cost Estimates

- 2008 NRC Report: $8 billion (assuming that the government pays 100% of the distributed hydrogen infrastructure cost)
- This model: assume that industry pays for 70% of infrastructure, making a reasonable* return on investment by selling hydrogen.
- Initial Government investments reduced by assuming low-cost mobile refuelers and liquid hydrogen stations instead of on-site reformers or electrolyzers (see next slide) ⟶

*Required hurdle rate IRR starts at 25%, dropping to 20% and then 15% as risk is reduced over time.

Hydrogen Cost vs. Station Capital Cost

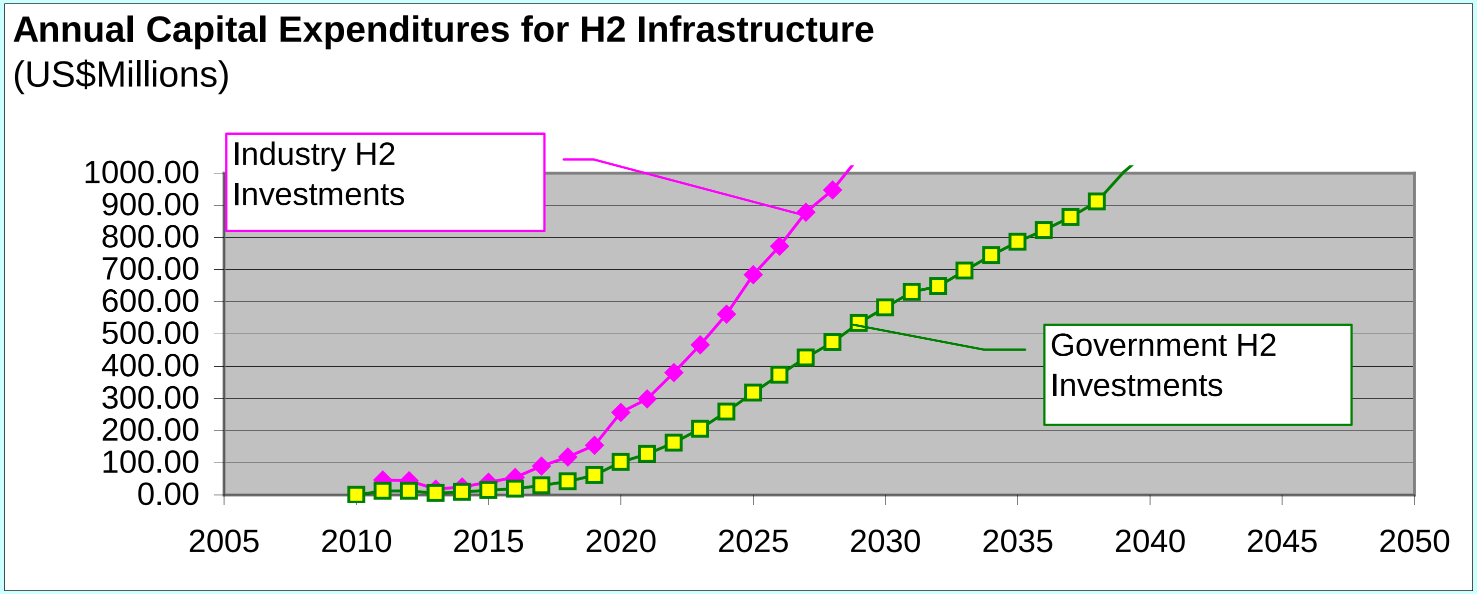


Install Mobile Refuelers and liquid hydrogen stations to minimize initial capital investments

Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; F 27 4/26 /2010

Sources: JX Weinert & TE Lipman, Institute for Transportation Studies (2006), U of California at Davis, USDOE's H2A Model, & SFA Pacific

Hydrogen Infrastructure Investments

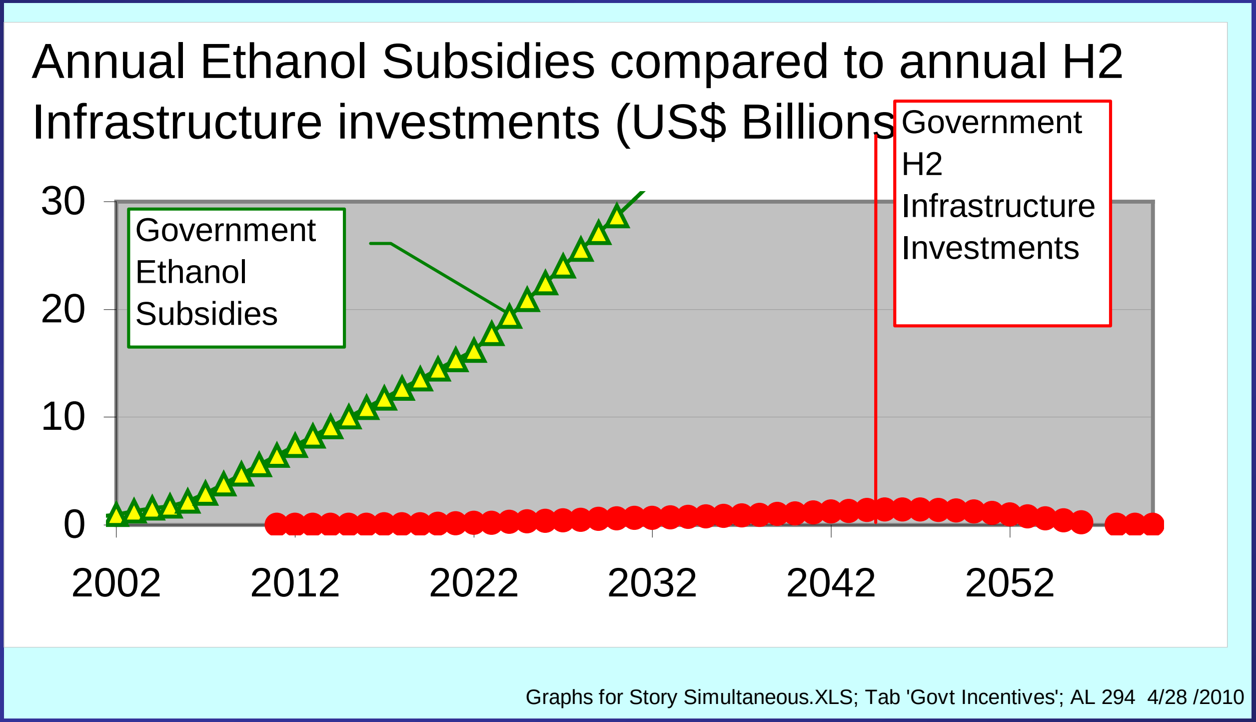


		NPV @10% Discount:		
Total Government H2 Investments	29,313.0	$	2,124.1	Million
Total IndustryH2 Investments	51,623.03	$	4,150.8	Million
Total H2 Investments	80,936.04			

Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; AS 214 5/4 /2010

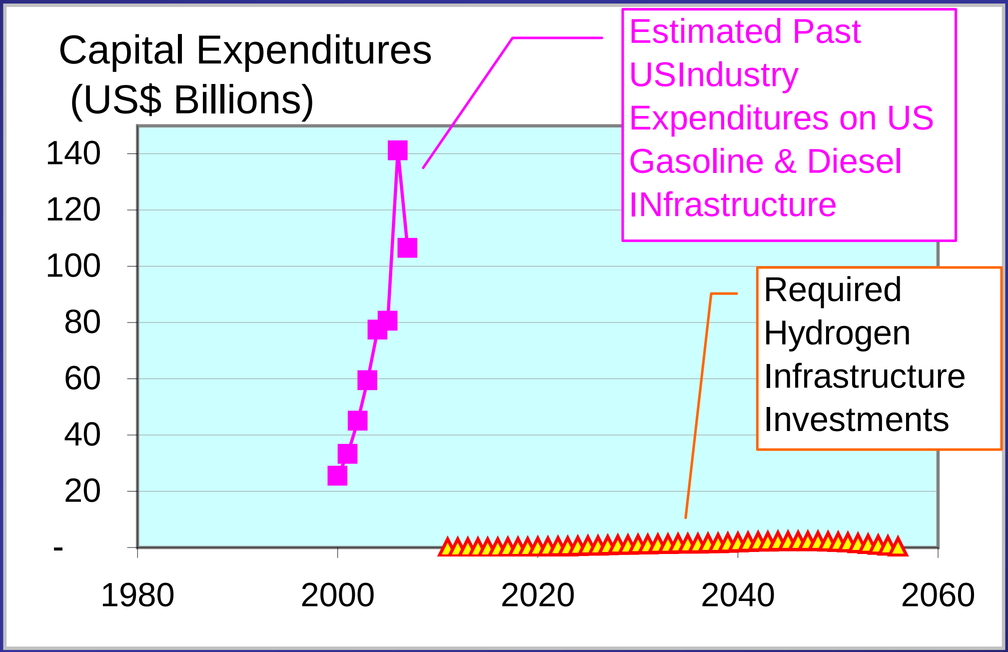
Total Government investment of $29 Billion through 2056 (10% NPV of $2.1 Billion) compared to $8Billion by NRC though 2024 ($1.06 Billion in this model through 2024)

US Government Subsidies for Ethanol vs Required Hydrogen infrastructure investments



US Ethanol target is 36 billion gallons by 2022, or $16 Billion/year at 45 cents/gal (vs 51 cents/gallon now) [Maximum Govt. H2 investment is $1.4 Billion/year]

Industry annual Investments small compared to existing US gasoline & Diesel infrastructure annual expenditures



Story Economics.XLS; Tab 'Web Graphs'; AB 314 7/19 /2010

(Source for gasoline & Diesel infrastructure costs: Oil & Gas Journal) [Maximum Government H2 Investment is $2.4 Billion/year in 2048]

Outline

- Main Results from 100-year simulation
  - Greenhouse Gas Emissions
  - Oil consumption
- Battery vs. Fuel Cell system comparison
- Capital investments (industry & Government) required for:
  - Hydrogen infrastructure
  - Electrical charging infrastructure
- Government Incentives required for:
  - BEVs
  - FCEVs
- Natural Gas Vehicle Comparisons

Public Charging Infrastructure

- The Electrification Coalition recommends:
  - Two public outlets for each BEV initially
  - Decreasing to one public outlet for every two BEVs over time.

Source: The Electrification Coalition Roadmap
http://www.electrificationcoalition.org/

Members of the Electrification Coalition

- AeroVironment
- GridPoint
- NRG Energy
- Coda Automotive
- PG&E
- Rockwood Holdings
- Nissan
- Kleiner Perkins Caufield Byers
- Coulomb Technologies
- Johnson Controls
- Bright Automotive
- FedEx
- A123 Systems

Ref: The Electrification Coalition Roadmap
http://www.electrificationcoalition.org/

BEV outlet Cost Estimates

	Electricfication Coalition	Idaho National Laboratory	Coulomb Technologies
Type I residential 120-Volt EVSE		$833 to $878	
Type 2 Residential 220-Volt EVSE	$500 to $2,500	$1,520 to $2,146	
Type 2 Public 220-Volt EVSE	$2,000 to $3,000	$1,853	$ 8,043
Type 3 public fast charger	$15,000 to $50,000		

Story Economics=lite-mobile &42:42LH2.XLS; Tab 'EV Cost Graphs'; G 42 7/19 /2010

Electrification Coalition Roadmap request for government funding: $120 billion over 8 years or $15 billion per year to install public charging stations

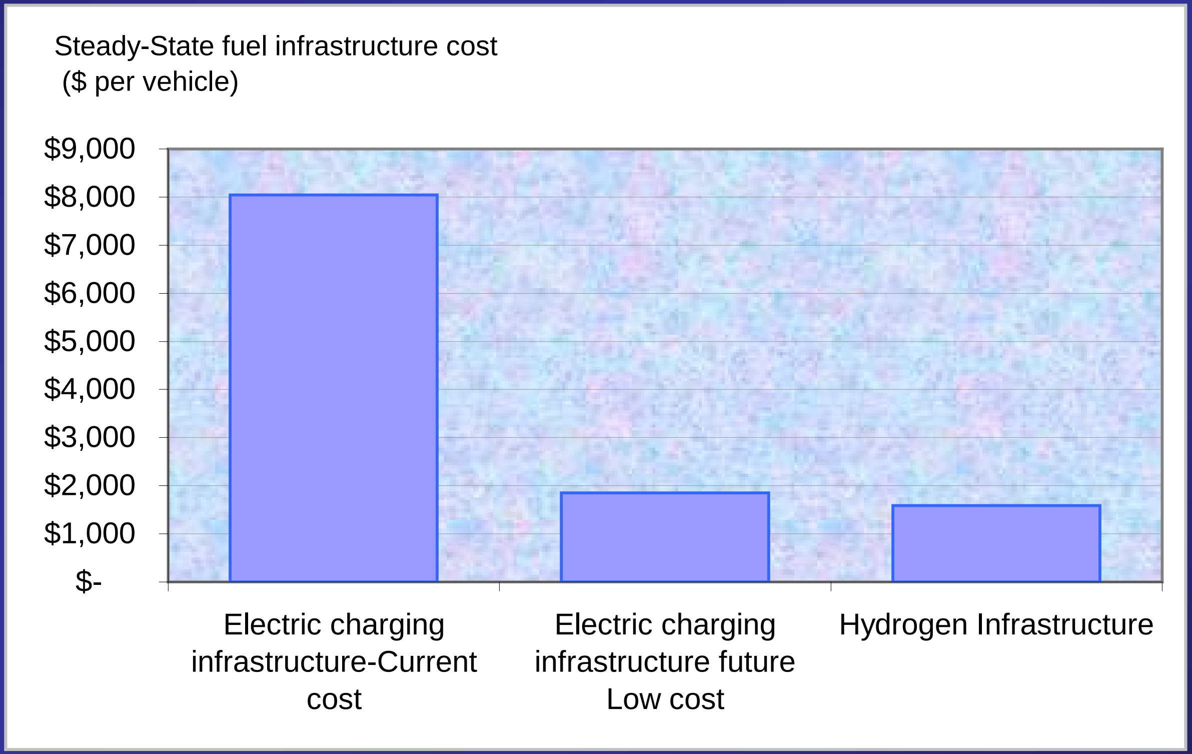
(Coulomb Technologies estimate based on installing 4,600 “Free” Type 2 public outlets for $37 million)

Quick Steady-State per vehicle infrastructure Cost estimates:

- Electrical charging outlets (one outlet required for each PHEV or BEV with 6 to 8 hour charging times, or $1,853 to $8,043 per BEV.
- Hydrogen fueling stations:
- According to the DOE's H2A model, a 1,500 kg/day on-site SMR system will cost approximately $3.2 million.
  - But each station can support approximately 2,013 FCEVs* or an average cost of $1,391 per FCEV.

* Assuming 13,000 miles/year; 68.3 miles/kg & 70% average SMR station capacity factor

Steady-State (mature market) fuel infrastructure cost per vehicle



Story Economics=lite-mobile &42:42LH2.XLS; Tab 'EV Cost Graphs'; G 75 7/19 /2010

Transition costs

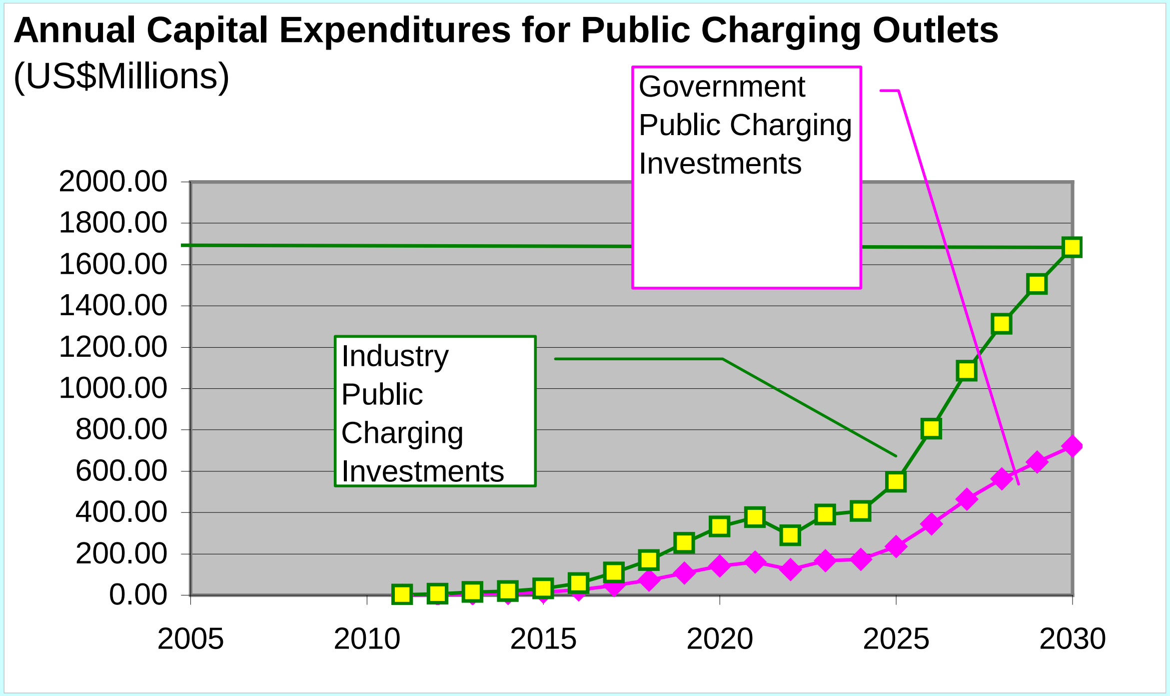
- Eventual fuel infrastructure cost per vehicle favors on-site hydrogen production, but what about the transition?
- What are the investment costs to get from here to there?

Electric charging infrastructure

- We assume that the same electrical outlet financial characteristics as for the hydrogen infrastructure:
  - Governments pay 30% of the installation costs
  - Industry pays 70% and borrows at 8% interest and makes an adequate ROI selling electricity* to PHEV and BEV owners.

*Technically private industry cannot “sell” electricity, so they would have to charge a fee to provide the charging infrastructure.

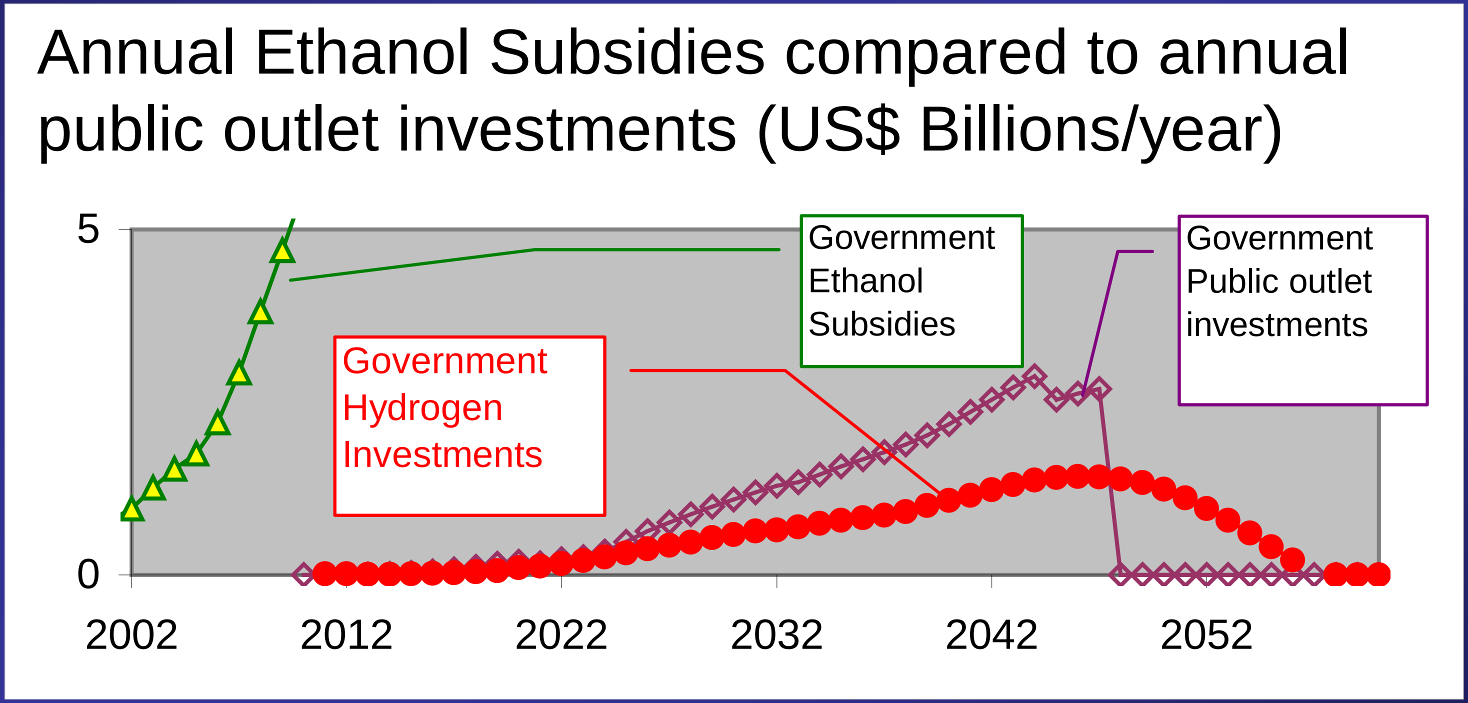
Public charging station investments required to meet Electrification Coalition goals



	(US$ Billions)			NPV (10%)
Total Industry Public Charging Investments	$	107	Billion	6.21
Total Government Public Charging Investments	$	42	Billion	$2.60
Total Public Charging Investments	$	148	Billion	8.81

Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; AG 171 4/27 /2010

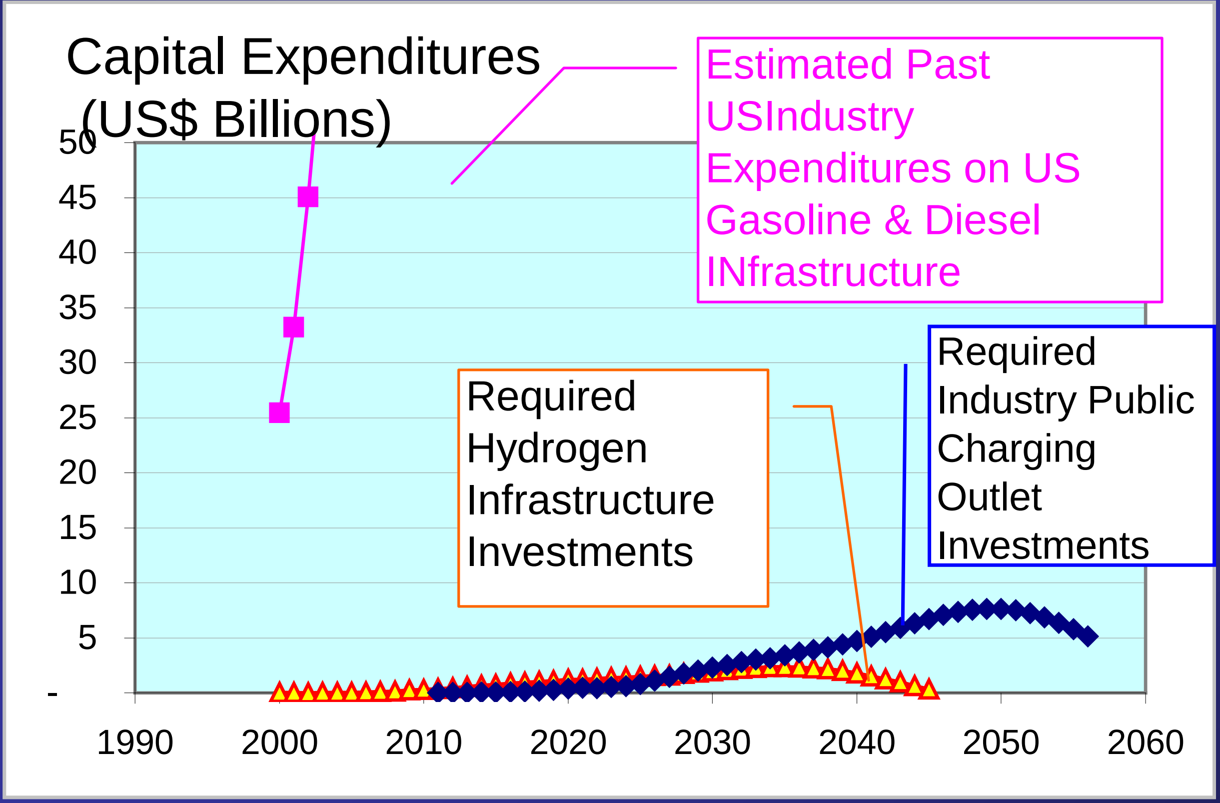
Government incentives compared to projected Ethanol subsidies



Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; AL 256 7/19 /2010

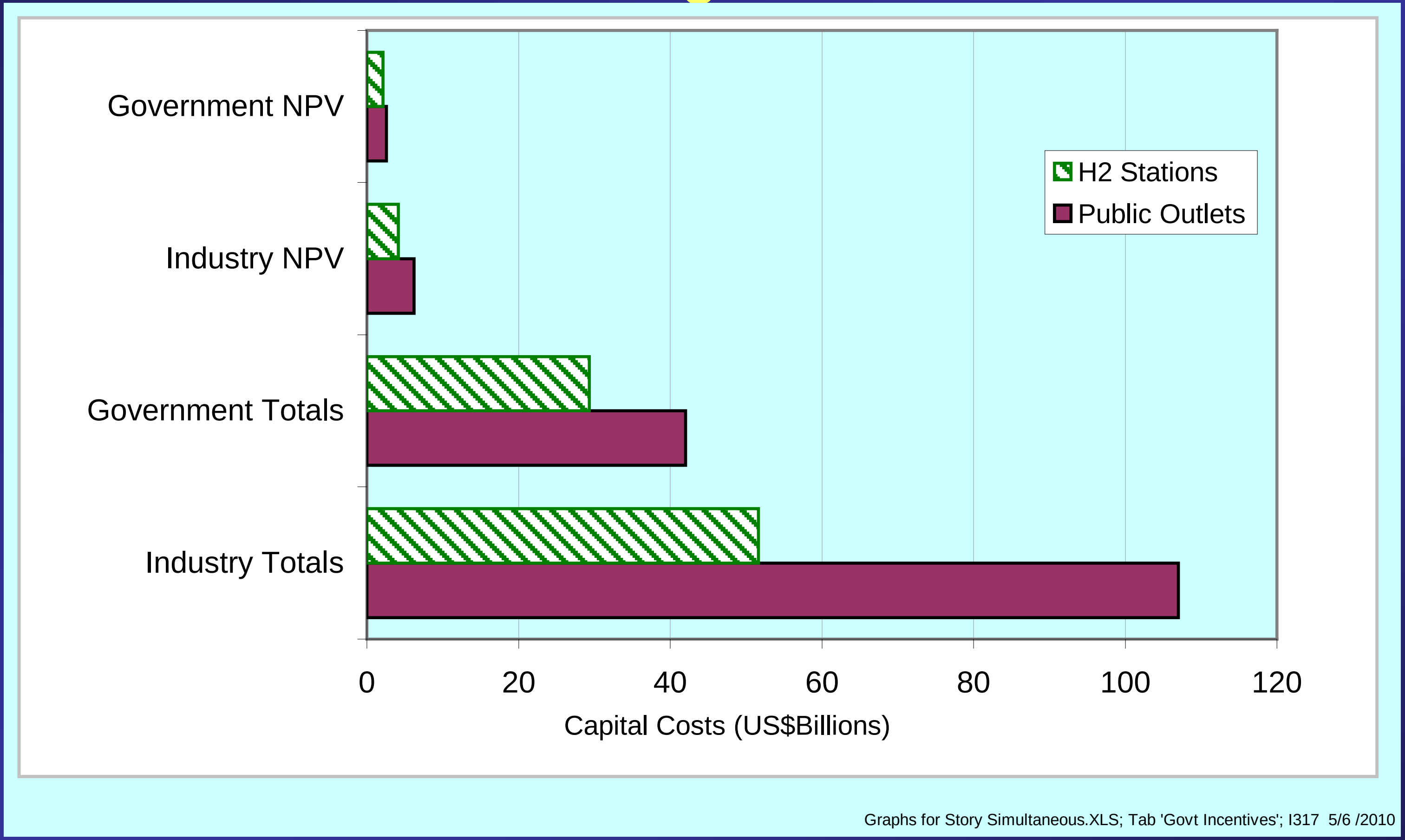
Ethanol goal: 36 billion gallons by 2022 X 45 cents/gal = $16.2 billion/year

Industry Public Charging Station Annual Investments compared to past gasoline & Diesel Infrastructure annual investments



Story Economics.XLS; Tab 'Web Graphs'; AB 336 5/9 /2010

Summary Comparison of Hydrogen infrastructure costs & Public outlet costs through 2056



Public charging outlet investments are 2 to 2.6 times more than hydrogen infrastructure investments

Outline

- Main Results from 100-year simulation
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  - FCEVs
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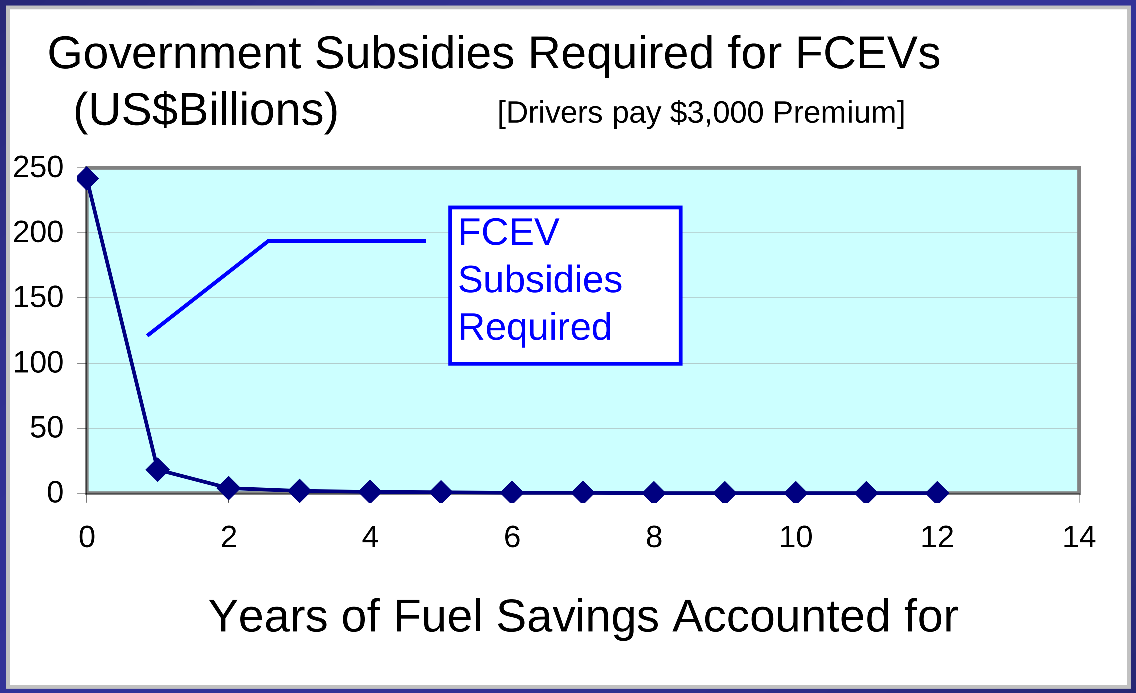
Alternative Vehicles

- Government Subsidies required for
  - FCEVs
  - BEVs

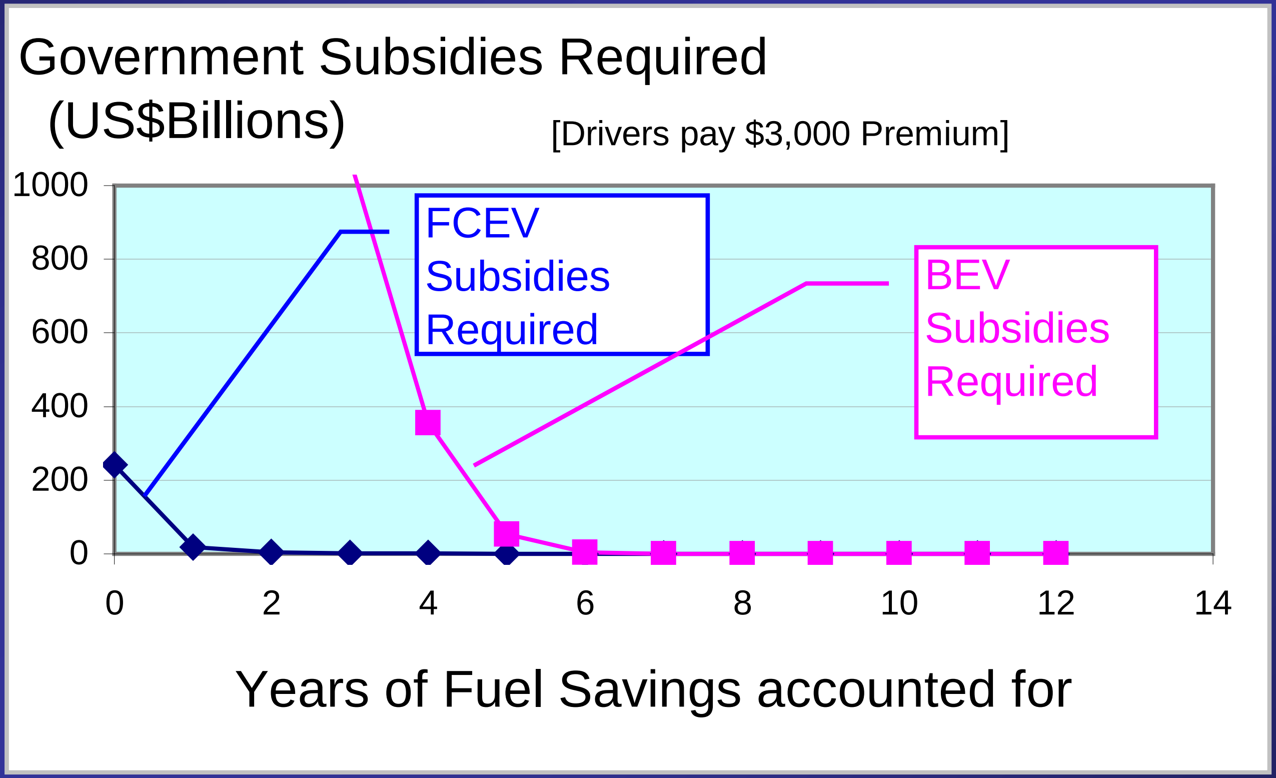
Government subsidies can be reduced if driver's pay a premium and account for fuel savings



Graphs for Simultaneous Story.XLS;' WS 'AFV Subsidies'; M 21 7/21 /2010

The $40 billion in government subsidies estimated by the NRC could be reduced below $38 Billion ($9.1 Billion NPV) if drivers paid a $3,000 premium and accounted for at least two year's fuel savings

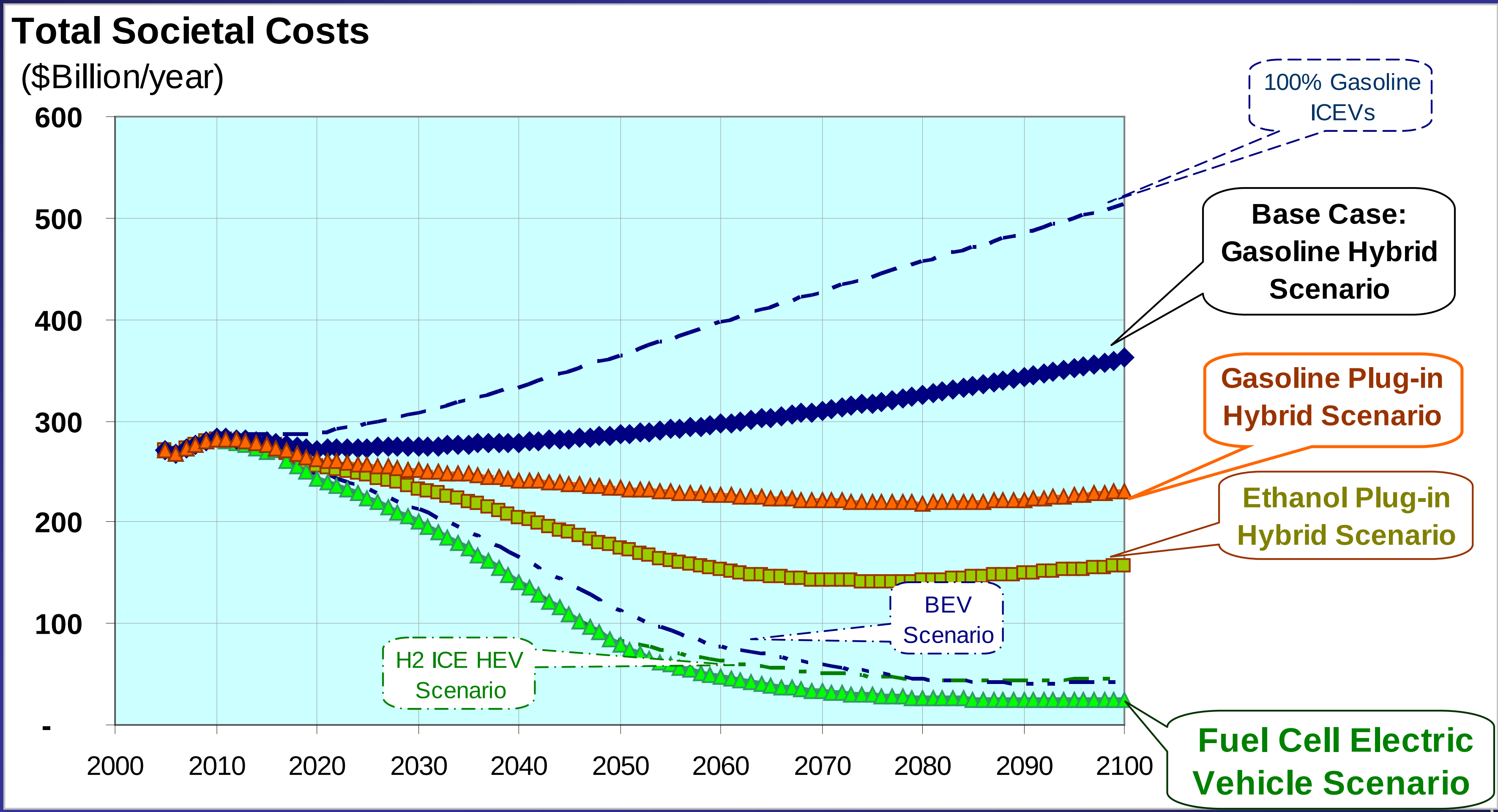
Under the same conditions, the subsidies for BEVs would exceed $400 billion unless drivers accounted for 4 or more years of fuel savings:



Graphs for Simultaneous Story.XLS;' WS 'AFV Subsidies'; M 38 7/21 /2010

Societal Costs

(of greenhouse gases, oil imports and urban air pollution)



Societal Costs & Benefits

	NPV (10%) of Govt Incentives 2011-2058	10% NPV of Societal Savings 2011-2100	Ratio Benefits/Costs
FCEV	2.1 Billion	$1.240 Trillion	590,476
BEV**	2.6 Billion	$1.235 Trillion	475,000

Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; F 70 7/22 /2010

Hydrogen & FCEVs have 1.2 times greater benefit/cost ratio than electricity & BEVs

Outline

- Main Results from 100-year simulation
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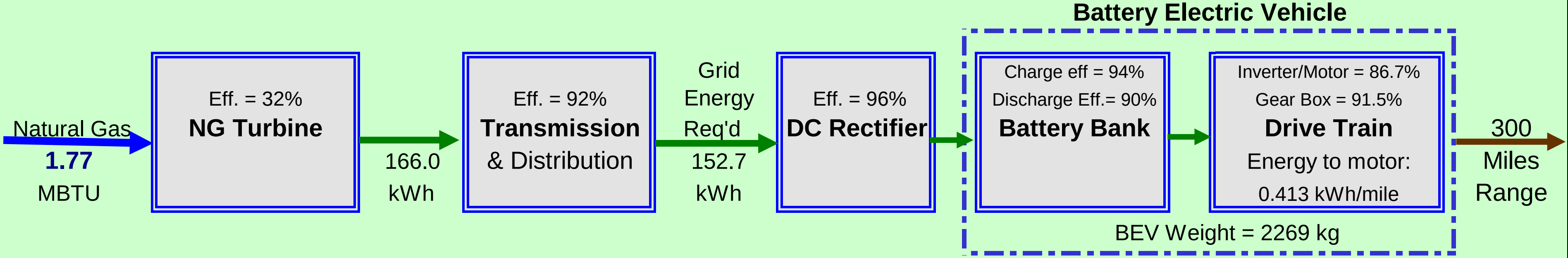
- Natural Gas Vehicle Comparisons

Energy Efficiency

Natural Gas Utilization

- New natural gas reserves in shale formations are welcomed, but which is better?
  - To make hydrogen from natural gas for FCEVs, or
  - To make electricity for BEVs?

Natural Gas: Battery EVs via Electricity? Or Fuel Cell EVs via Hydrogen?



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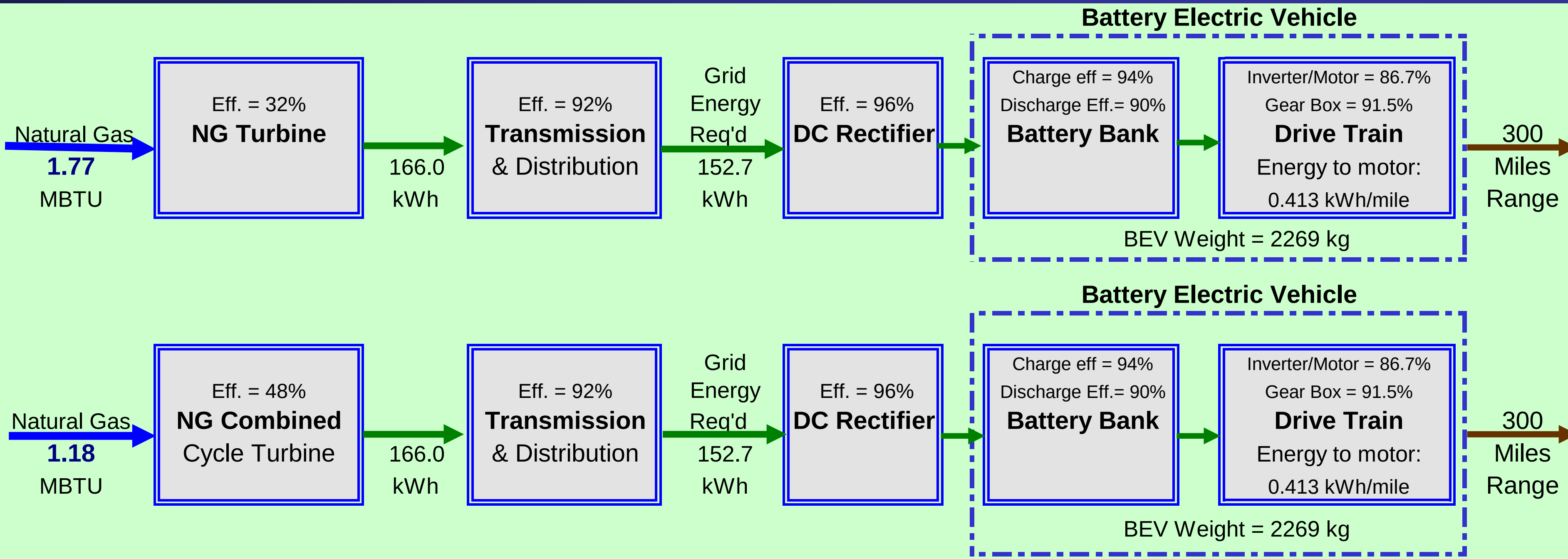

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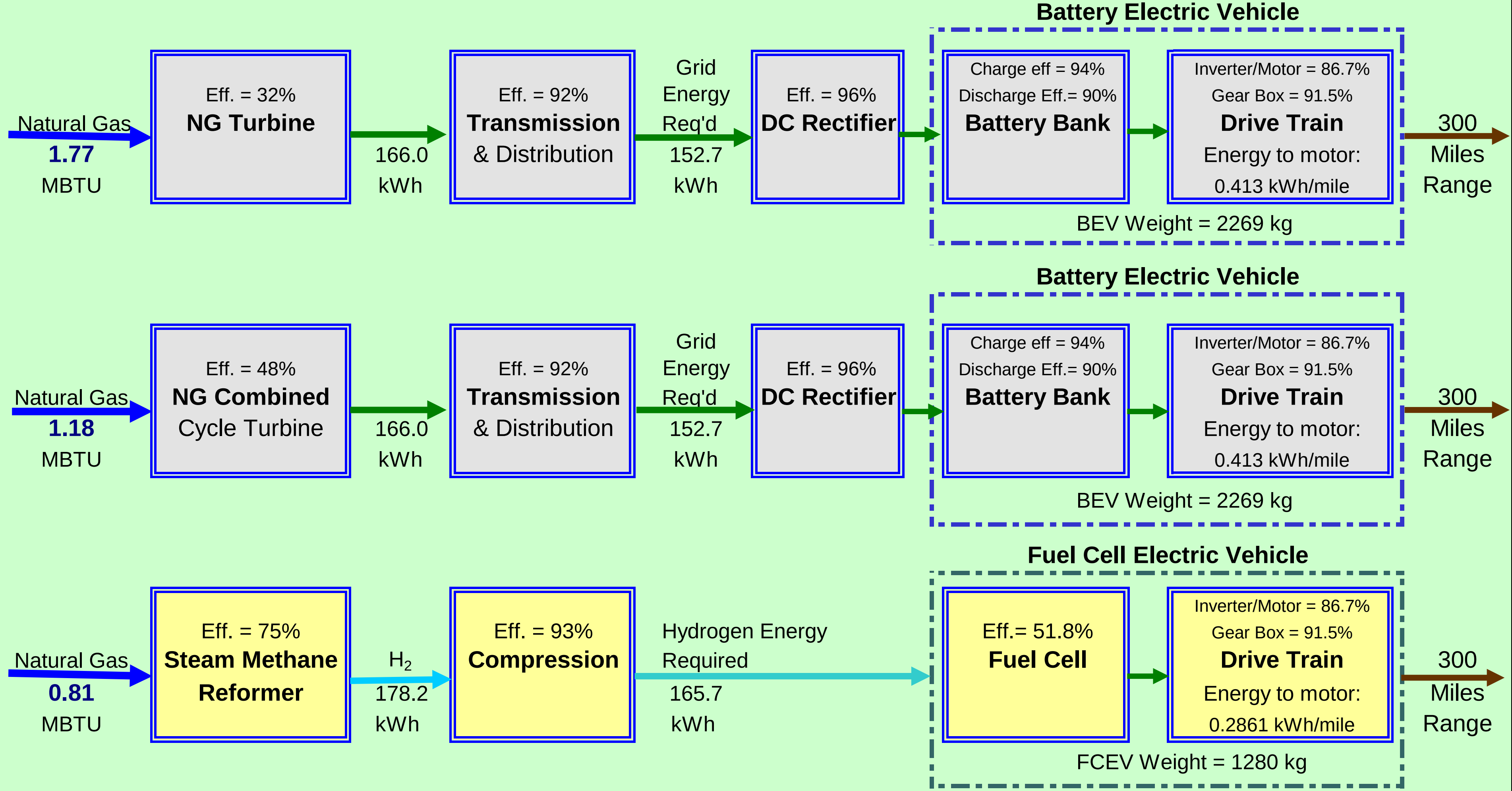
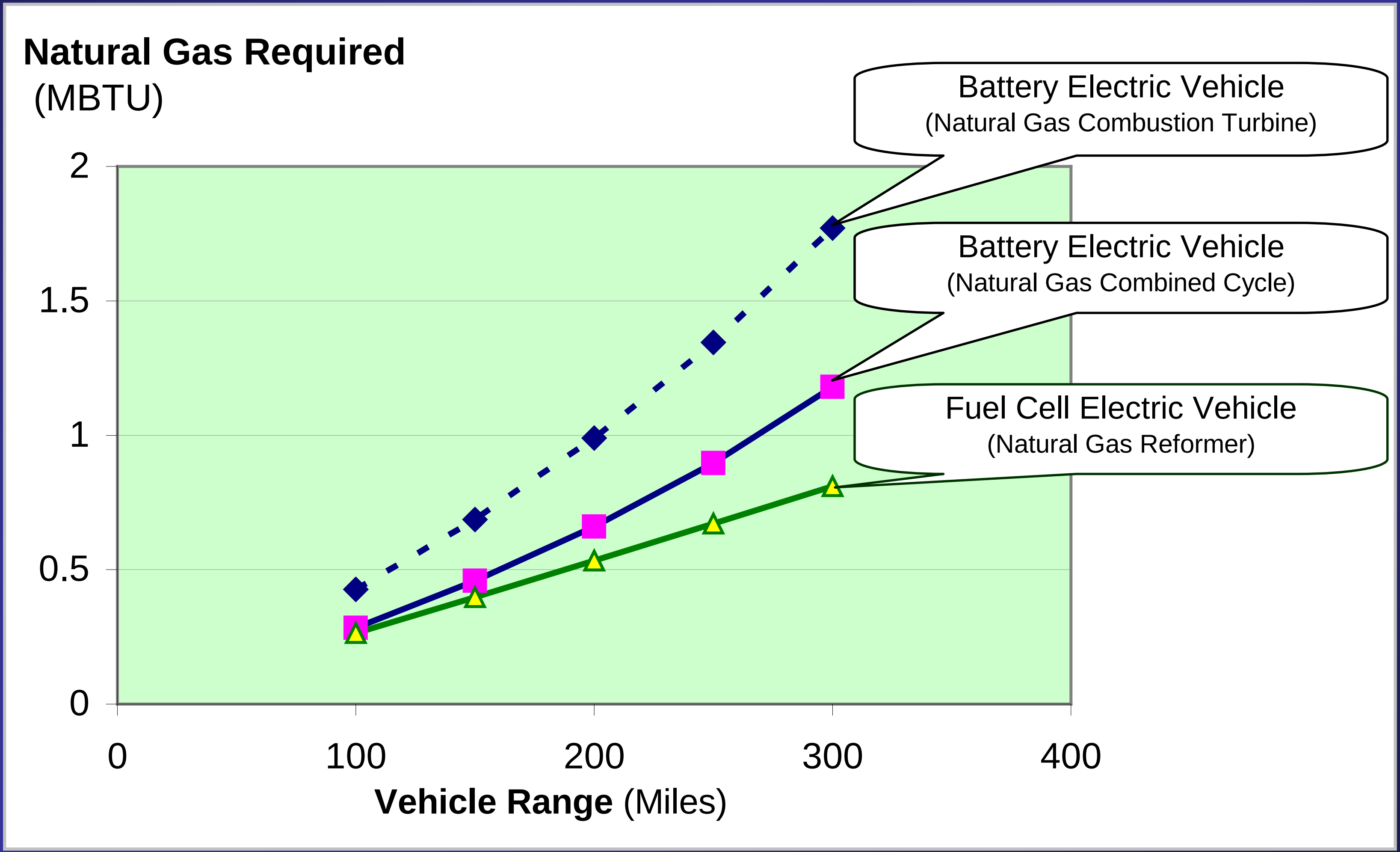


Hydrogen Production Efficiency.XLS; Tab NG'; S 44 3/12 /2009

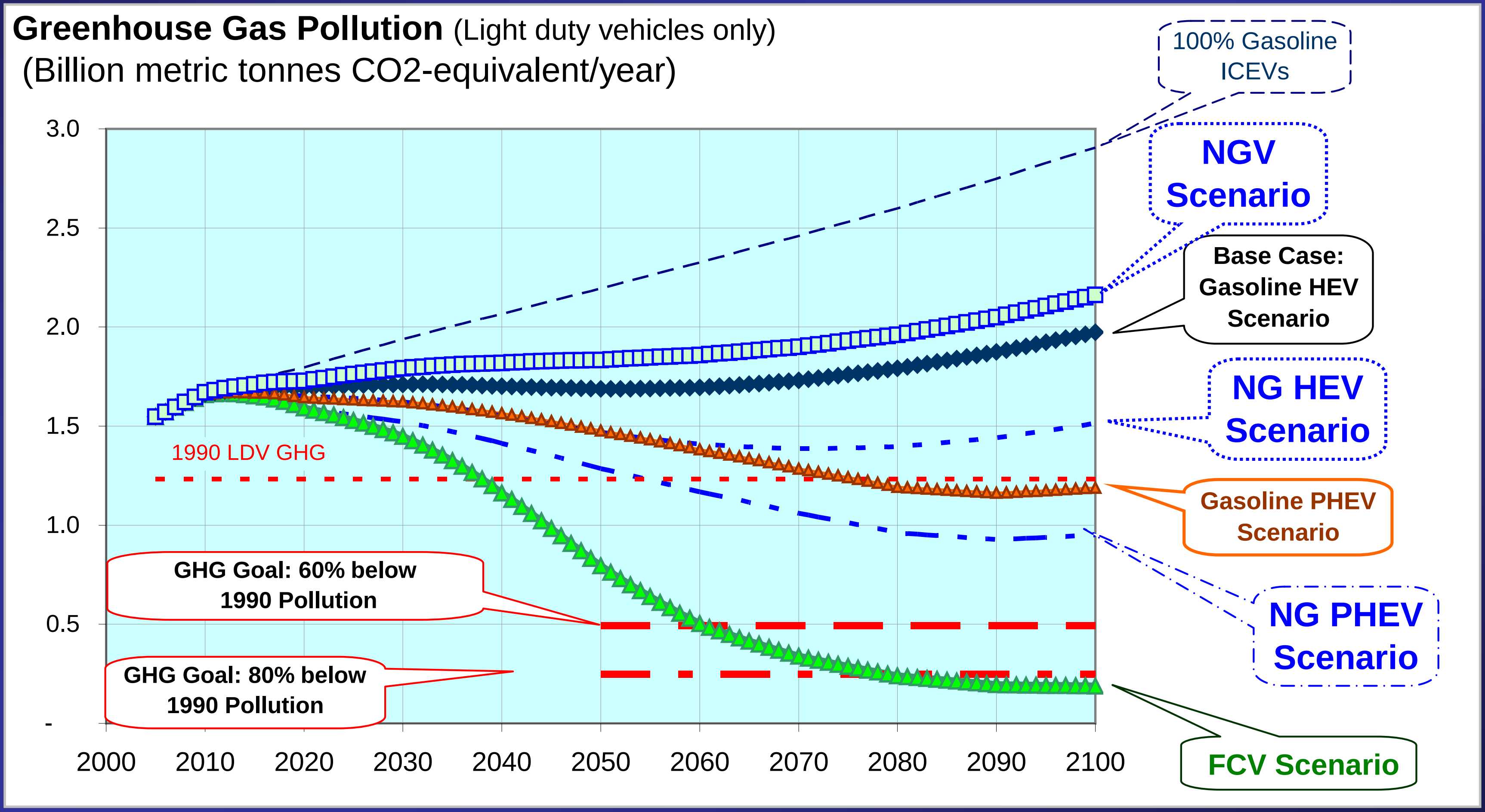
Natural gas will propel a vehicle between 2.19 and1.44 times farther if it is converted to hydrogen instead of electricity

Natural Gas Required for Electric Vehicles



Hydrogen Production Efficiency.XLS; Tab NG per mile'; AM 32 3/12 /2009

Greenhouse Gases with Natural Gas Vehicles



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

Based on old AEO 2008 data

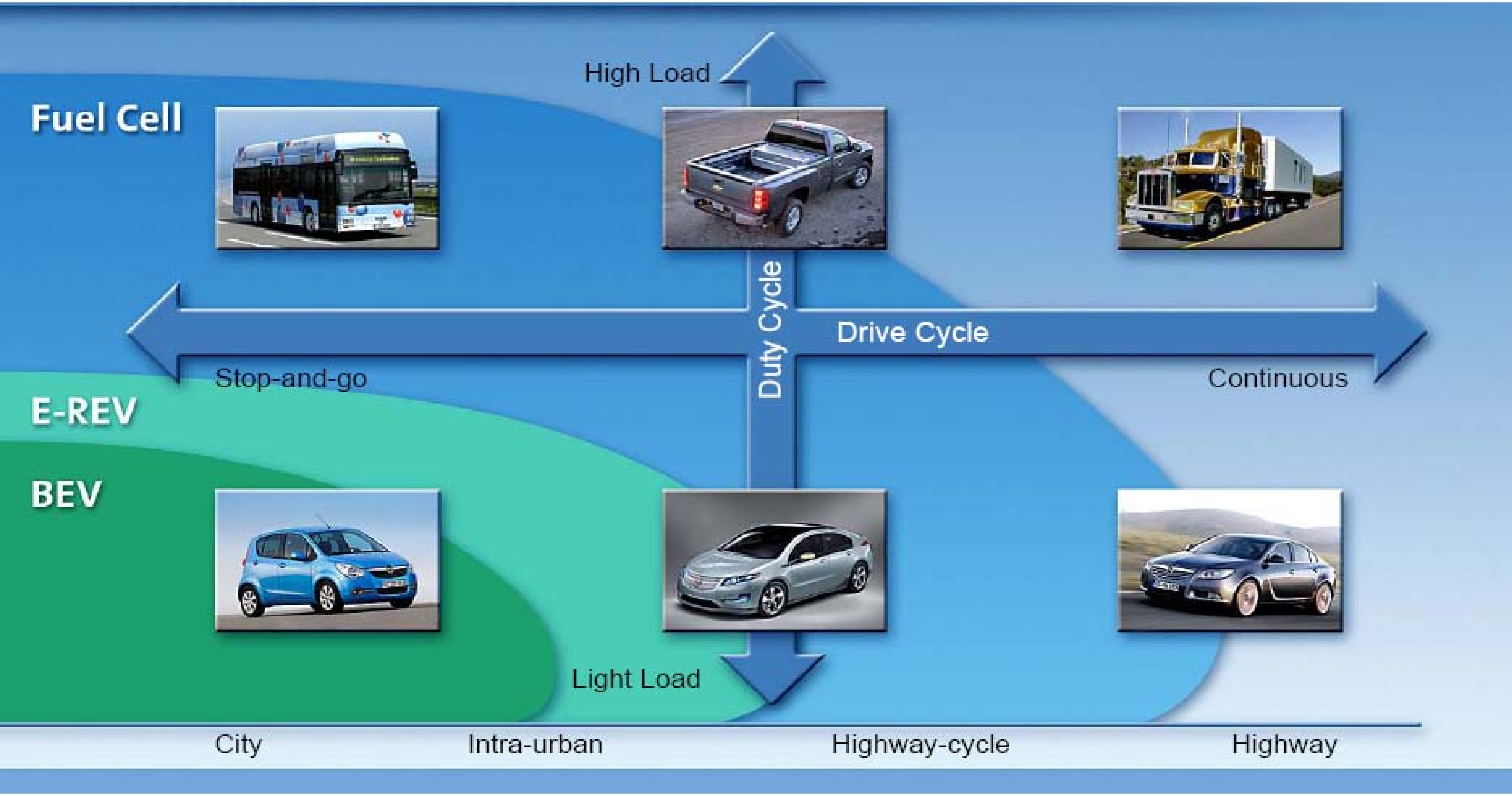
Summary on Natural Gas Utilization

- Converting natural gas to hydrogen for FCEVs will increase NG VMTs by a factor between 1.4 and 2.2
- Natural gas used in a PHEV (most efficient) will not allow an 80% reduction in GHGs, while FCEVs can achieve that goal

Next Steps

- Fund next phase of vehicle market transformation projects, including more hydrogen fueling stations ($45 Million suggested vs. $11 million DOE request for vehicle & infrastructure deployment & $13 million this year), since several auto companies are now projecting commercial introduction of FCEVs in the 2015-2017 time period.
- Continue development of fuel cell electric vehicles and hydrogen technologies
- Continue development of PHEVs and BEVs (we need all of the above, as indicated by auto OEMs) →

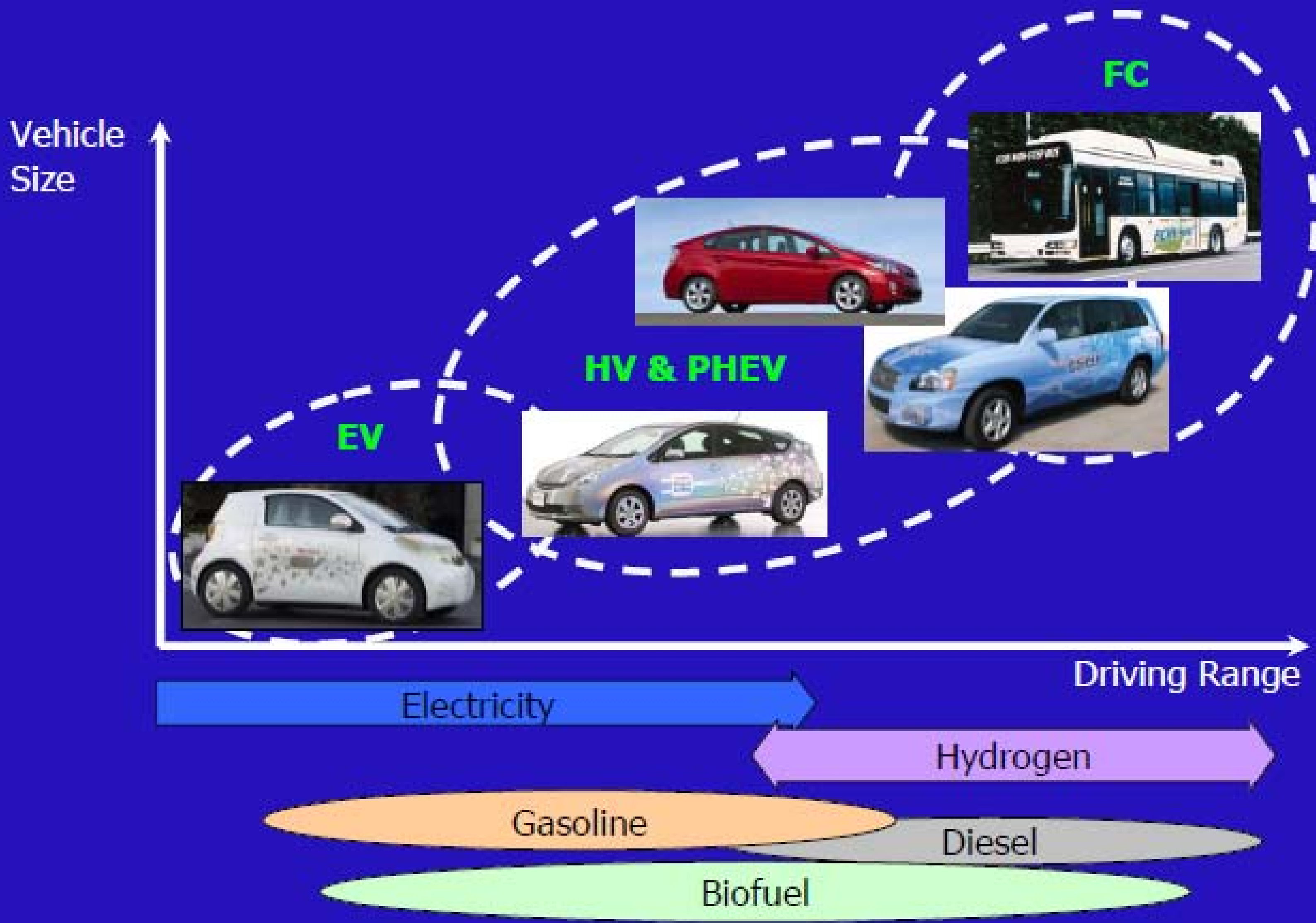
Application Map for Electric Vehicle Technologies



No Silver Bullet !!!

Toyota View or Alternative Vehicle Space:

Market Segments for Each Technologies



Drivetrains for Various Driving Cycles

Long Distance	Suburban	Urban
		

- Combustion Engine
- Hybridization
- Plug-In / Range Extender
- Electric Drive with Battery
- Electric Drive with Fuel Cell

➢ **Only fuel cell technology is suited equally for both, short and long distance mobility**

Or Combine all of the above, as Ford did with their PHEV-25 FCEV based on the Edge SUV:

25 miles all-electric range and 223 miles total on 4.5 kg of hydrogen, “with frugal driving pushing that to almost 400 miles?!”

Thank You

- Contact Information:
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  - National Hydrogen Association
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  - Washington, DC.
  - PSERFASS@ttcorp.com

  C.E. (Sandy) Thomas, ex-President (ret.)
  H2Gen Innovations, Inc.
  Alexandria, Virginia 22304
  703-507/8149
  thomas@cleancaroptions.com
  - NHA Energy Evolution web page:
  - http://www.hydrogenassociation.org/general/evolution.asp
  - Simulation details at: http://www.cleancaroptions.com

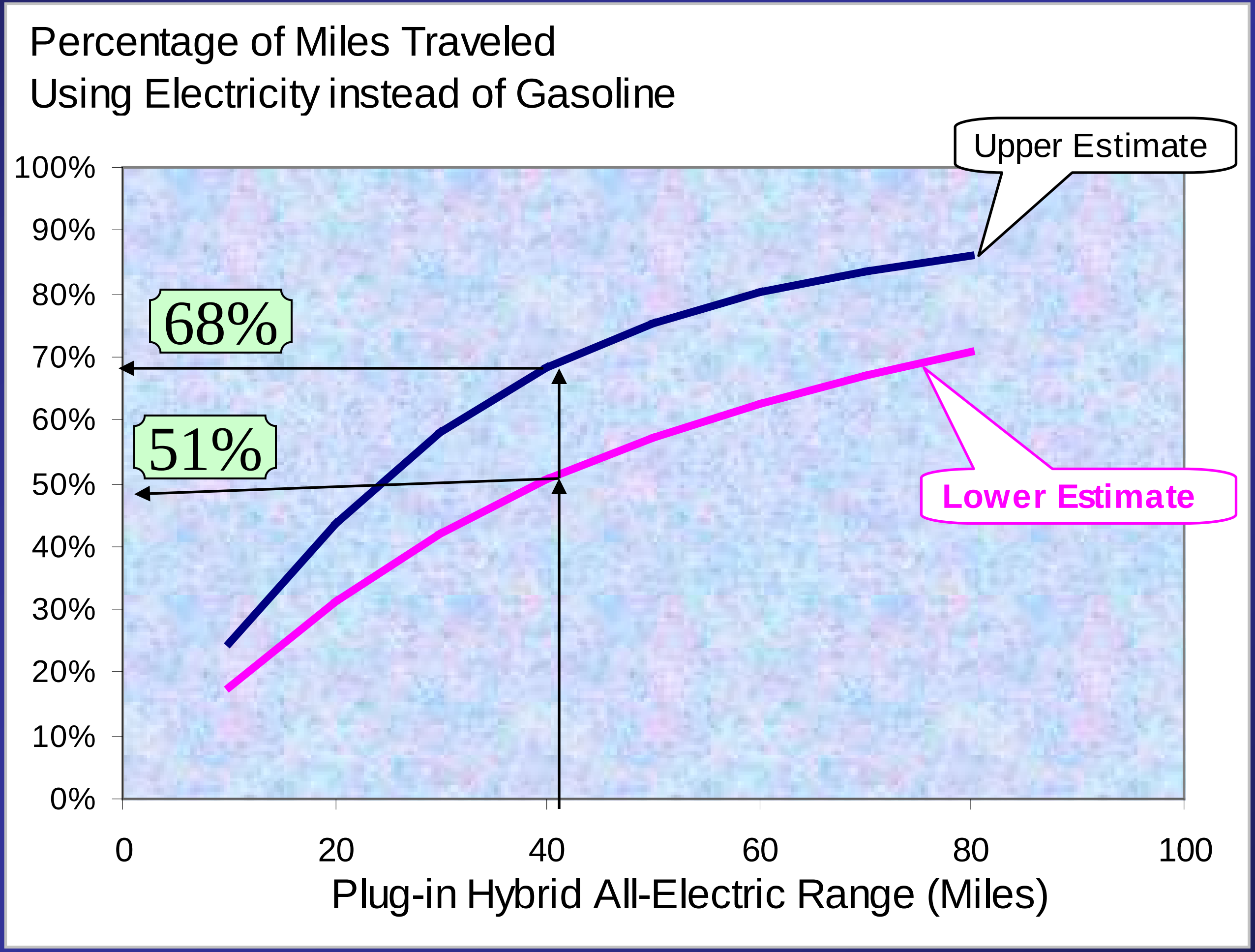
Backup Slides

How much electricity would be used with PHEVs?

Example PHEV-40

- Driver lives 5 miles from work
- Work week travel by electricity: 50 miles
- Weekend travel: 200 miles to Grandma's house or 250 miles total travel:
  - First 40 miles on electricity (90 miles total on the grid)
  - 160 miles on gasoline
- Total on electricity: 90 miles out of 250 or 36% from grid and 64% from gasoline or 1.9 times further on gasoline than electricity

Percent of Typical driving on electricity based on actual US driver histories



Sources: SAE J1711; EPRI 2001; Markel 2006; ORNL 2004

How Far We Travel

- Americans total 1.3 trillion person-miles of long distance travel a year on about 2.6 billion long distance trips.
- The median distances on these trips are:
    - Air - 2,068 miles
    - Bus - 287 miles
    - **Personal vehicle - 194 miles**
    - Train - 192 miles

Source:2001 National Household Travel Survey

Why We Travel

- 45 percent of daily trips are taken for shopping and errands
- 27 percent of daily trips are social and recreational, such as visiting a friend
- 15 percent of daily trips are taken for commuting

Source:2001 National Household Travel Survey

HGM 10000: Filling 100 cars or 15 busses/day

All-in life cycle costs today: Production: $3.26/kg*

Production, compression & storage: $4.83/kg

($2.04/gallon-range equivalent basis)

* Natural gas = $8.00/MBTU

HGM 2000:
Filling 20 cars or 3 busses / day

H2Gen

CH_4 + $2H_2O$ =========> $4H_2$ + CO_2

Natural Gas

Water

Electricity

Instrument Air

Hydrogen,
Up to 99.9999%
pure

HGM-2000 Field Units

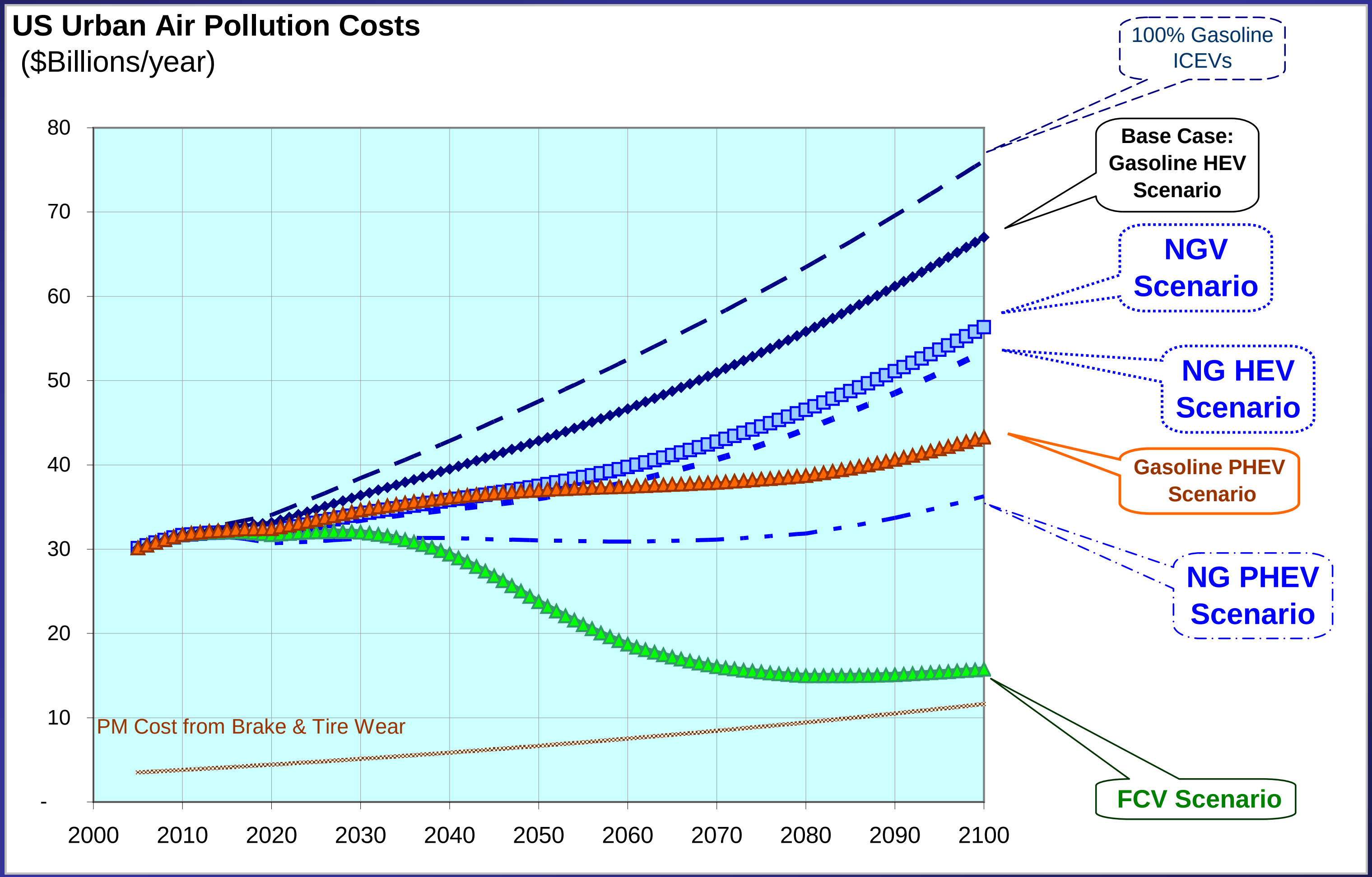
Battery goals vs current status

	Current Status	MIT Goal	Improvement Factor Req'd
Specific energy	0.899 kWh/kg 42.4 useful kWh & 47.6 kg	150 kWh/kg	1,688
Cost	$1,000/kWh	$270/kWh	3.7
Source	Audi e-tron (Car & Driver, March 2010, pg 27		

Battery goals vs current status

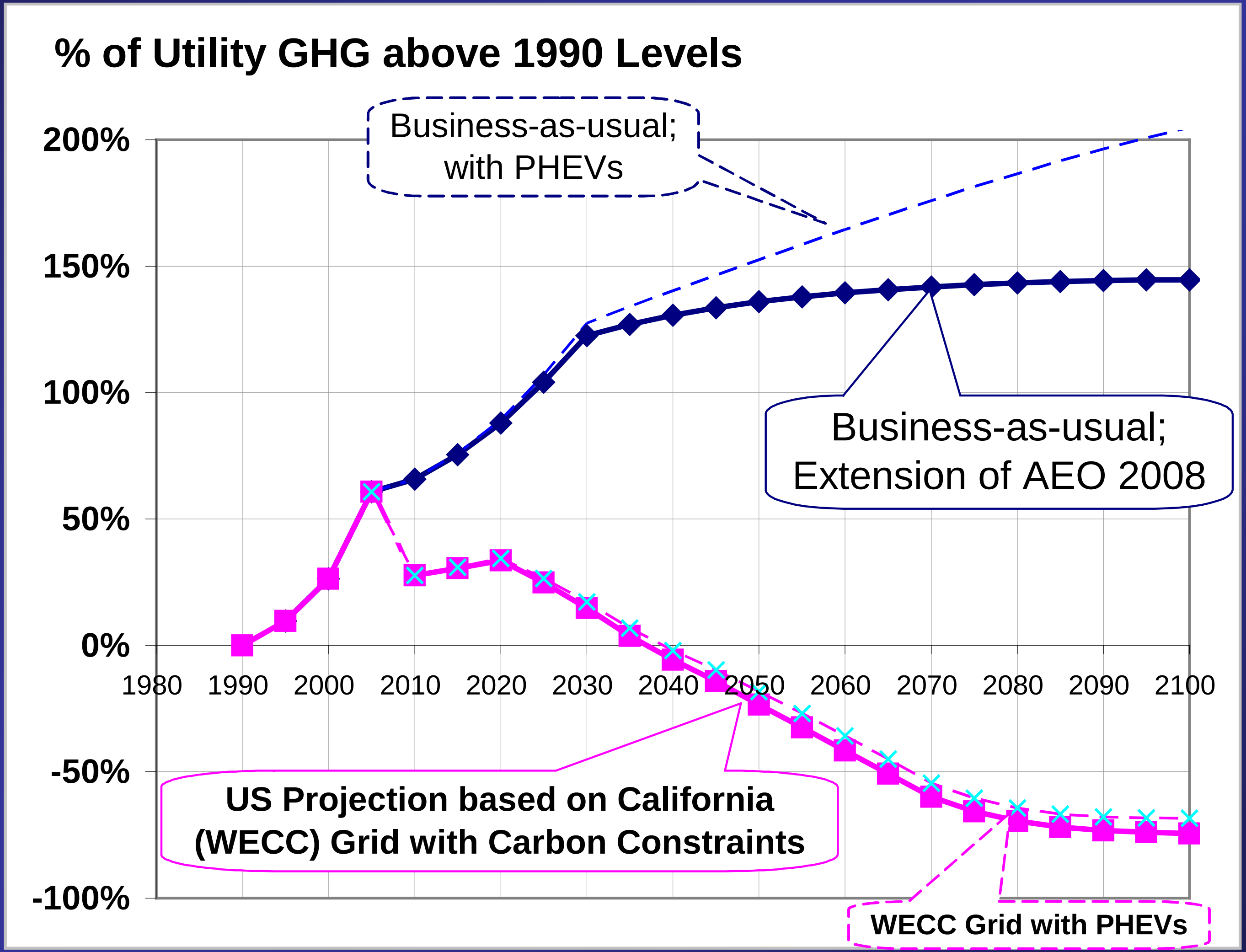
	Current Status	MIT Goal	Improvement Factor Req'd
Specific energy	0.0441 kWh/kg 8 useful kWh & 181 kg	0.15 kWh/kg	3.4
Cost	$1,000/kWh	$270/kWh	3.7
Source	Chevy Volt; Automobilemag.com January 2010		

Urban Air Pollution with Natural Gas Vehicles



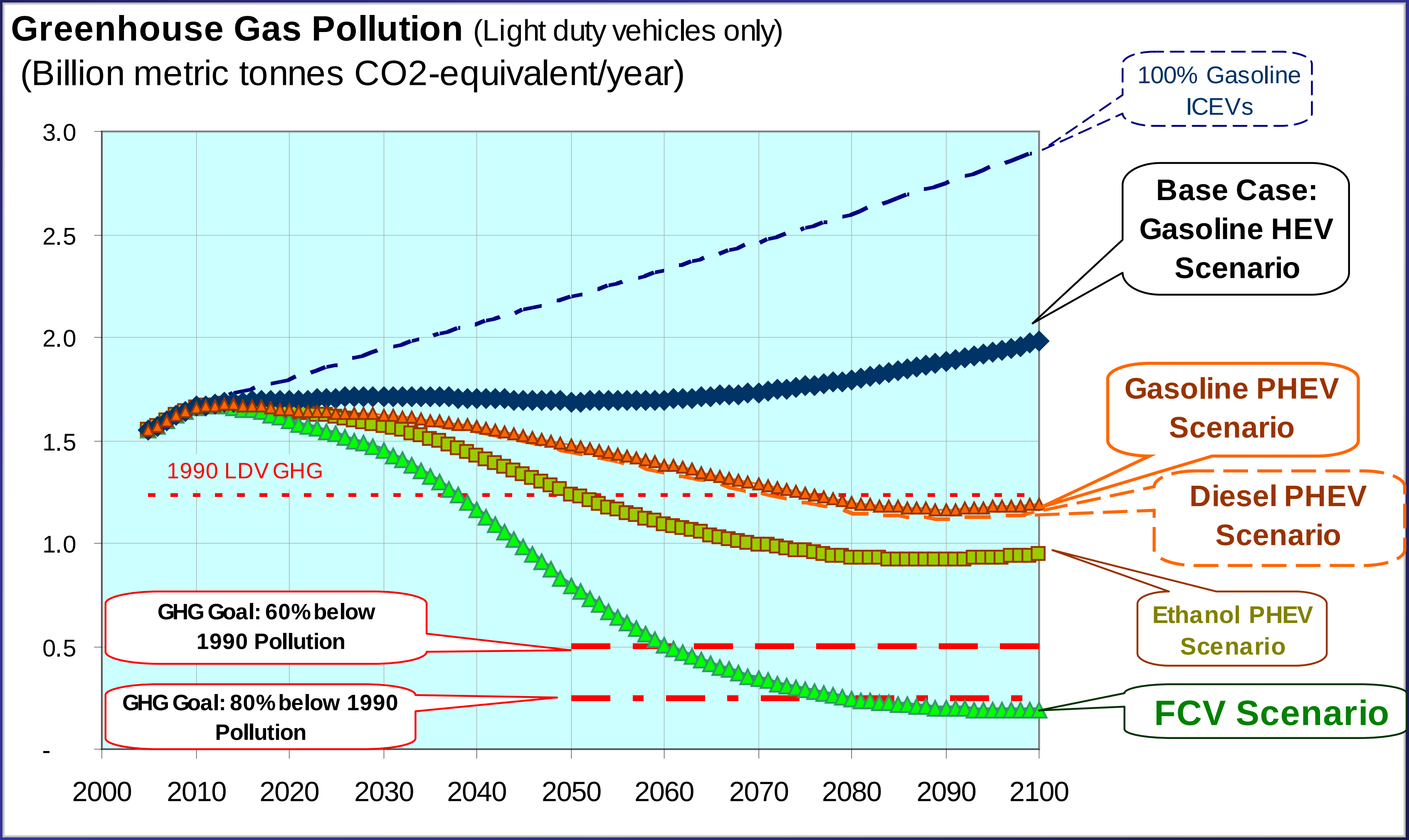
Story Simultaneous.XLS; Tab 'Graphs'; DF 102 9/8 /2008

Grid GHGs Relative to 1990



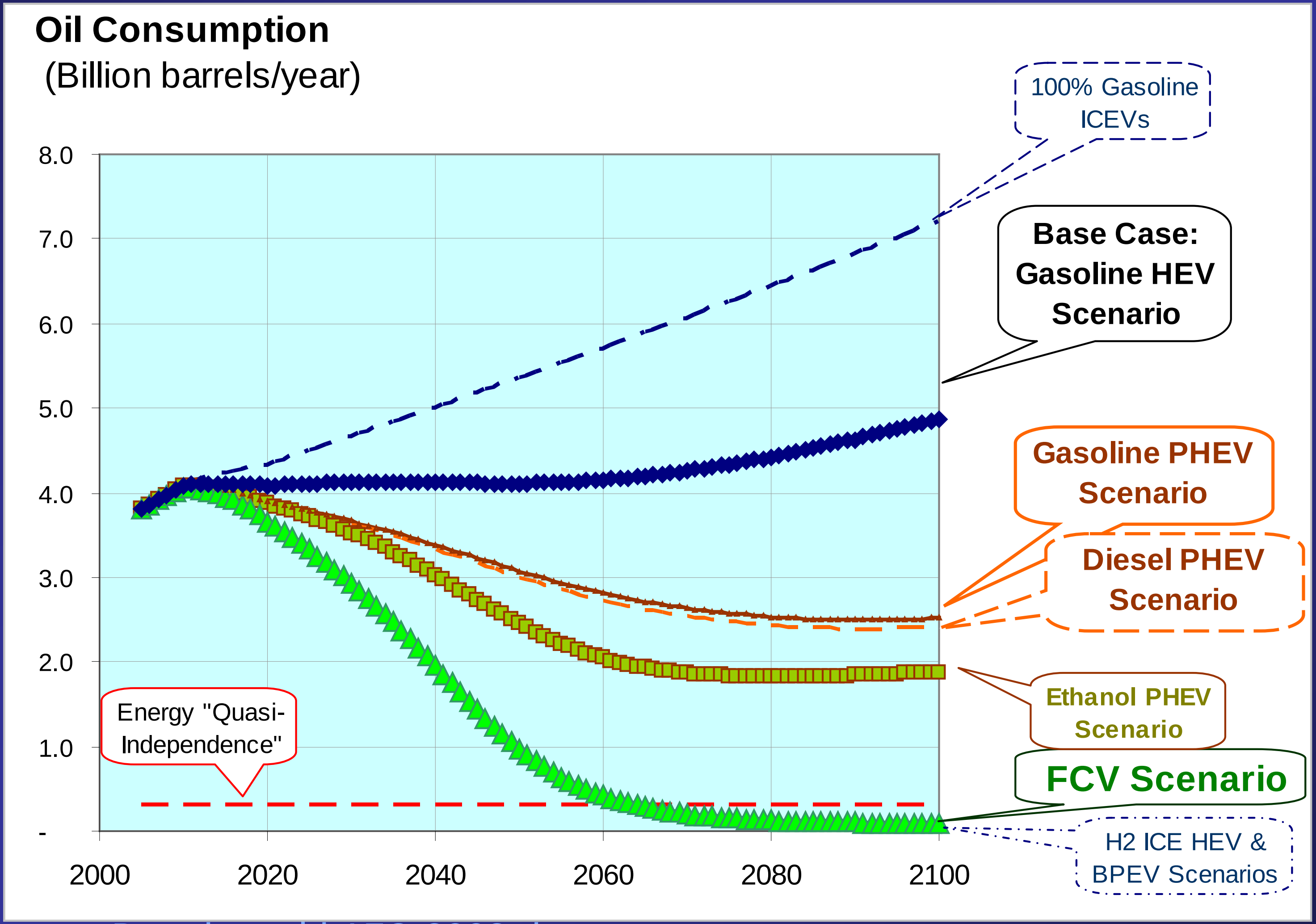
GHG.XLS, Tab 'Climate Change Projections'; K421;3/28/2008

Diesel PHEV GHGs



Based on old AEO 2008 data

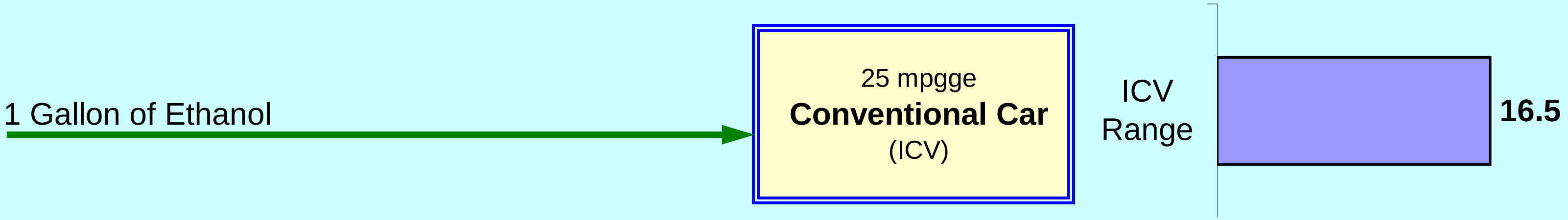
Diesel PHEV Oil Consumption



Based on old AEO 2008 data

Why Hydrogen from Ethanol?

ICV fuel economy	**25**	mpgge
HEV mpg/ ICV mpg	**1.45**	
FCEV mpg/ ICV mpg	**2.4**	
SMR HHV Efficiency	**76%**	



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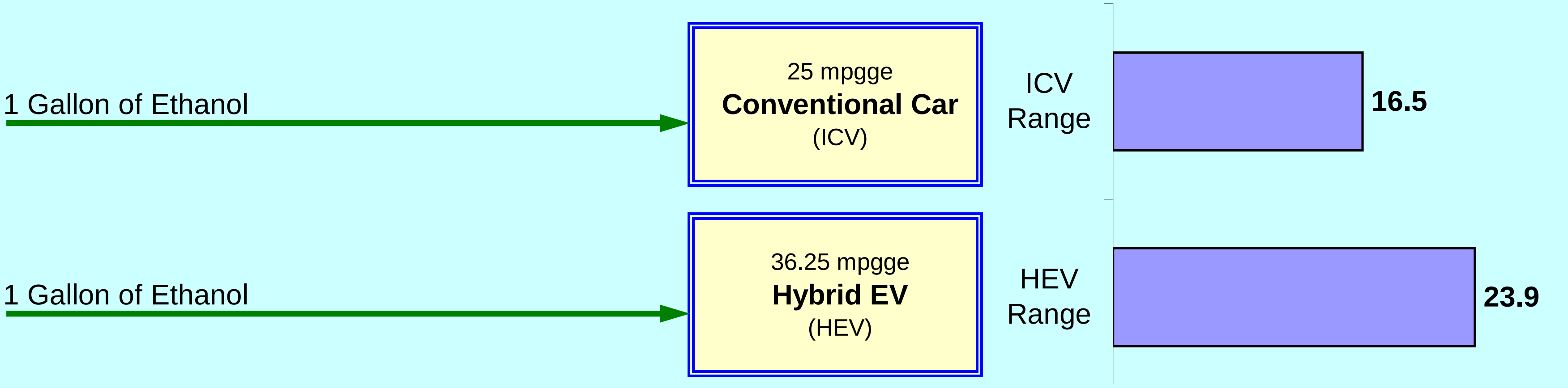

Why hydrogen from ethanol.XLS; Tab 'Chart'; Q 31 2/24/2009

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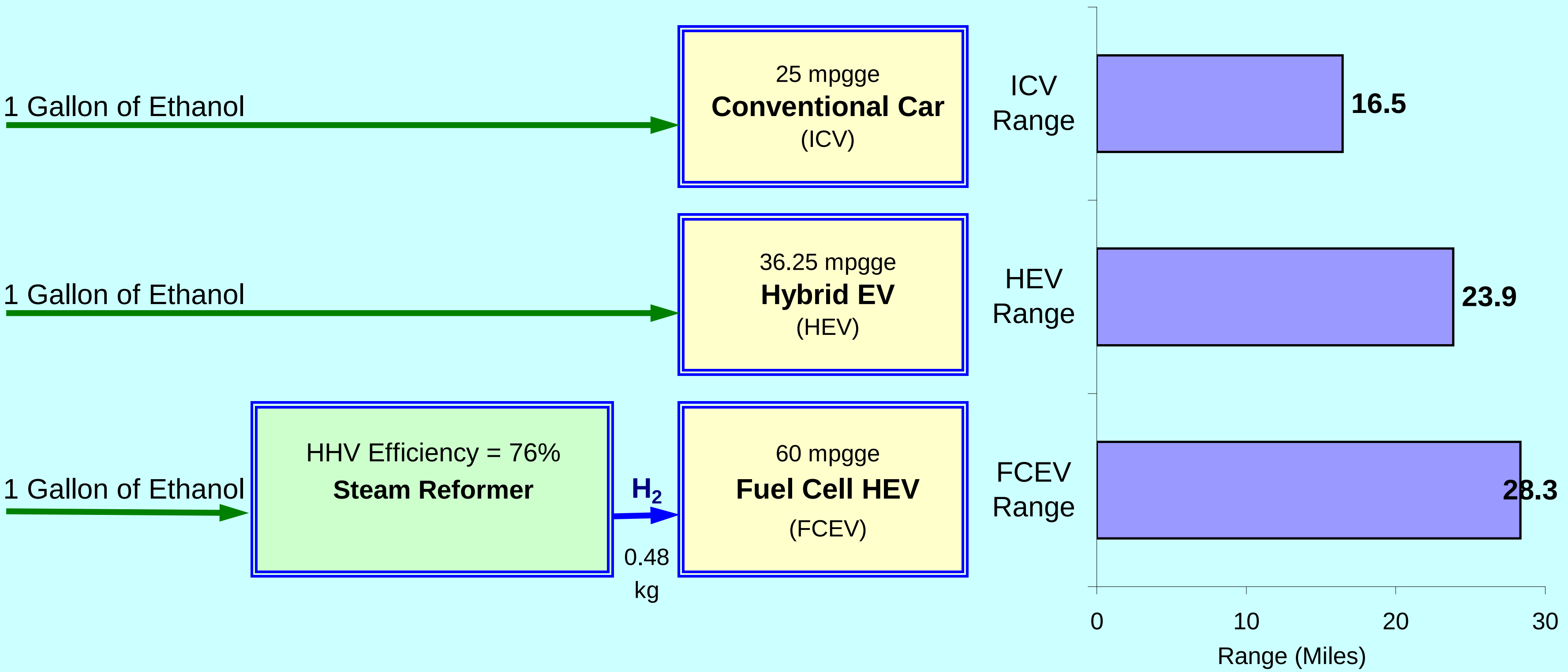

Why hydrogen from ethanol.XLS; Tab 'Chart'; Q 31 2/24 /2009

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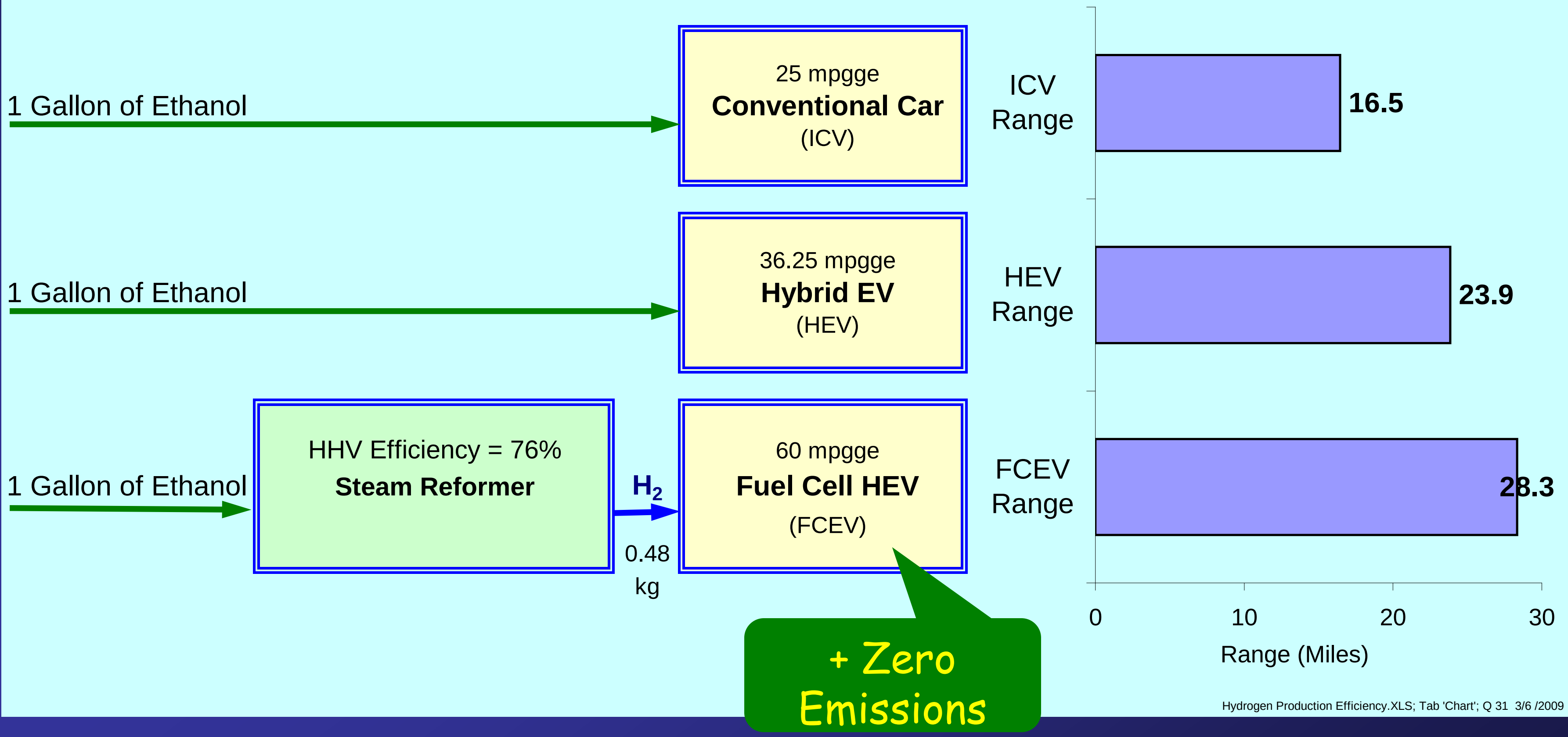
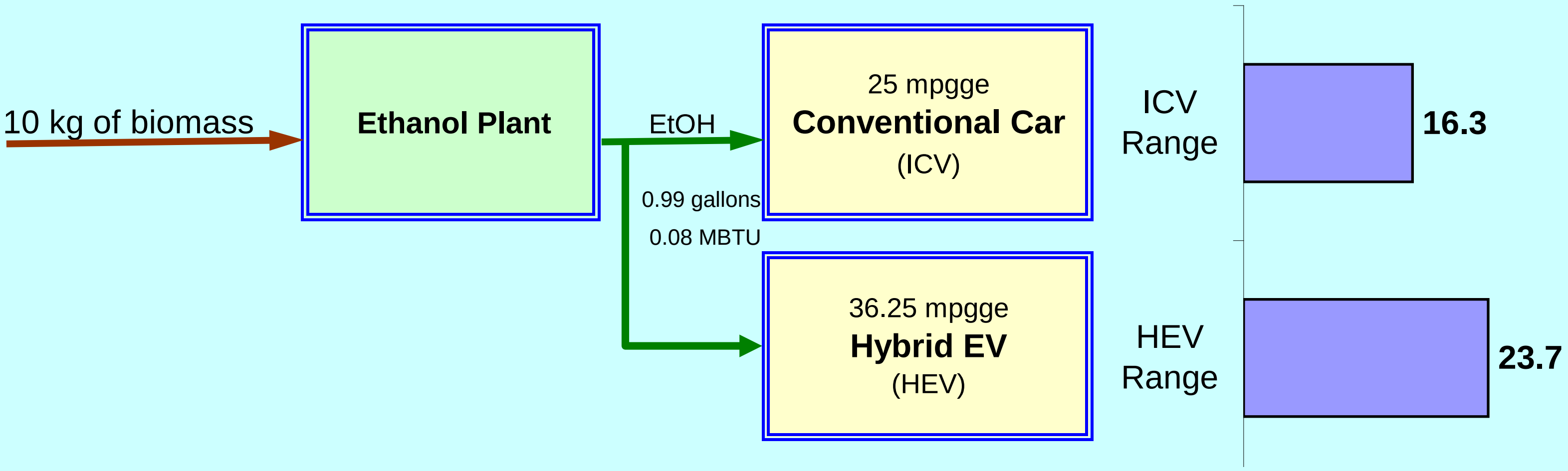
FCEV Range Increase Factors	
w/r to ICV:	**1.72**
w/r to HEV	**1.19**



Hydrogen Production Efficiency.XLS; Tab 'Chart'; Q 31 3/6 /2009

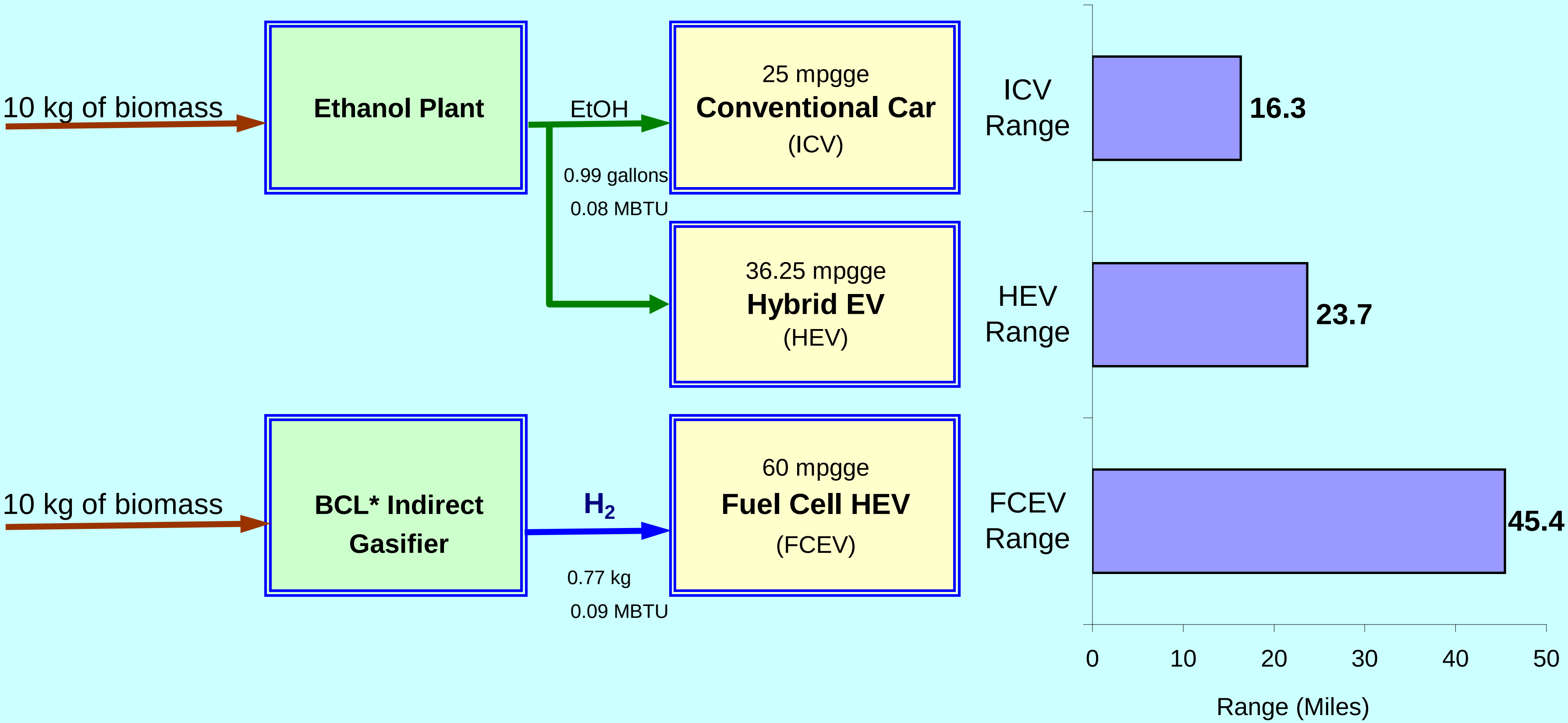
Consider Biomass Feedstock

ICV fuel economy	**25**	mpgge
HEV mpg/ ICV mpg	**1.45**	
FCEV mpg/ ICV mpg	**2.4**	
Biomass Gasifier LHV Efficiency	**49%**	
Ethanol Plant Productivity	**90**	gal EtOH/ton biomass



Better yet: Biomass Gasification

ICV fuel economy	**25**	mpgge
HEV mpg/ ICV mpg	**1.45**	
FCEV mpg/ ICV mpg	**2.4**	
Biomass Gasifier LHV Efficiency	**49%**	
Ethanol Plant Productivity	**90**	gal EtOH/ton biomass



BCL* = Battelle Columbus Laboratory

Why hydrogen from ethanol.XLS; Tab 'Chart Biomass'; Q 32 2/24 /2009

Better yet: Biomass Gasification

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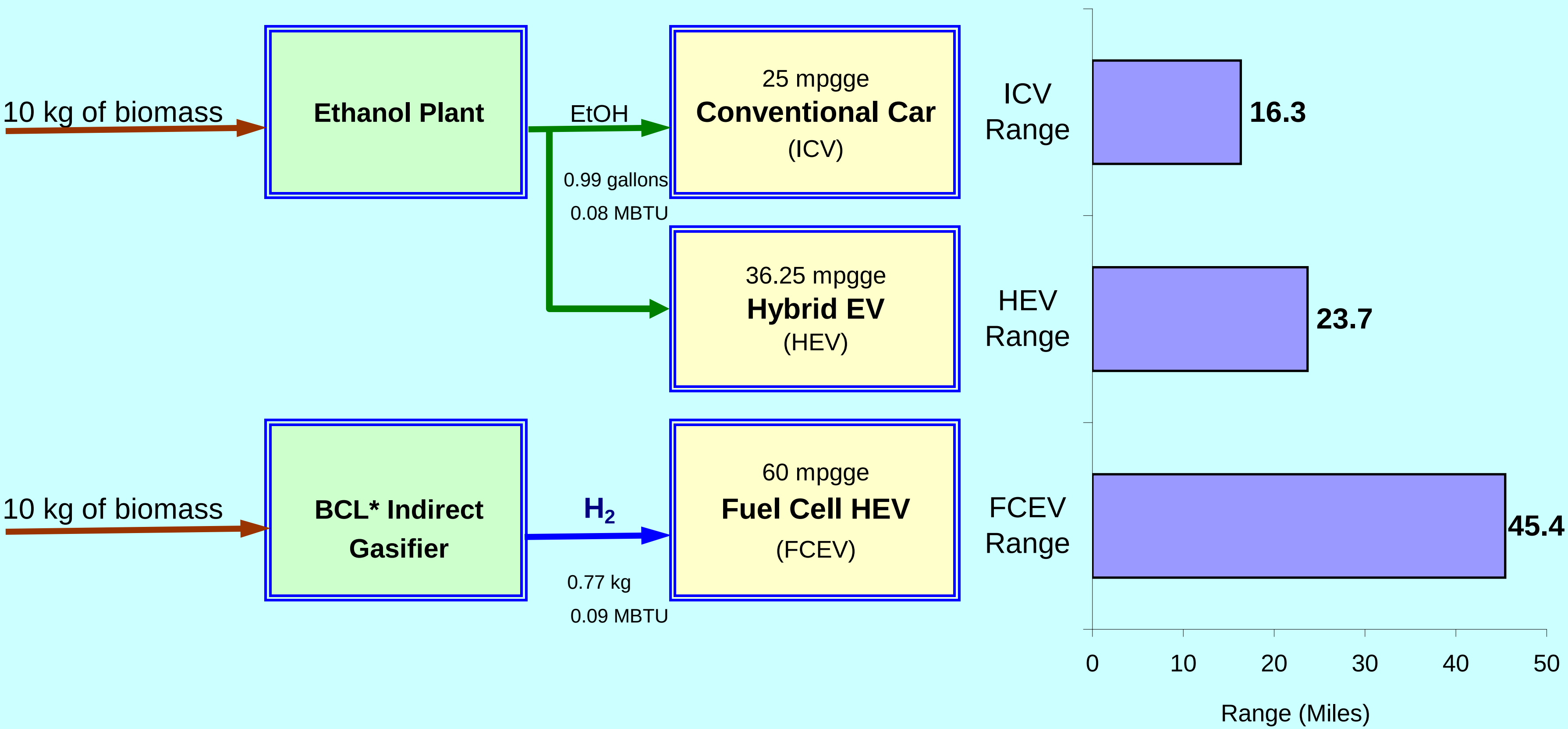
Biomass Gasifier LHV Efficiency	**49%**	
Ethanol Plant Productivity	**90**	gal EtOH/ton biomass

FCEV Range Increase Factors

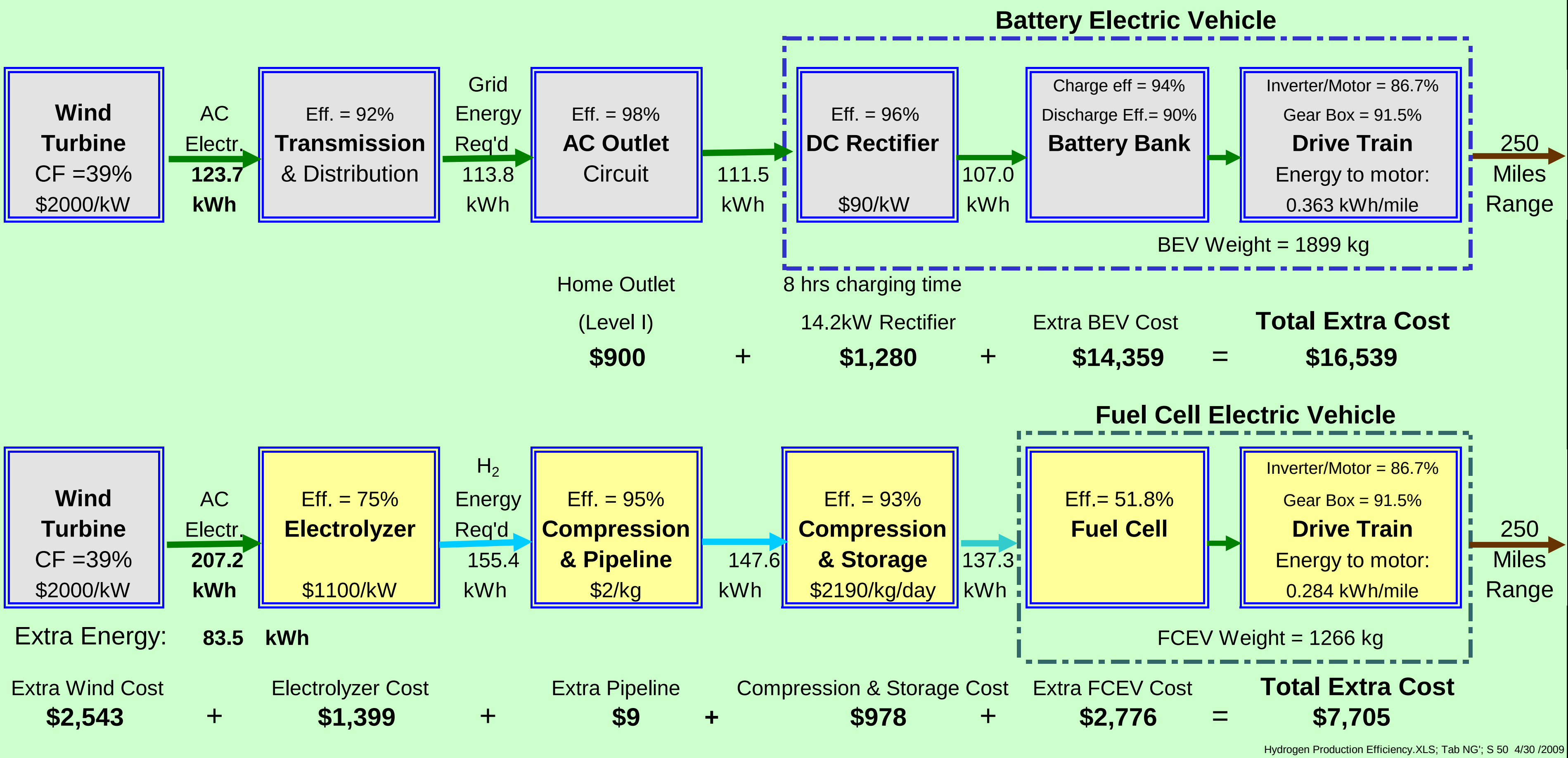
w/r to ICV:	**2.8**
w/r to HEV	**1.9**



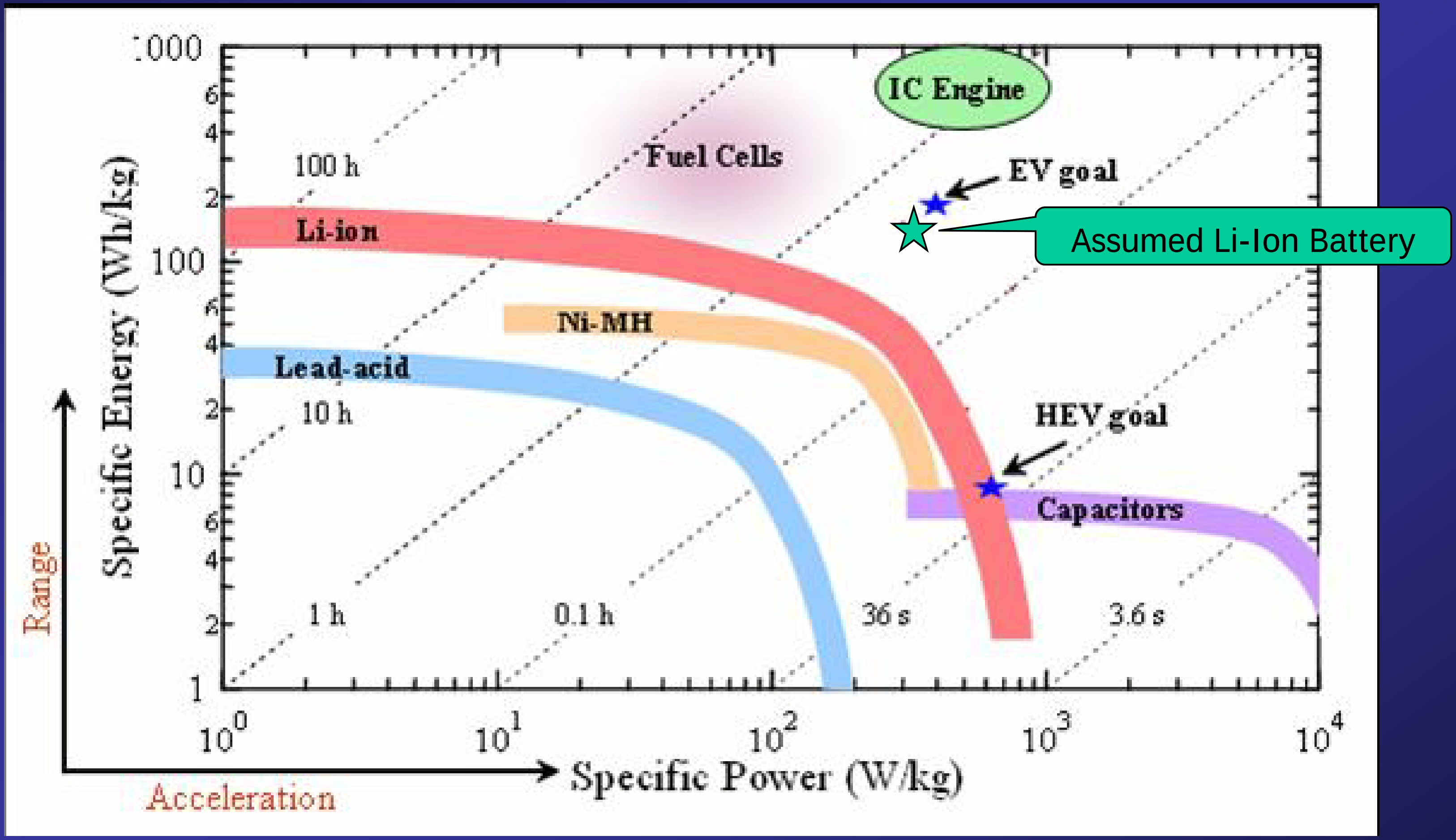
BCL* = Battelle Columbus Laboratory

Why hydrogen from ethanol.XLS; Tab 'Chart Biomass'; Q 32 3/6 /2009

Wind Electricity: BEV or FCEV?

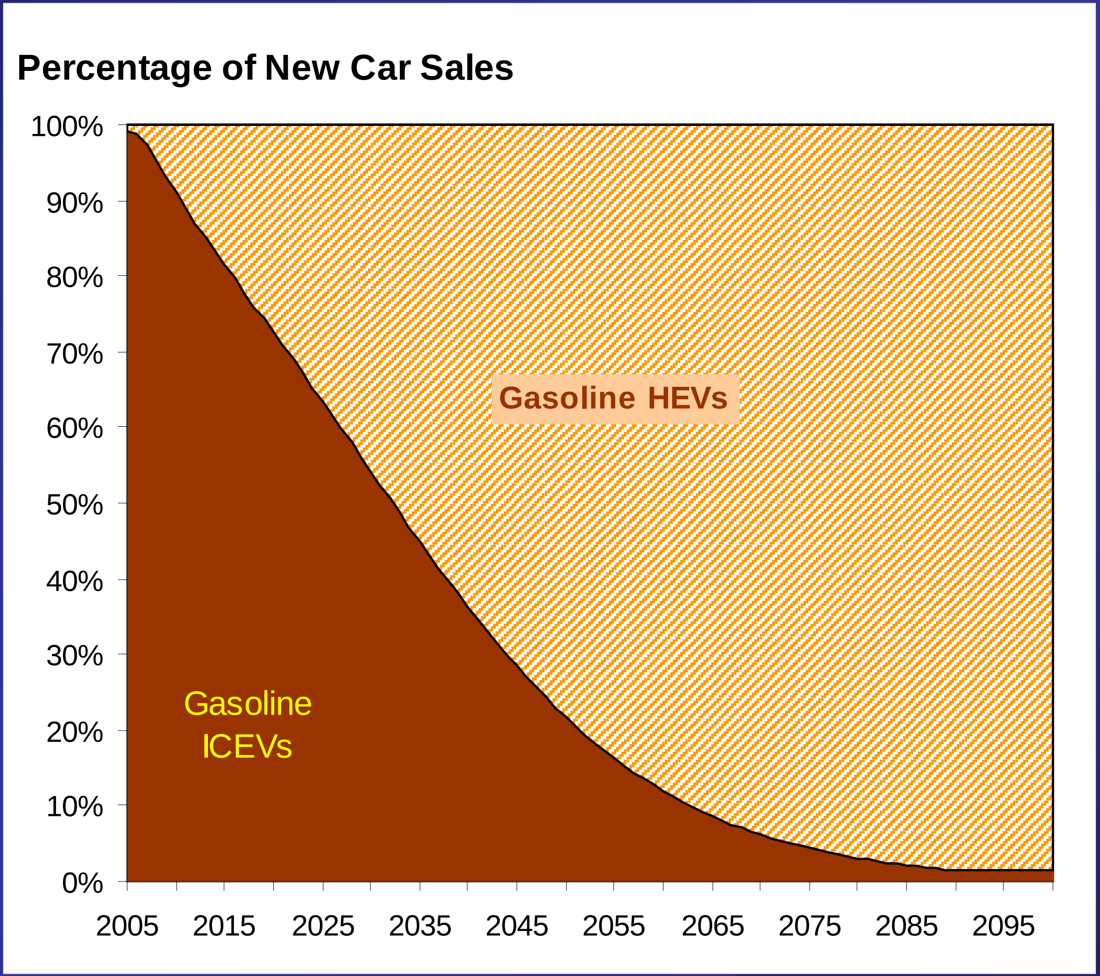


Battery Power vs. Energy Trade-off



Ref: Kromer, Matthew & J.B. Heywood, "Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet," Sloan Automotive Laboratory, Massachusetts Institute of Technology, Publication Number LFEE 2007-03 RP, May 2007

Gasoline Hybrid Scenario Market Shares



(50% Market Share Potential by 2024)

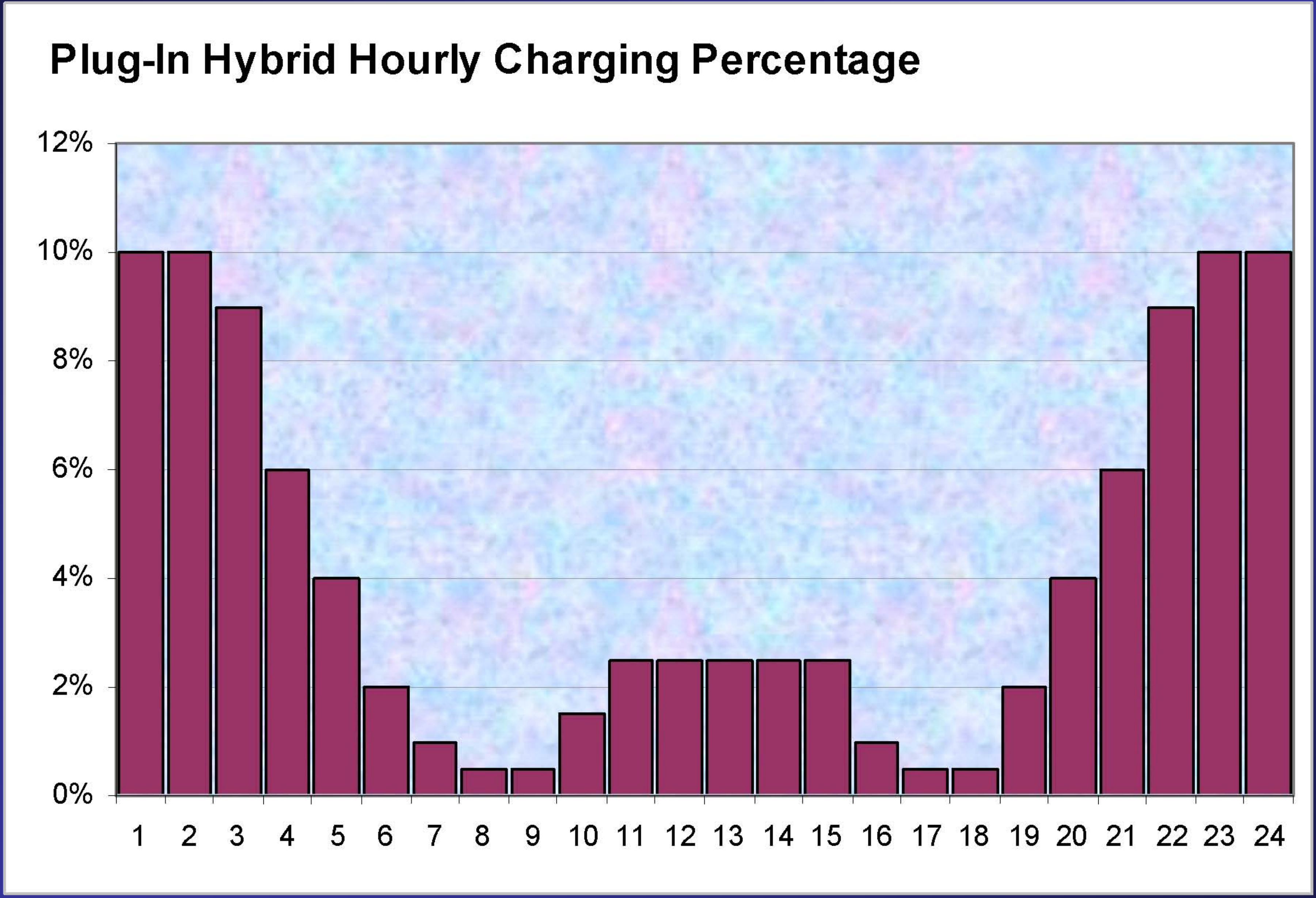
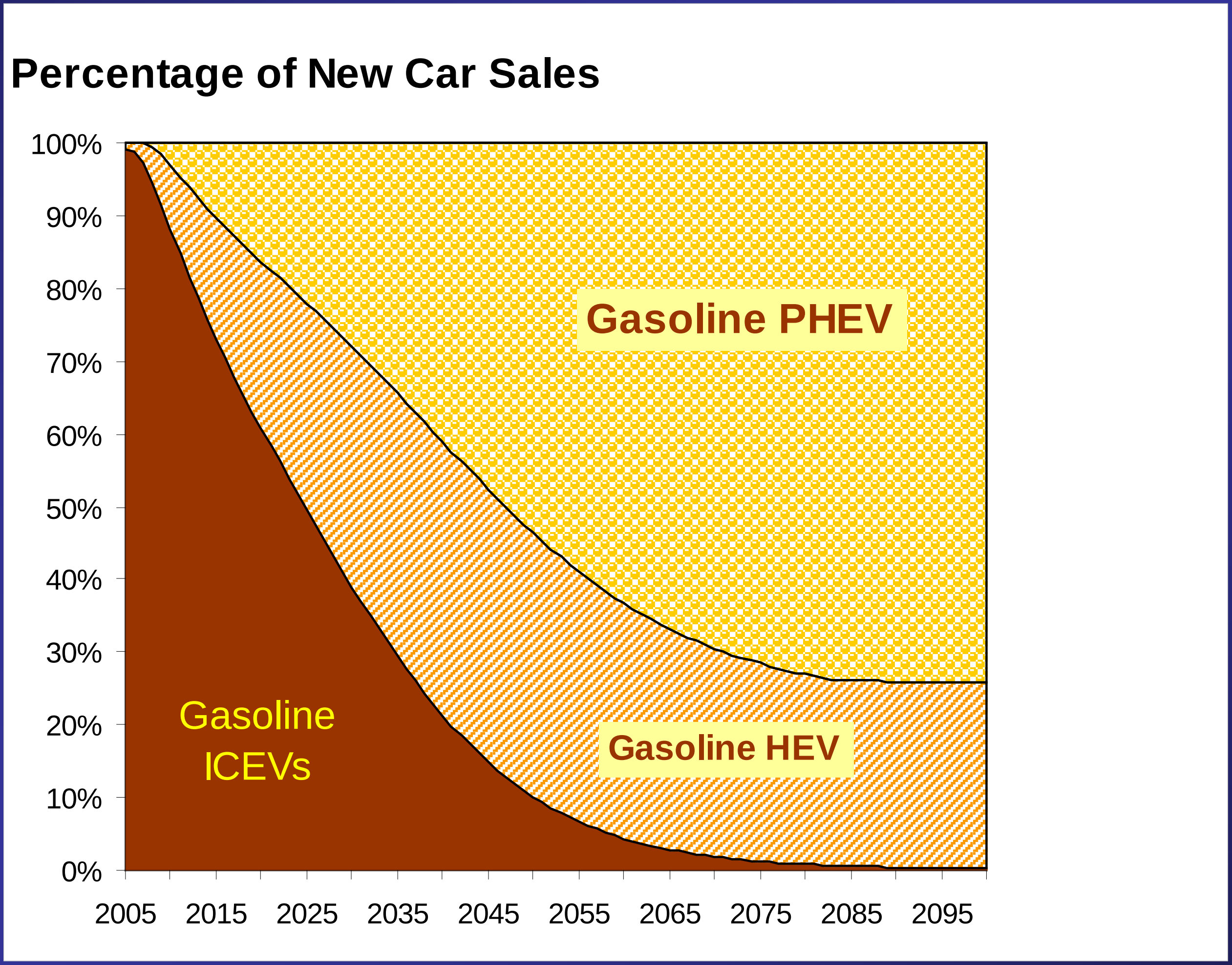


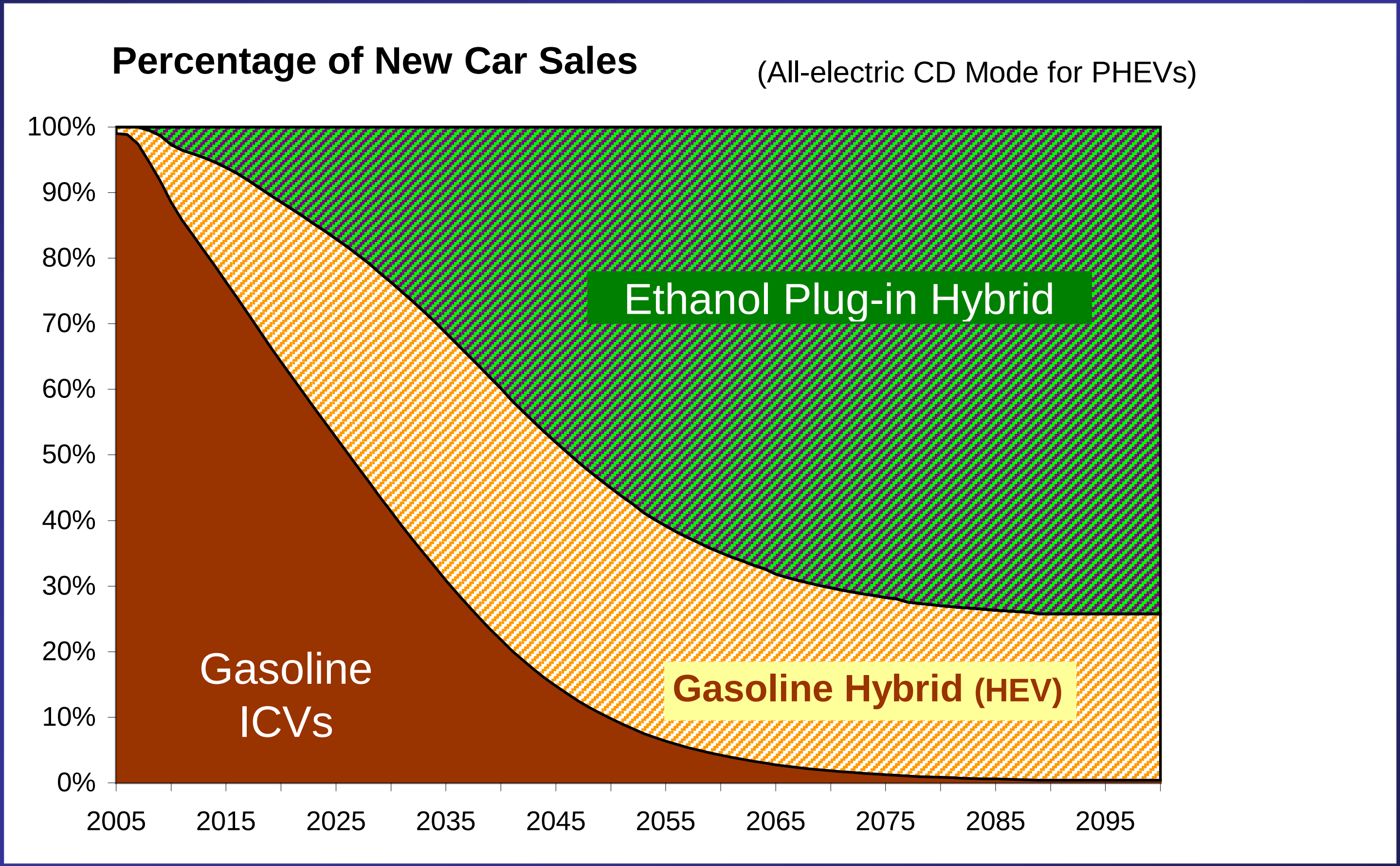
Figure 1. PHEV charging profile suggested by EPRI

Gasoline (& Diesel) Plug-In Hybrid Scenario Market Shares



(50% market share potential by 2031; 75% plug-in potential limited by charging outlet availability; 12 to 52 mile all-electric range; 18% to 65% of VMT from grid)

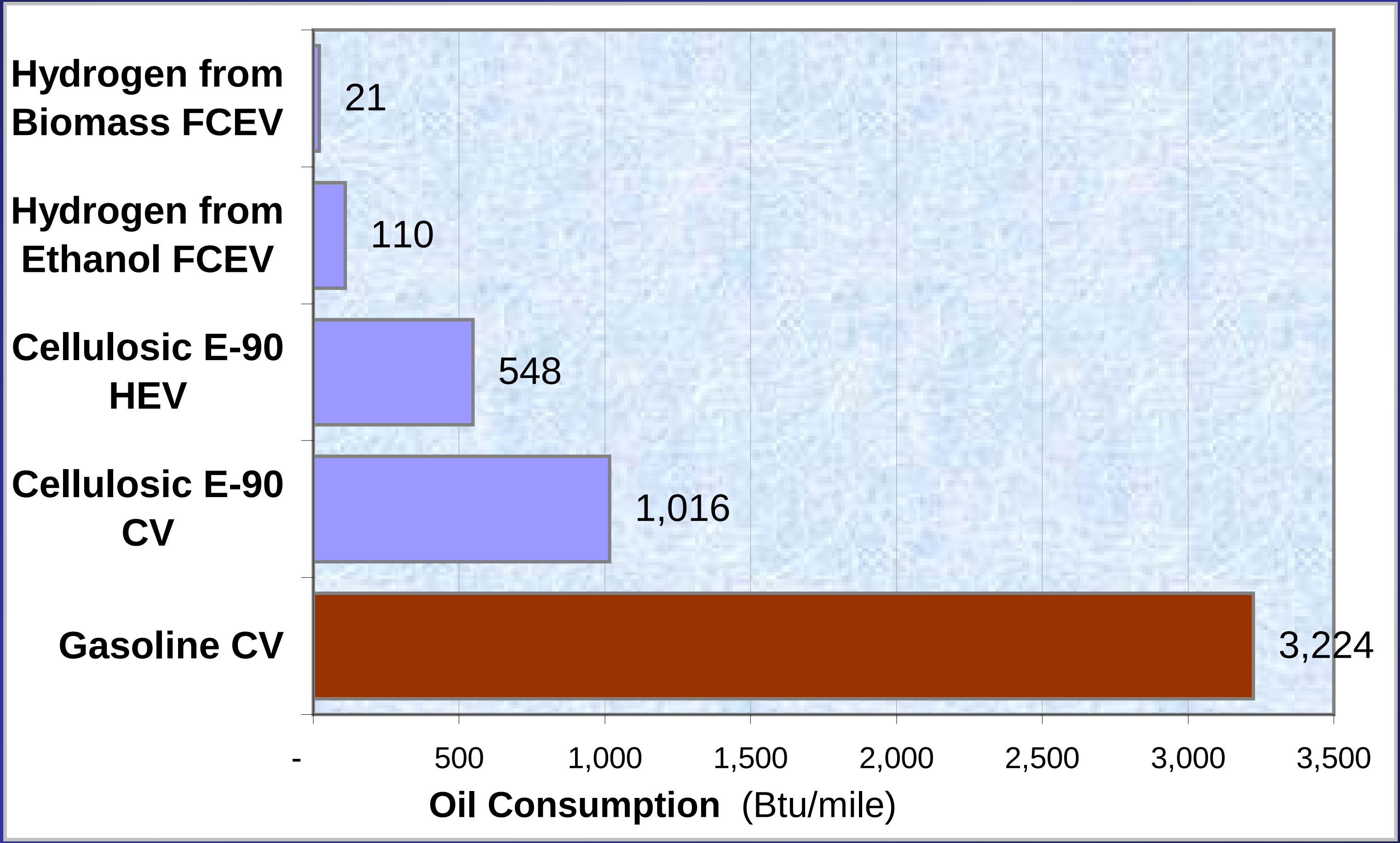
Ethanol Plug-In Hybrid Scenario Market Shares



Story Simultaneous.XLS; Tab 'Graphs'; ED 30 2/17 /2009

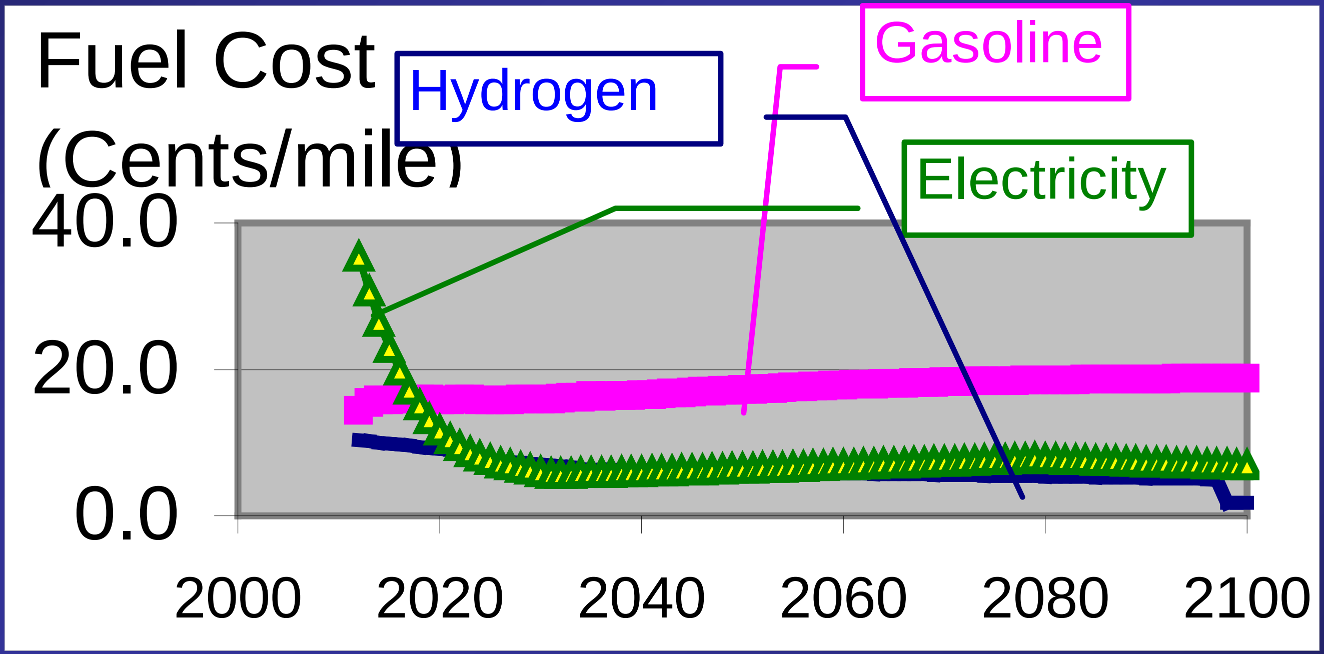
[50% market share potential by 2031, 75% plug-in potential limited by charging outlet availability, 85 billion gallon/year ethanol production (vs. 7 B/yr now, 90 B/ gallon/yr potential projected by Sandia-Livermore, and 60 B gallon/yr limit used by NRC)]

Hydrogen from Ethanol & Biomass: Oil Consumption per mile Comparison



Hydrogen Production Efficiency.XLS; Tab 'GREET'; J 53 3/6 /2009

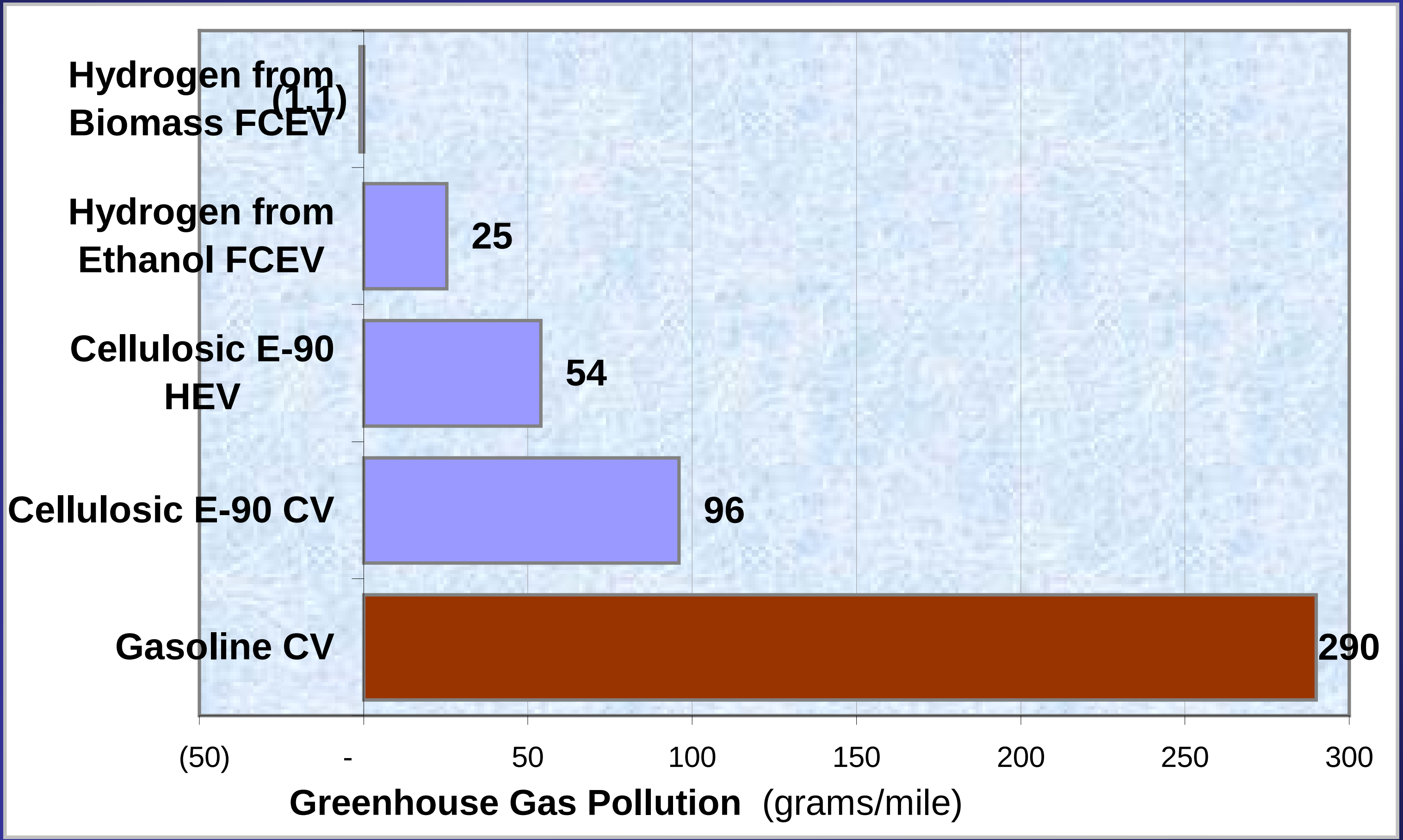
Both hydrogen & Electricity will cost less per mile than gasoline



Graphs for Simultaneous Story.XLS;' WS 'Fuel Savings'; BF 101 3/2 /2010

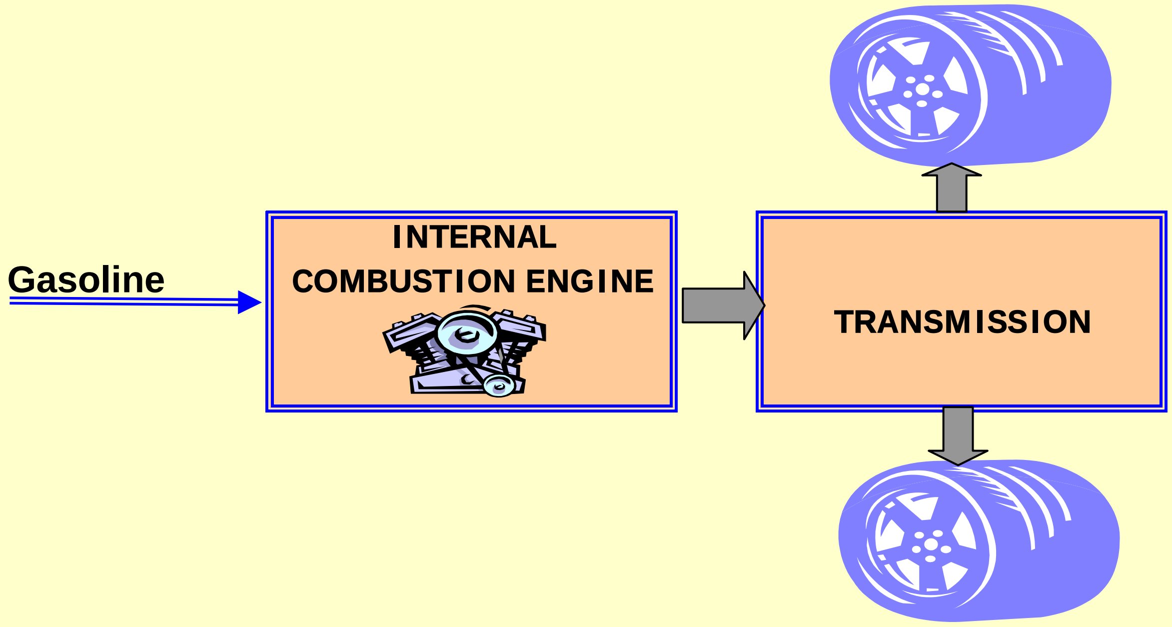
SO drivers purchasing BEVs and FCEVS will pay more up front, but save money on fuel over the long-run

Hydrogen from Ethanol & Biomass: Greenhouse Gas per mile Comparisons

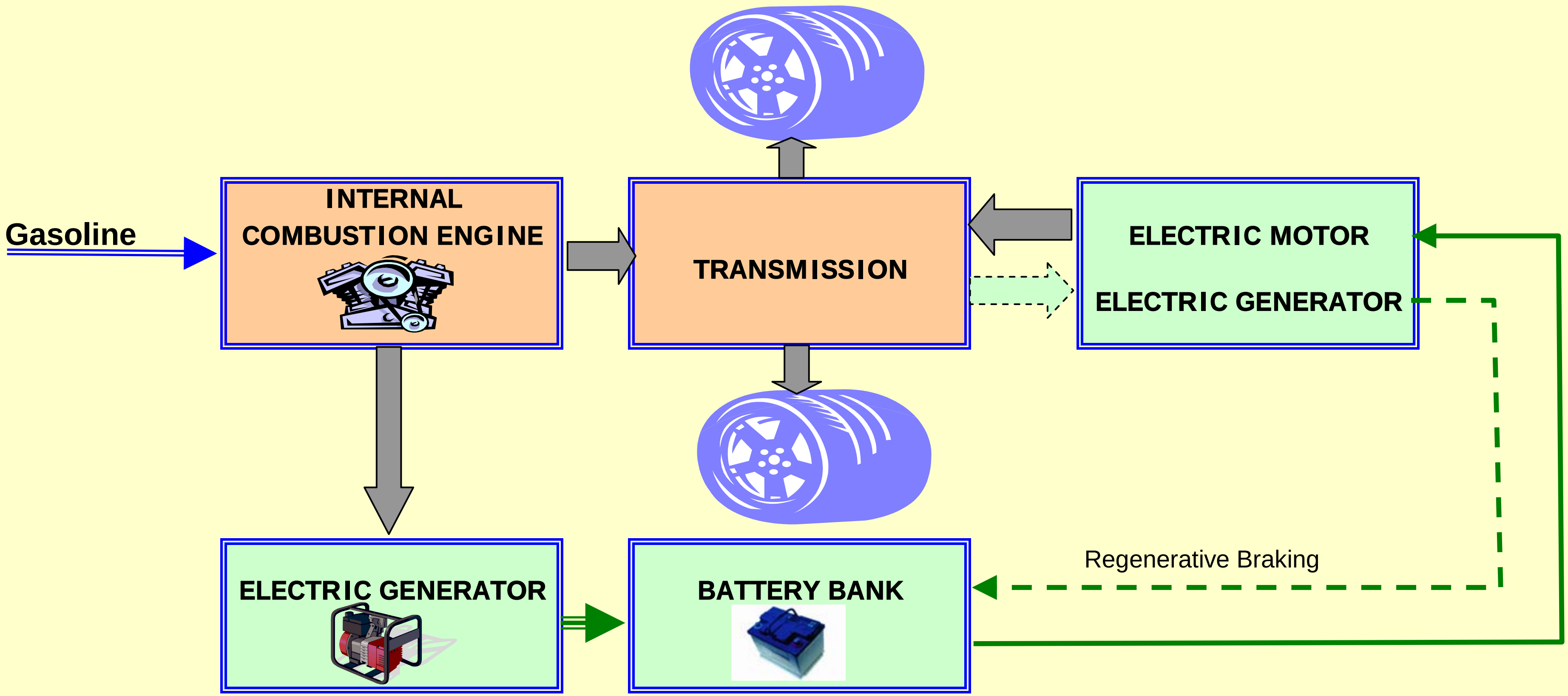


Hydrogen Production Efficiency.XLS; Tab 'GREET'; J 74 3/6 /2009

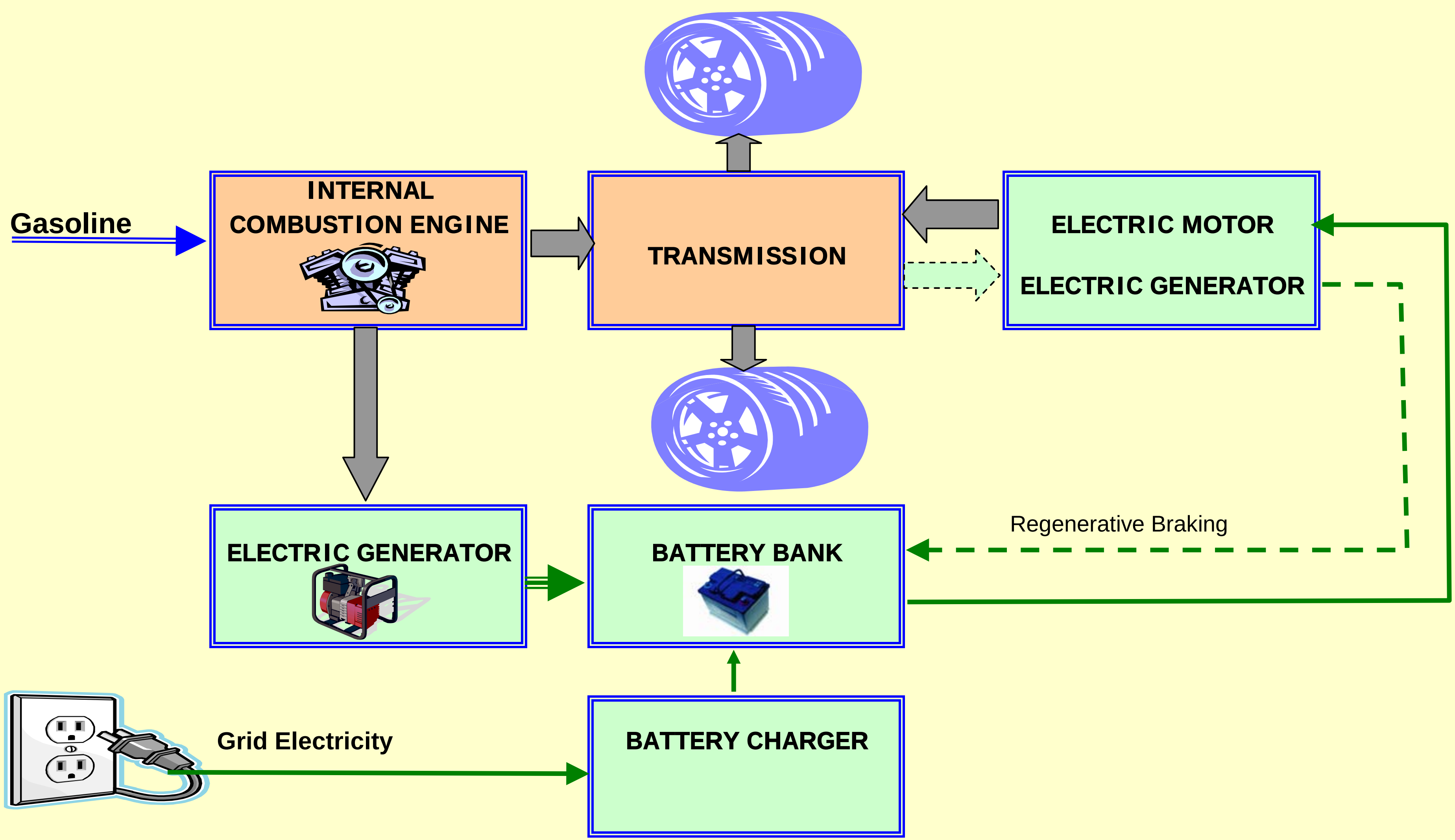
Conventional Gasoline Car



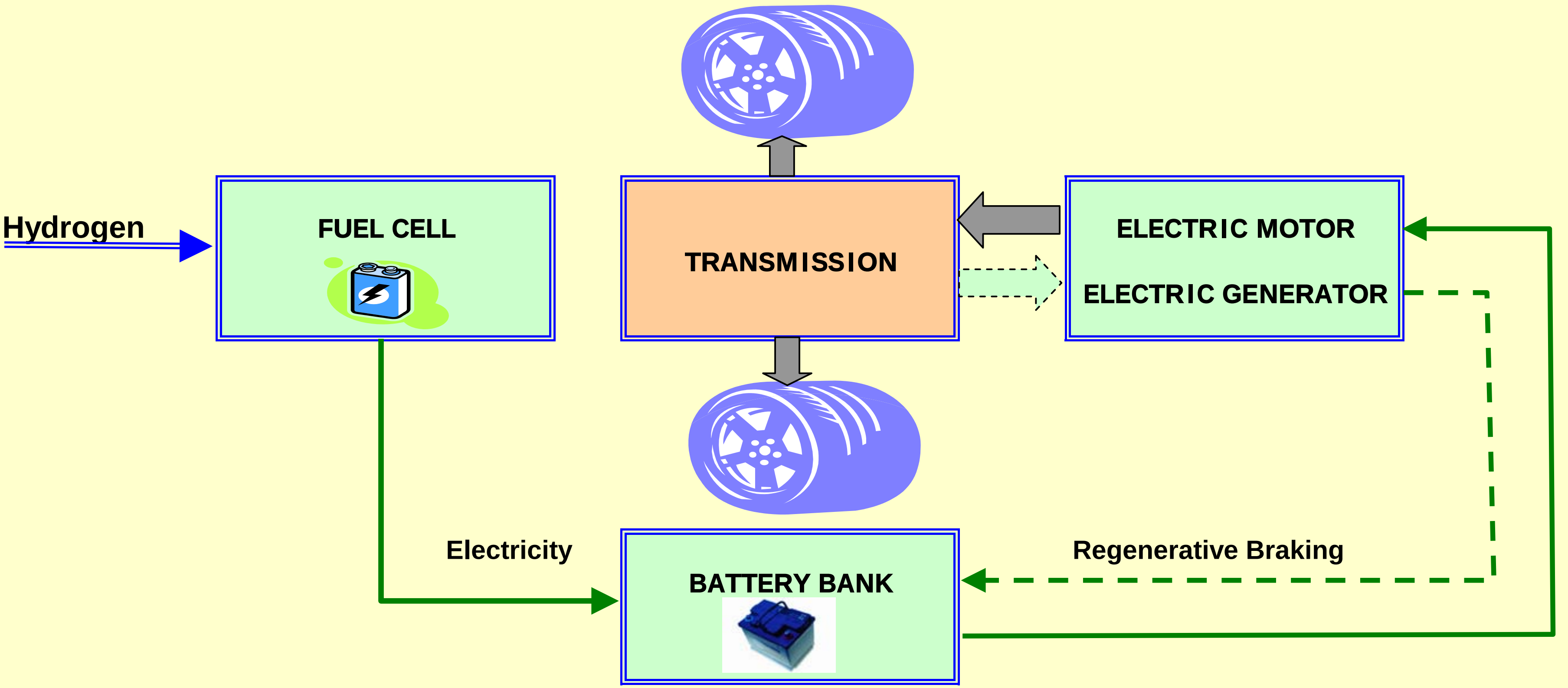
Hybrid Electric Vehicle (HEV)



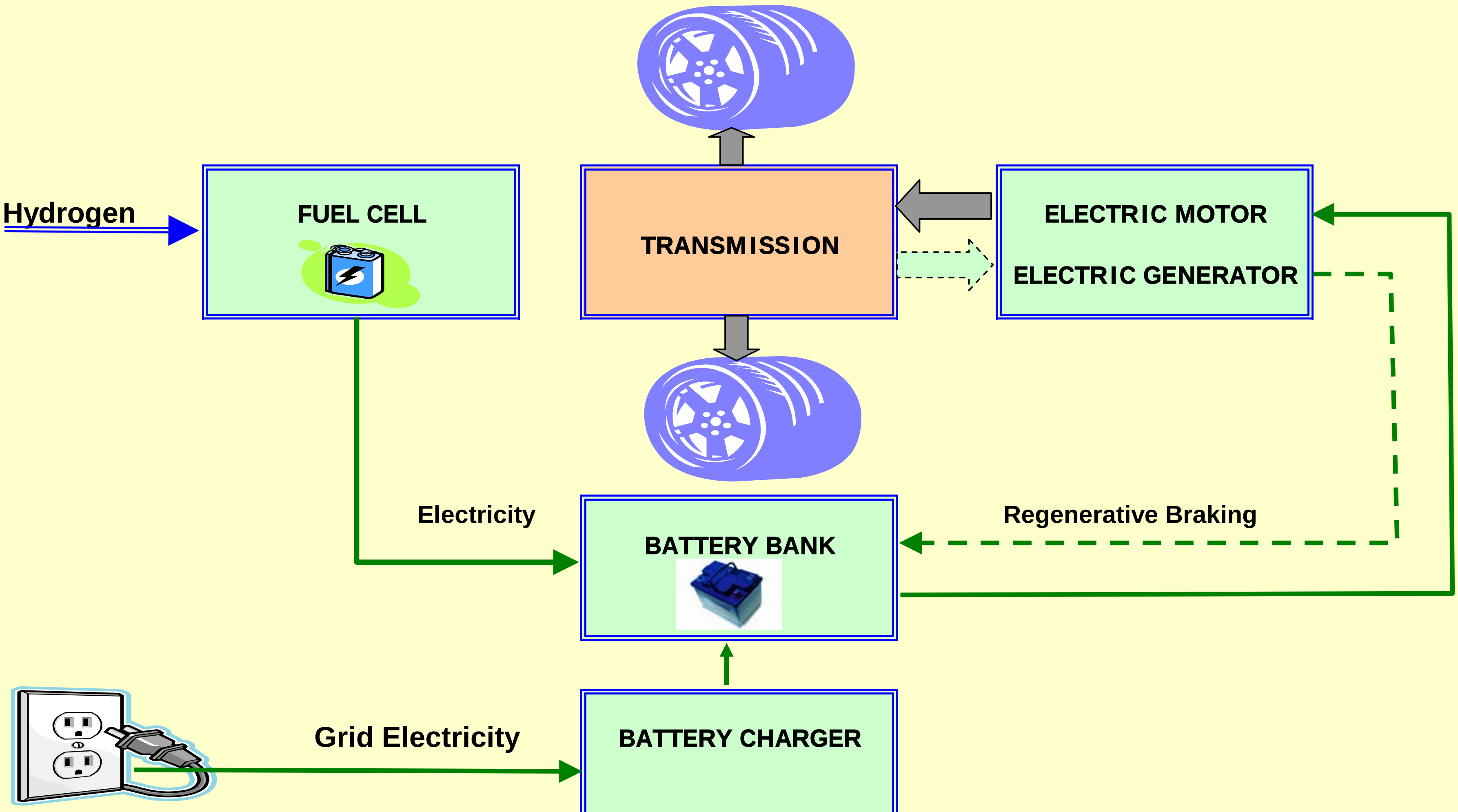
Plug-In Hybrid Electric Vehicle (PHEV)



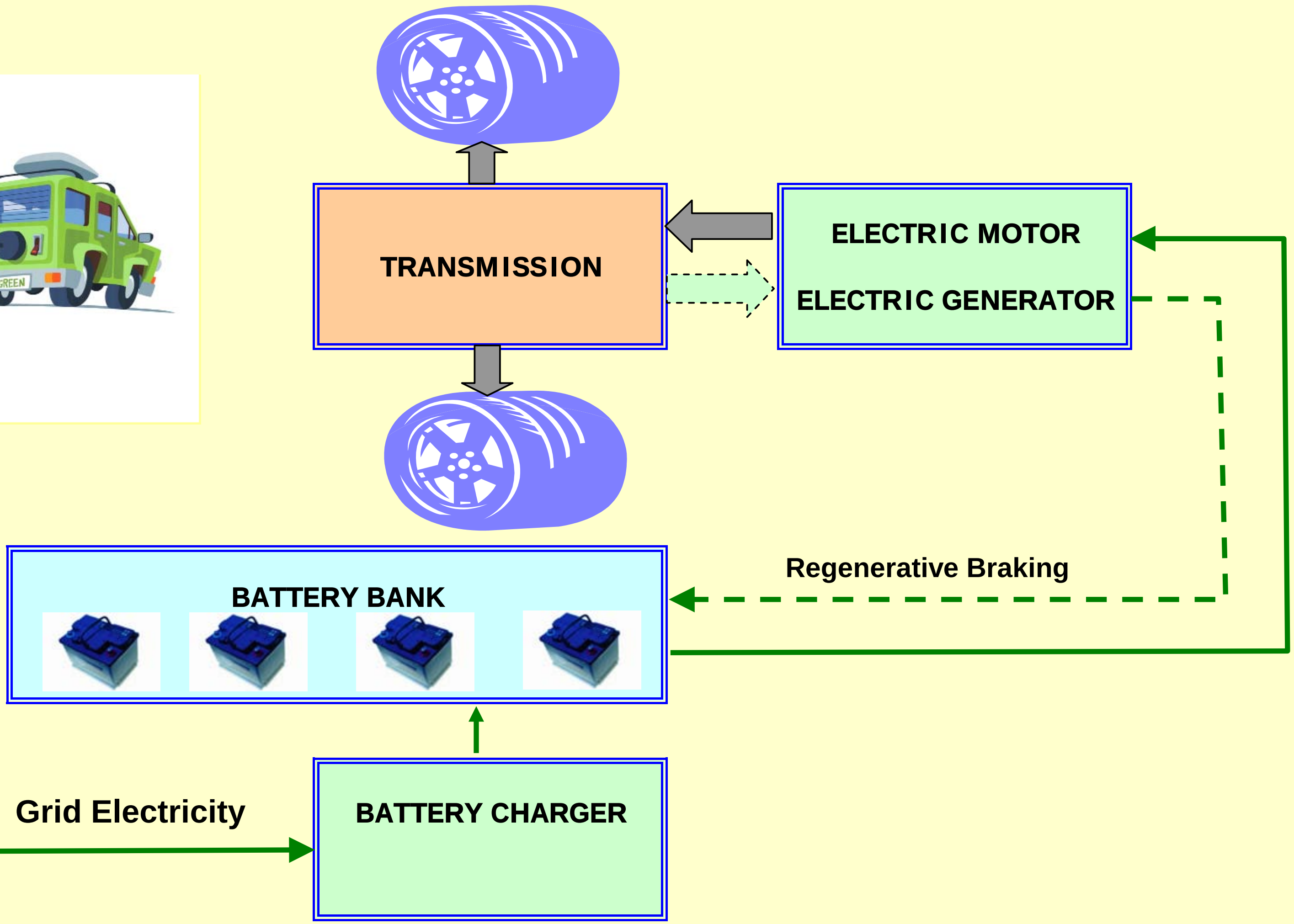
Fuel Cell Electric Vehicle (FCEV)



Plug-In Fuel Cell Electric Vehicle

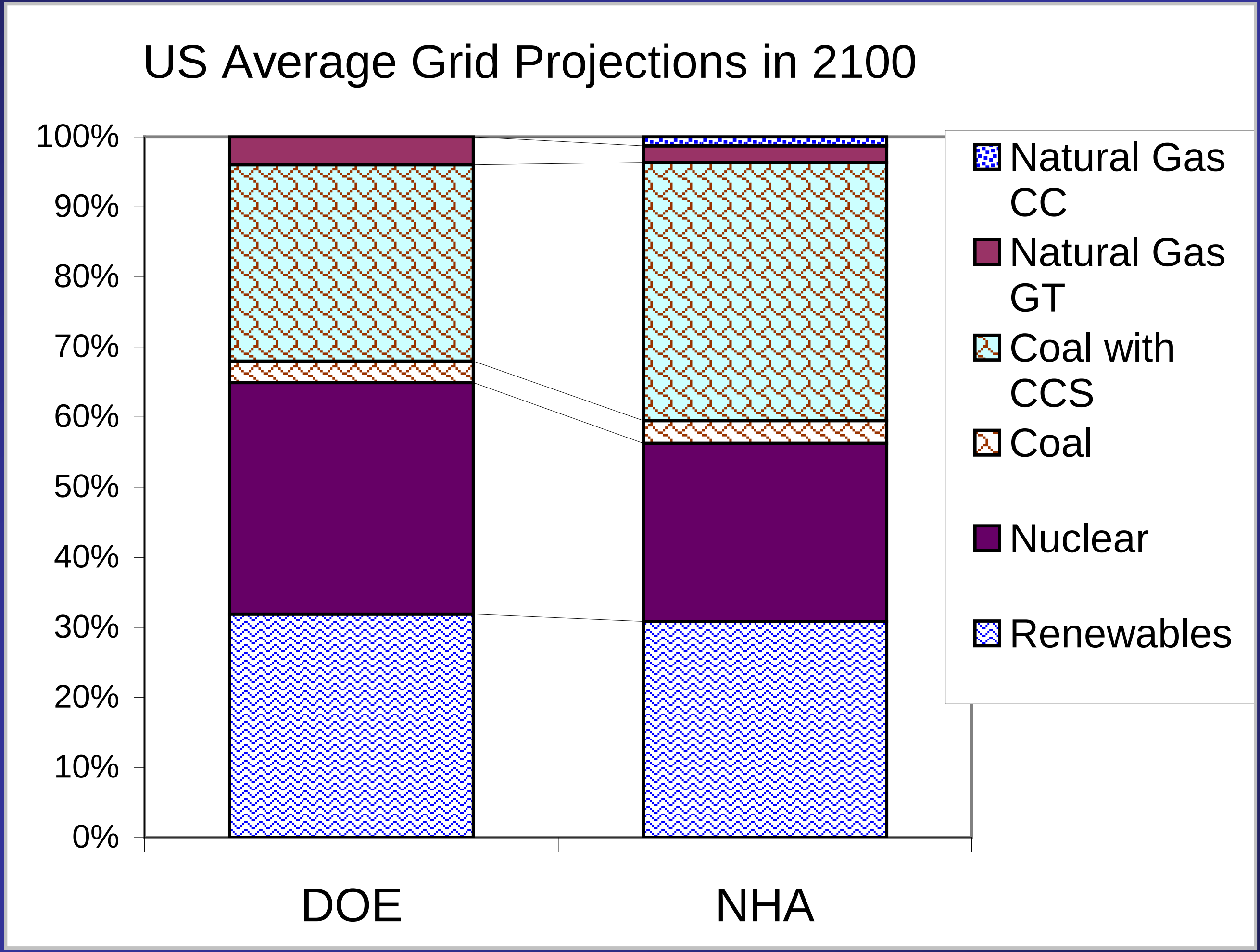


Battery Electric Vehicle (BEV)



DOE vs. NHA Grid Mixes

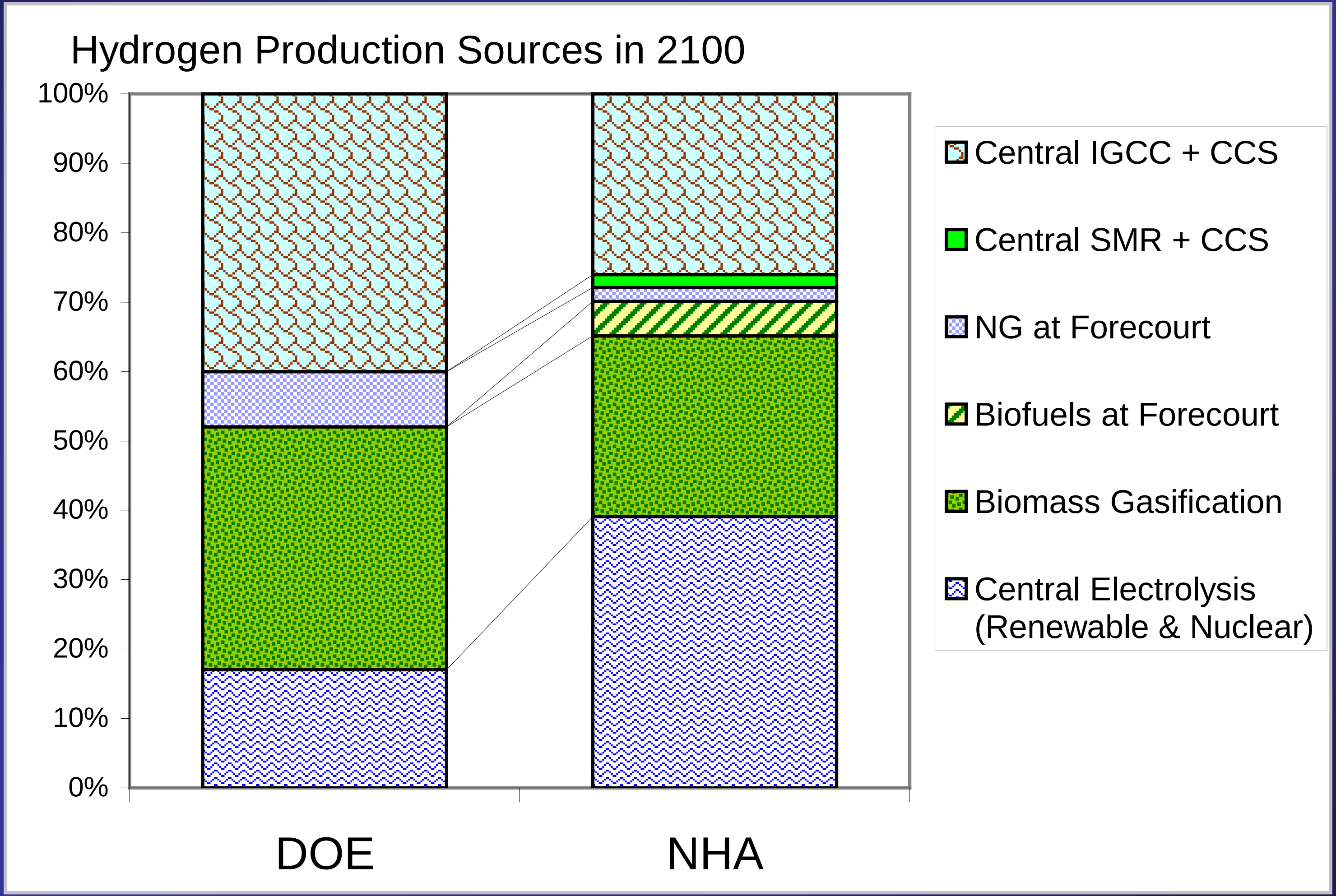
(DOE Grid slightly "greener")



GHG.XLS, Tab 'US Grid'; W115;2/4/2009

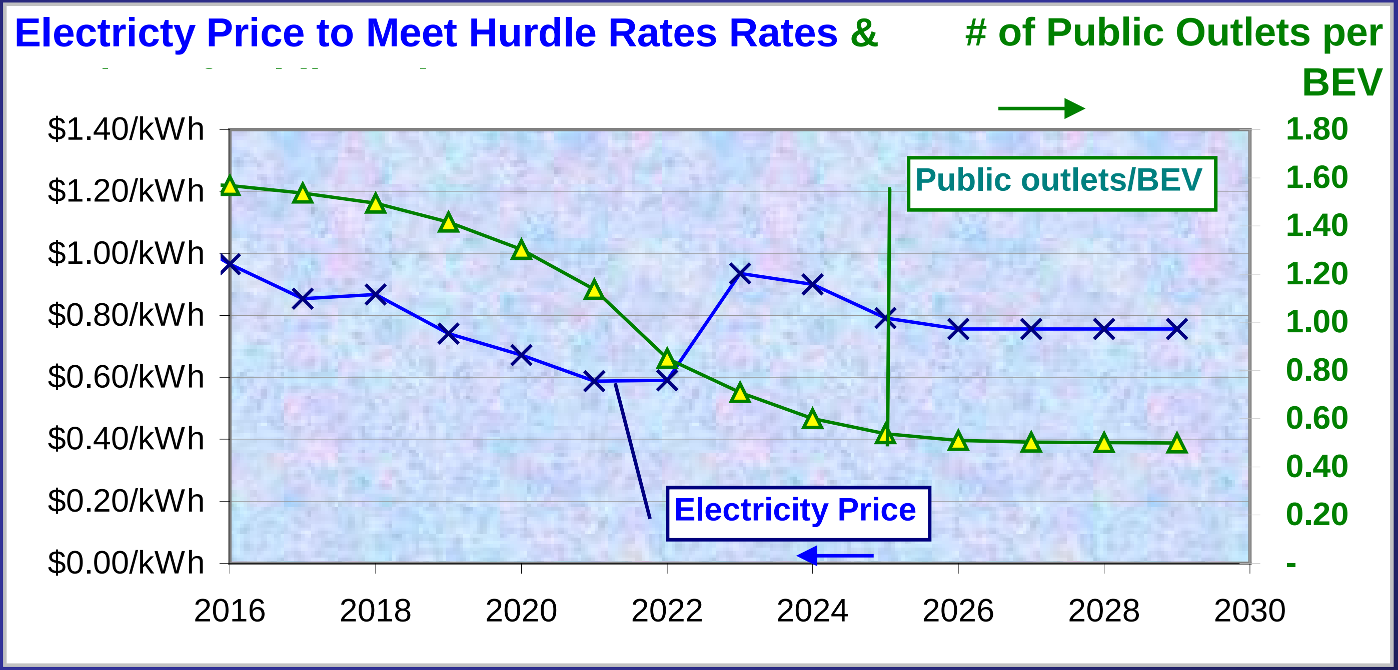
DOE vs. NHA H2 Production

(DOE H2 less green)



Summary Greet 1.8a.XLS; Tab 'Fuel TS'; W 65 2/16 /2009

Number of Public Charging Outlets per BEV and Electricity price @ public outlet to make >25% IRR

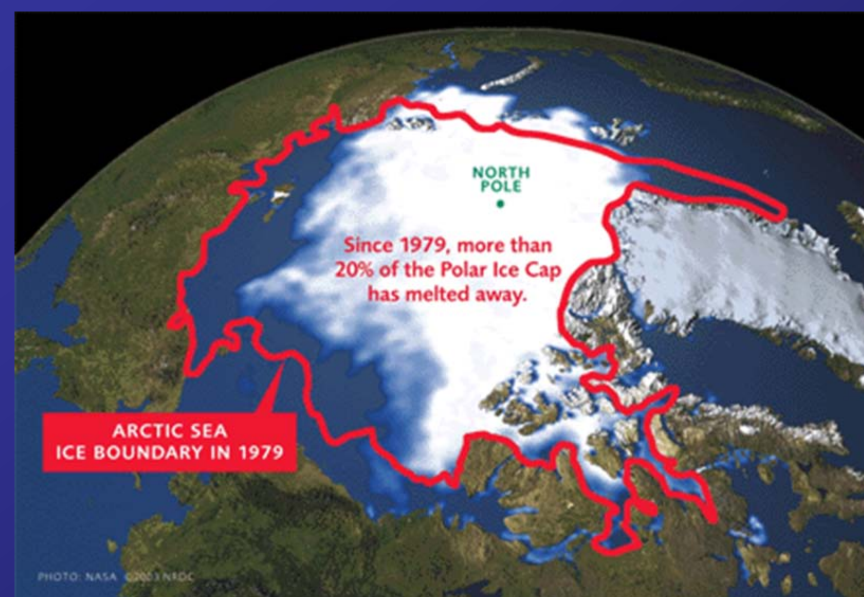


Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives';AM 38 5/9 /2010

Key Threat to Society: ***Oil Consumption***

Energy Security

Climate Change



Estimated Potential Distribution Transformer Risk of Failure Rates from plugging in one PHEV

	Feeder A		Feeder B	
	On-peak	Off-peak	On-peak	Off-peak
120V	7.8%	0.0%	5.9%	0.0%
240V	53.0%	45.0%	66.0%	58.0%

Graphs for Story Simultaneous.XLS; Tab 'Transformers'; F 24 4/28 /2010

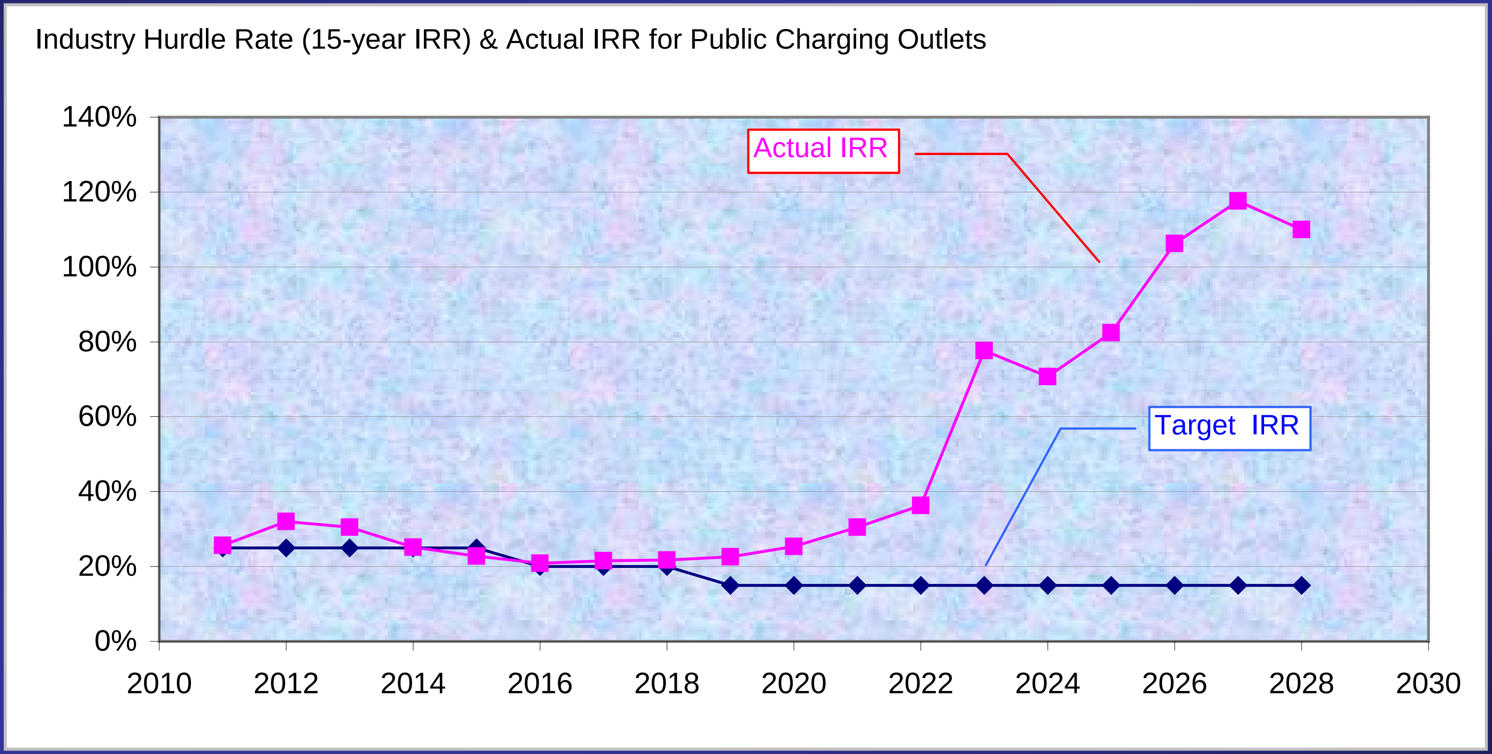
Source: Maitra, A, Kook, K.S., Giumento, A, Taylor J, Brooks,D, Alexander M, Duvall M. "Evaluation of PEV Loading Characteristics on Hydro-Québec's Distribution System Operations," EVS24, Stravanger, Norway May 13-16 2009. (EPRI and Hydro-Québec Distribution) Note: these feeder circuits were heavily loaded before adding the load from one PHEV

Investments do NOT include Local Distribution Transformers

- EPRI analyzed 53 residential Neighborhoods
- They estimated that plugging in one PHEV during the day would overload36 of the 53 distribution transformers (68%), and plugging in just one PHEV at night would overload 5 of 53(9%)neighborhood transformers. [Each transformer serves 5 to 15 homes.]
- At a cost of $5,000 per transformer, the cost per PHEV or BEV would increase substantially

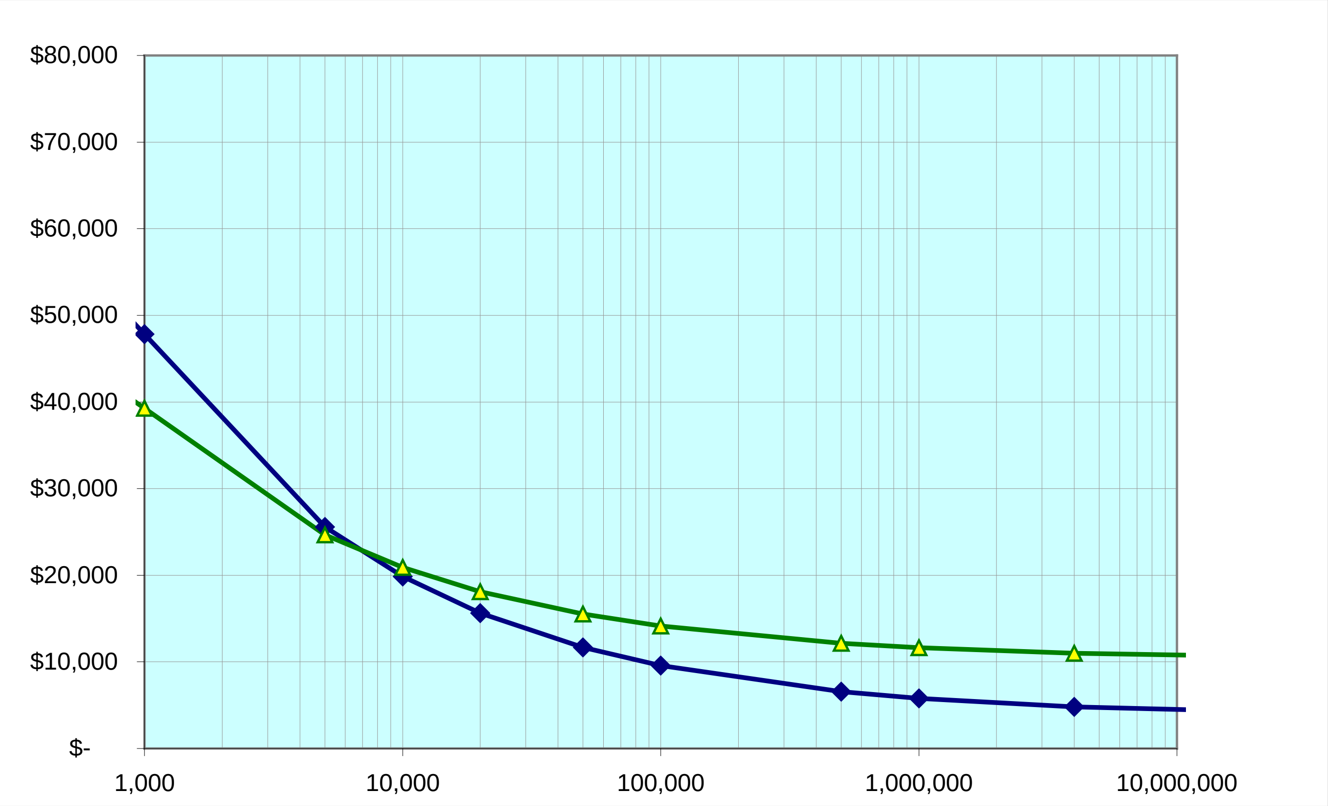
Source: The Electrification Roadmap, page 102

Target Hurdle Rates and Actual IRR's for Public charging stations



Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; U272 5/9 /2010

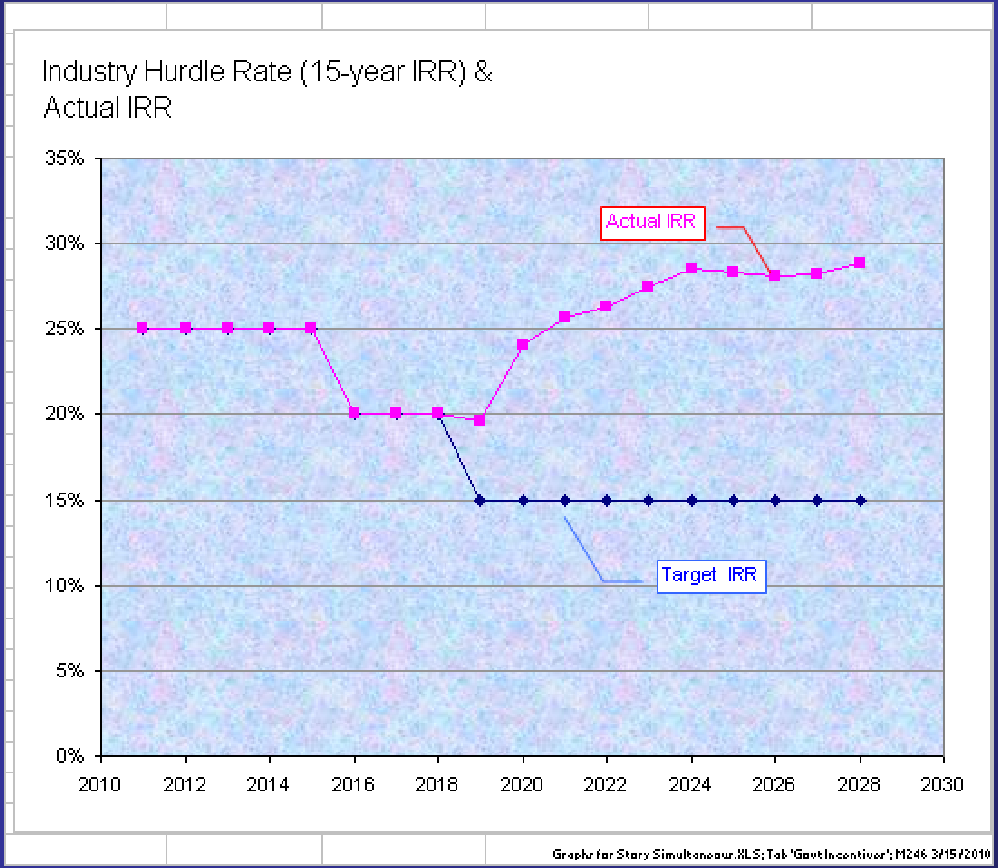
FCEV & BEV costs vs. Production volume



Incremental Costs	FCEV-350	BEV-200
Single Vehicle	$ 250,000	$ 180,000
2020 (428,000 cars)	$ 6,781	$ 12,290
2030 (12 million cars)	$ 4,348	$ 10,691
Mass Production	$ 3,600	$ 10,200

Story Economics.XLS; Tab 'Static AFV'; AM 73 5/10 /2010

Industry IRR Hurdle rates & Actual IRRs for infrastructure



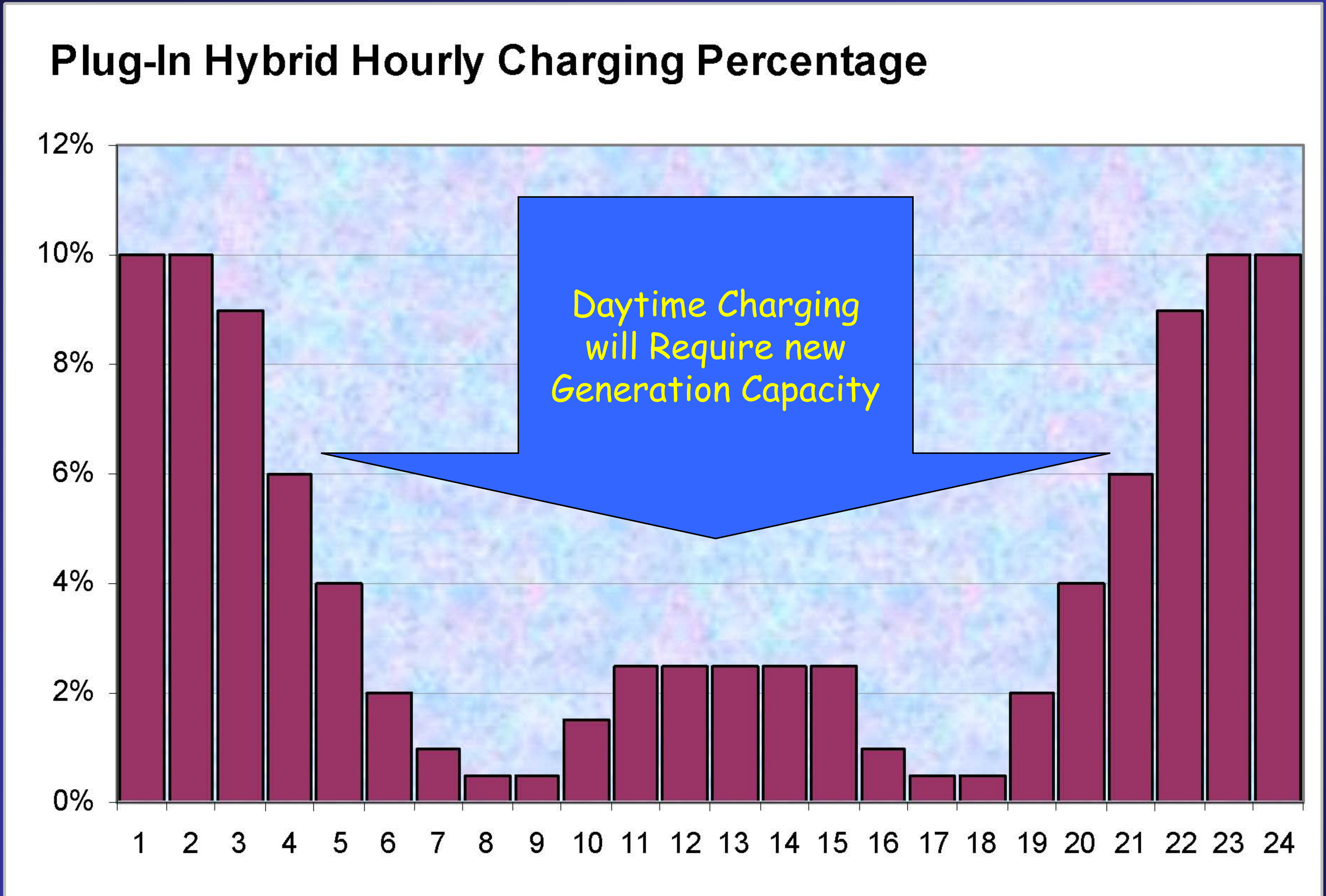
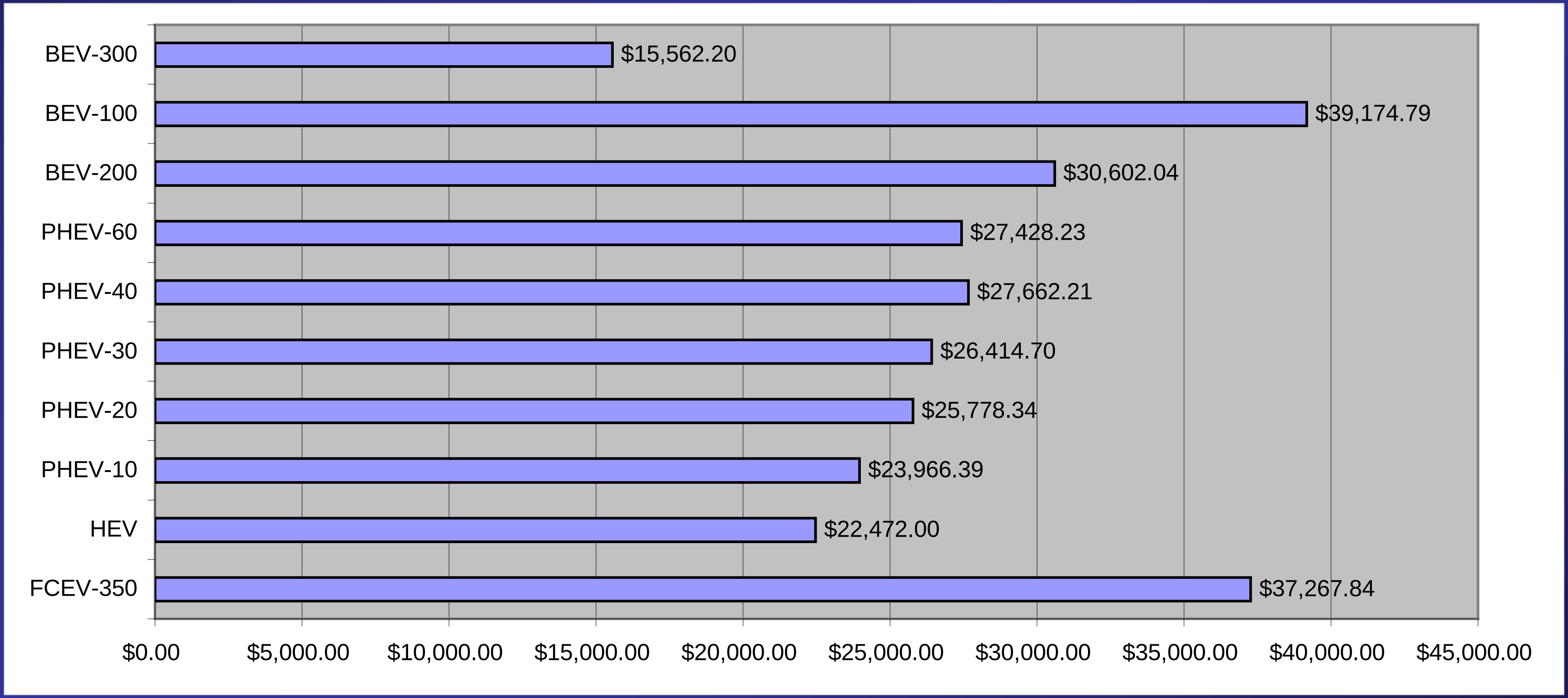


Figure 1. PHEV charging profile suggested by EPRI

business case for Fleet owners: 15-year Net Present Value (10% Discount Rate)



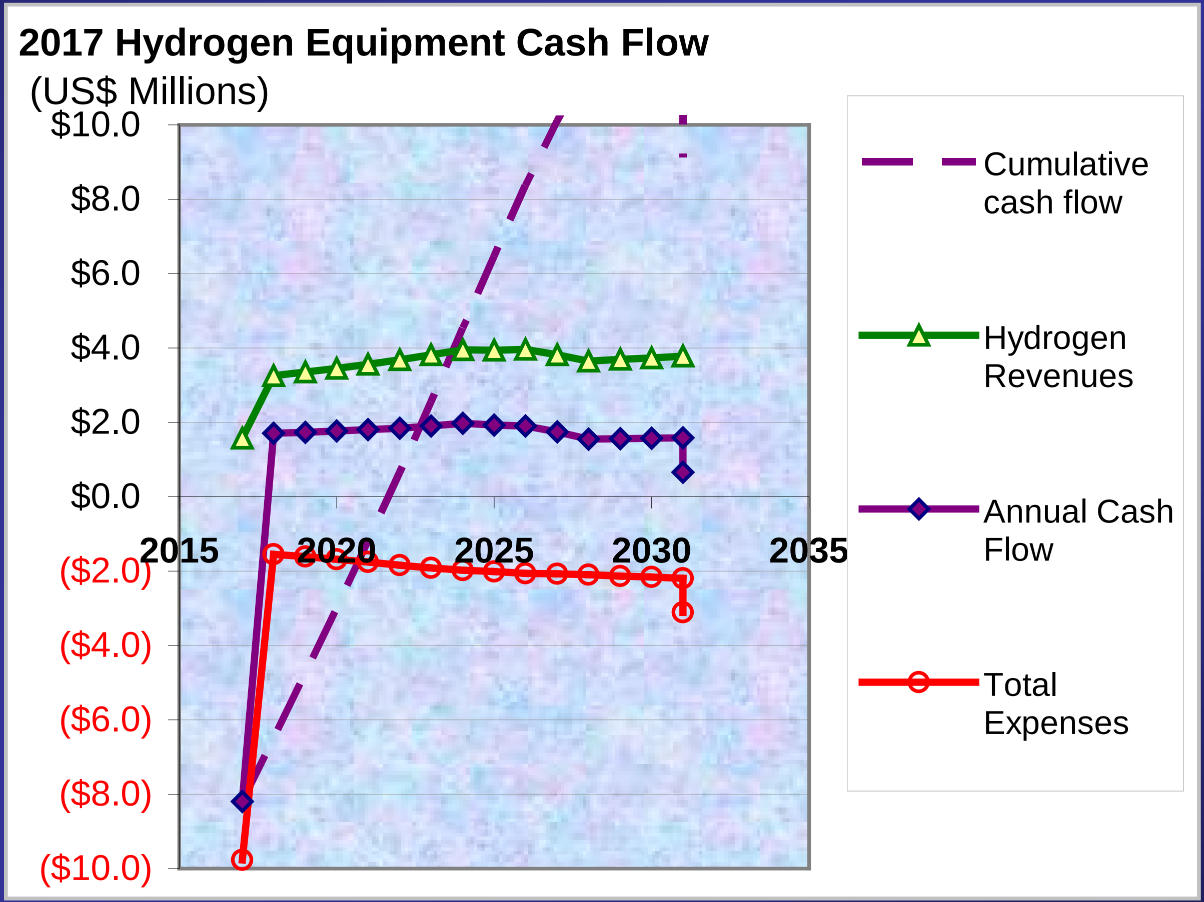
Graphs for Simultaneous Story.XLS;' WS 'Fuel Savings'; BZ 27 3/3 /2010

AFV Cost & fuel economy data

		ICV	HEV	PHEV-10	PHEV-20	PHEV-30	PHEV-40	PHEV-60		BEV-100	BEV-200	BEV-300	FCEV-350
Vehicle mass	kg	1284	1290	1296	1315	1338	1366	1434	2029	1377	1648	2214	1292
All-electric range	miles			10	20	30	40	60		100	200	300	350
ICE Fuel Economy/ ICV fuel economy		1	1.544	1.54	1.527	1.515	1.492	1.463					2.4
Gasoline energy-equivalent fuel e	mpgge	25	38.6	38.5	38.2	37.9	37.3	36.6					60
Fraction of VMT on electricity				13.3%	27.2%	38.4%	46.7%	54.9%		1.0	1.0	1.0	
Grid Electricity consumption in Al	kWh/mile			0.356	0.358	0.362	0.366	0.377		0.368	0.410	0.497	
Gasoline Fuel Cost	$/year	$ 1,871	$ 1,212	$ 1,053	$ 891	$ 761	$ 668	$ 576					
Electricity Fuel Cost	$/year			$ 91	$ 187	$ 266	$ 327	$ 396		$ 704	$ 785	$ 951	
Total Annual Fuel Cost	$/year	$ 1,871	$ 1,212	$ 1,144	$ 1,078	$ 1,027	$ 995	$ 973		$ 704	$ 785	$ 951	$ 685
Annual Driver Savings in Fuel	**$/year**	**$ -**	**$ 659**	**$ 727**	**$ 793**	**$ 844**	**$ 875**	**$ 898**		**$ 1,166**	**$ 1,086**	**$ 920**	**$ 1,185**
Battery Mass Production Cost	($/kWh)												
Mass Production Incremental Price over ICV		0	$ 2,126	$ 8,388	$ 9,728	$ 11,414	$ 13,809	$ 15,995		$ 12,243	$ 20,889	$ 38,731	$ 19,866
Mass Production Payback Perioc	Years			$ 798	$ 798	$ 798	$ 798	$ 798		$ 798	$ 798	$ 798	

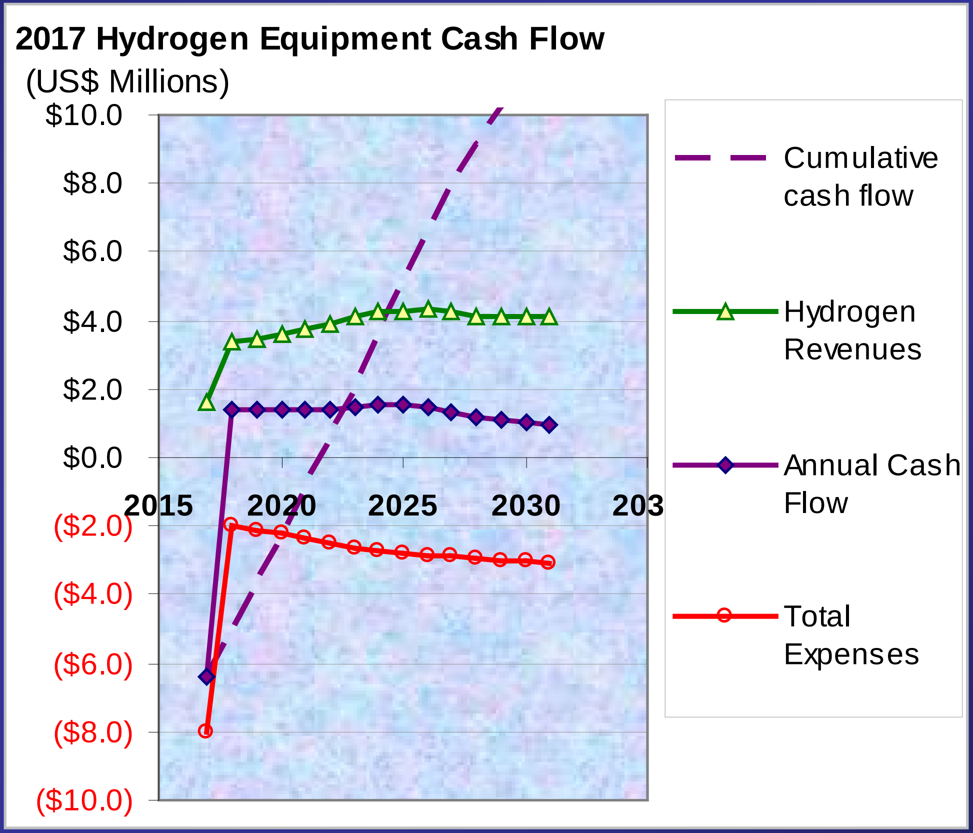
Graphs for Story Simultaneous.XLS; Tab 'AFV Data'; O 18 3/15 /2010

Hydrogen Industry Cash Flow for 2017



Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; Y69 3/15 /2010

Hydrogen Industry Cash Flow for 2017



Estimated Installed Cost for Hydrogen Fueling Stations

		DOE's H2A Model		
		Single Quantity**	500 units*	
Mobile Refueler***	100 kg/day	$ 1,000,000	$ 243,000	
LH2 Station	400 kg/day	$ 1,682,000	$ 1,071,000	
LH2 Station	1000 kg/day	$ 2,053,000	1285000	

* 500 quantity estimates from DOE H2A for LH2 Stations

** Single quantity estimates extrapolated from DOE H2A model

*** Mobile Refueler estimates from UC-Davis

Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; F 56 4/26 /2010

On-site Hydrogen is Competitive with Gasoline

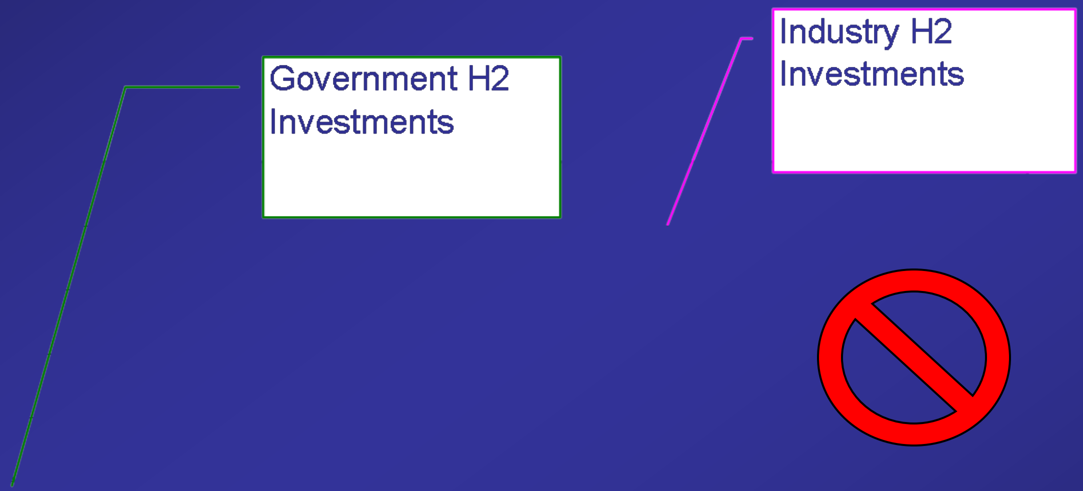
	Evaluation Year	2015	Hydrogen Cost From On-Site Steam Methane Reformer System ($/kg)			**FCEV Hydrogen Cost per Mile Traveled** ($/gallon of gasoline equivalent, untaxed)	
	Hydrogen Production Capacity	Equipment Production Quantities	Production Cost	Compression & Storage Cost	Total Cost ($/kg)	Relative to Hybrid Electric Vehicle	**Relative to Conventional Car**
Today HGM2k (20 cars/day)	**115 kg/day**	**> 10**	5.32	3.15	8.46	$5.18/ggre	**$3.57/ggre**
Today HGM3k (30 cars/day)	**172 kg/day**	**> 10**	4.07	2.56	6.63	$4.05/ggre	**$2.80/ggre**
Today HGM10k (100 cars/day)	**578 kg/day**	**> 10**	3.08	1.89	4.97	$3.04/ggre	**$2.10/ggre**
~4 Years HGM10k (100 cars/day)	**578 kg/day**	**> 200**	2.77	1.65	4.42	$2.70/ggre	**$1.86/ggre**
~6 Years (250 cars/day)	**1,500 kg/day**	**>500**	2.12	1.05	3.17	$1.94/ggre	**$1.34/ggre**

Assumptions: Annual Capital Recovery factor = 19.1%; Capacity Factor = 75%; Natural Gas = $6.44/MBTU
Electricity = 5.93 cents/kWh; FCV fuel economy = 2.4 X ICEV; HEV fuel economy =1.45 X ICEV
Gasoline price = $3.17gallon in 2015

H2Gen:Markets4.XLS, Tab'H2 Cost Table' M23;3/16/2010

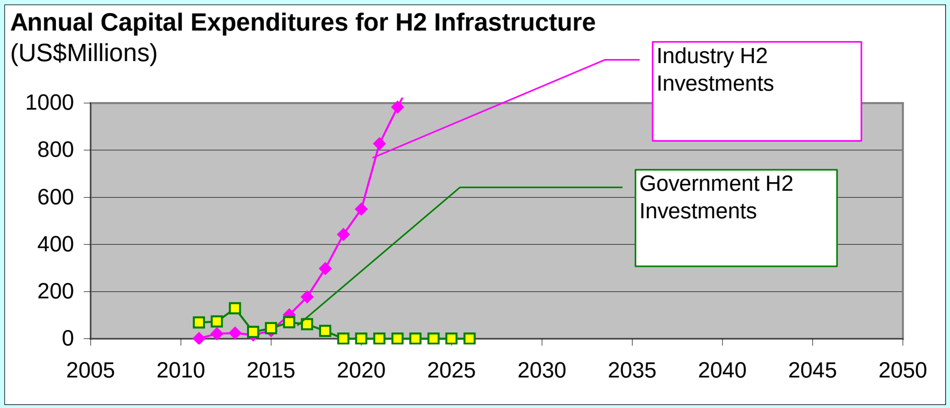
Based on 10% real, after-tax ROI with EIA 2010 Annual Energy Outlook fuel costs

Hydrogen Infrastructure Investments

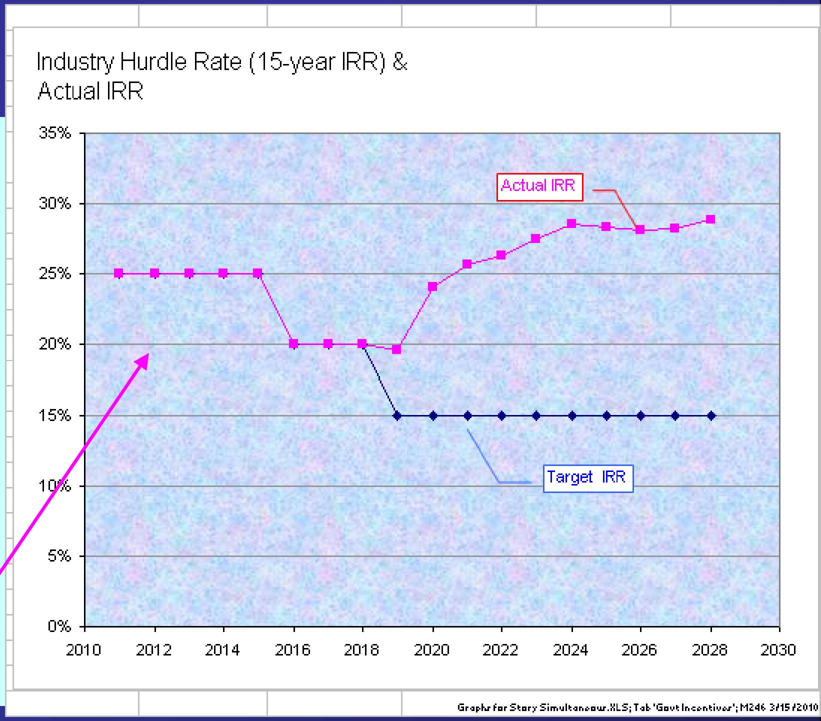


(Industry makes >25% IRR on all investments prior to 2015 and after 2022; No Government support required after 2023)

Hydrogen Infrastructure Investments

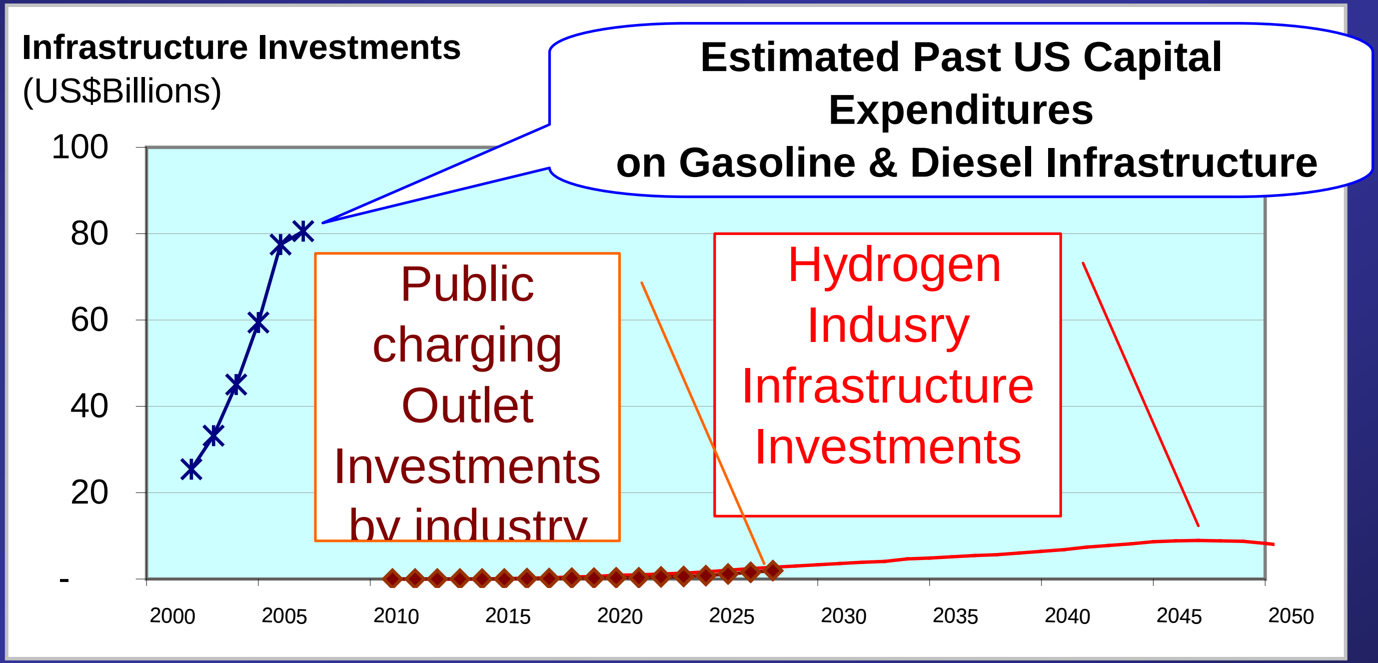


Total Government H2 Investments	506.05
Total INdustryH2 Investments	187,688.13
Total H2 Investments	188,194.18



(Industry makes >25% IRR on all investments prior to 2016 and after 2020; No Government support required after 2018)

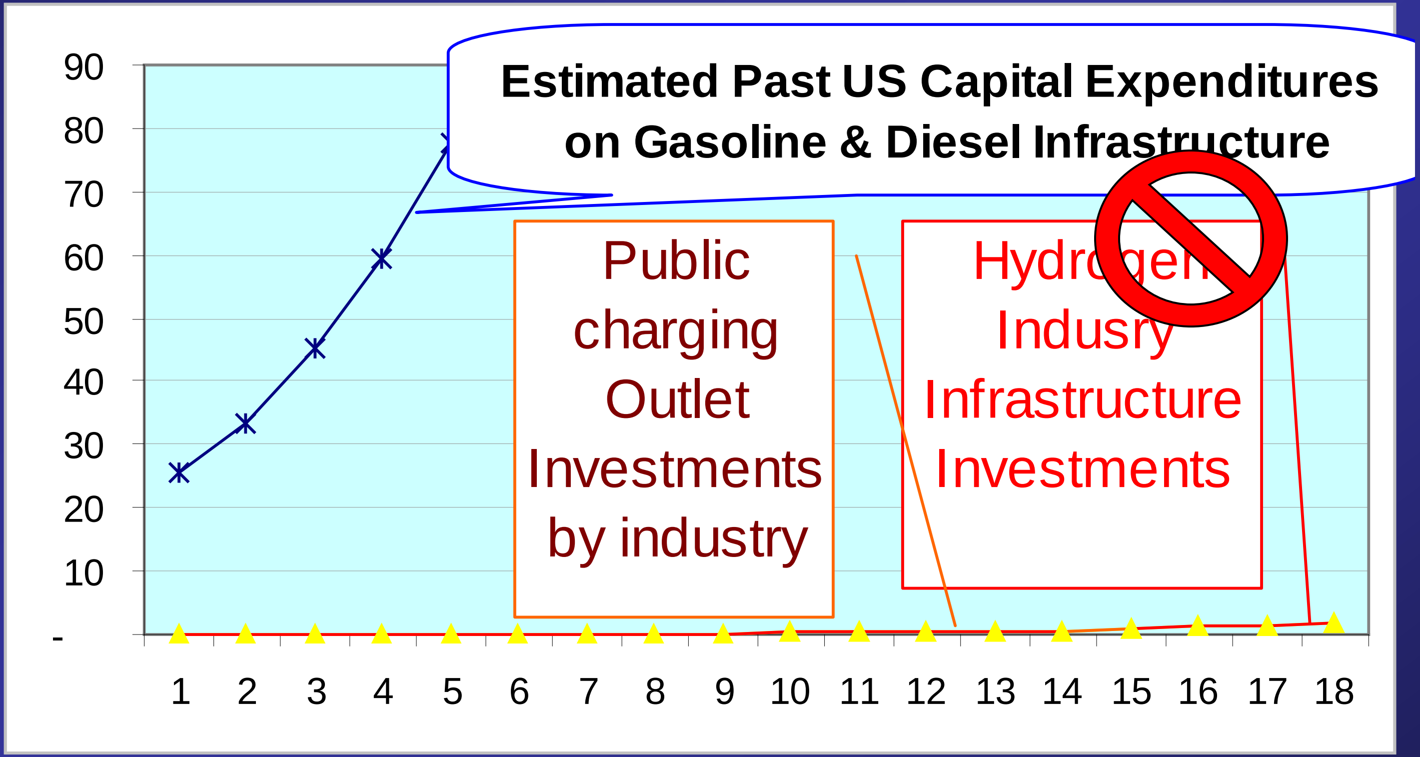
Industry annual Investments small compared to existing gasoline & Diesel infrastructure annual expenditures



Story Economics.XLS; Tab 'Web Graphs'; X 302 3/15 /2010

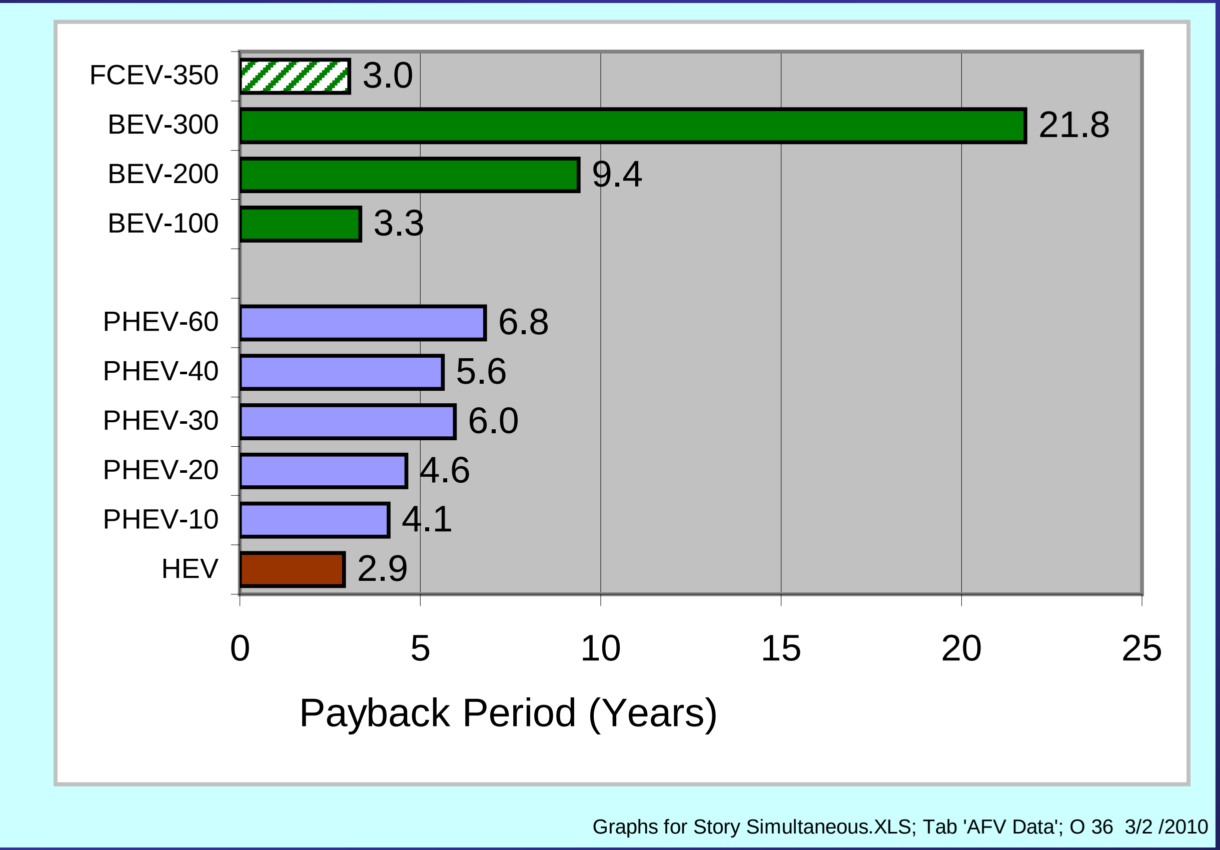
(Source for gasoline & Diesel infrastructure costs: Oil & Gas Journal)

Industry annual Investments small compared to existing gasoline & Diesel infrastructure annual expenditures

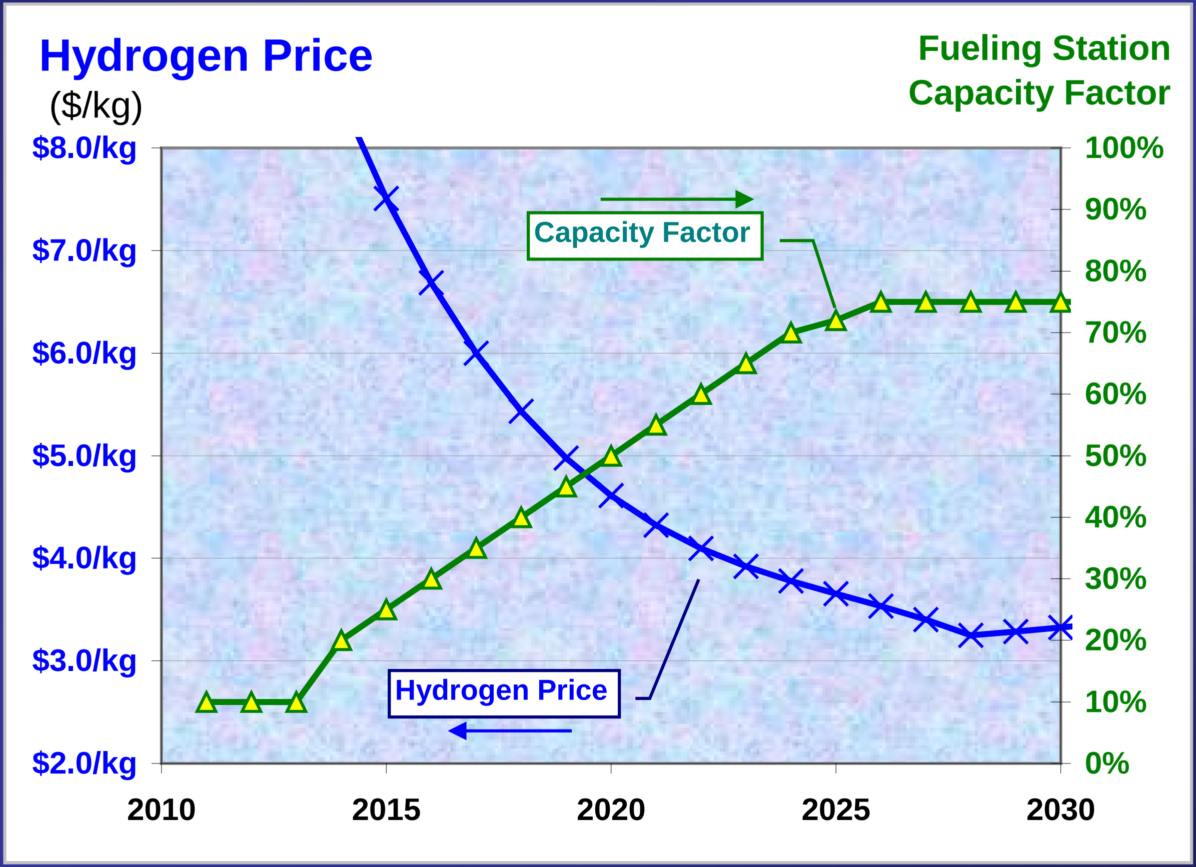


(Source for gasoline & Diesel infrastructure costs: Oil & Gas Journal)

Alternative Vehicle Pay-Back Period

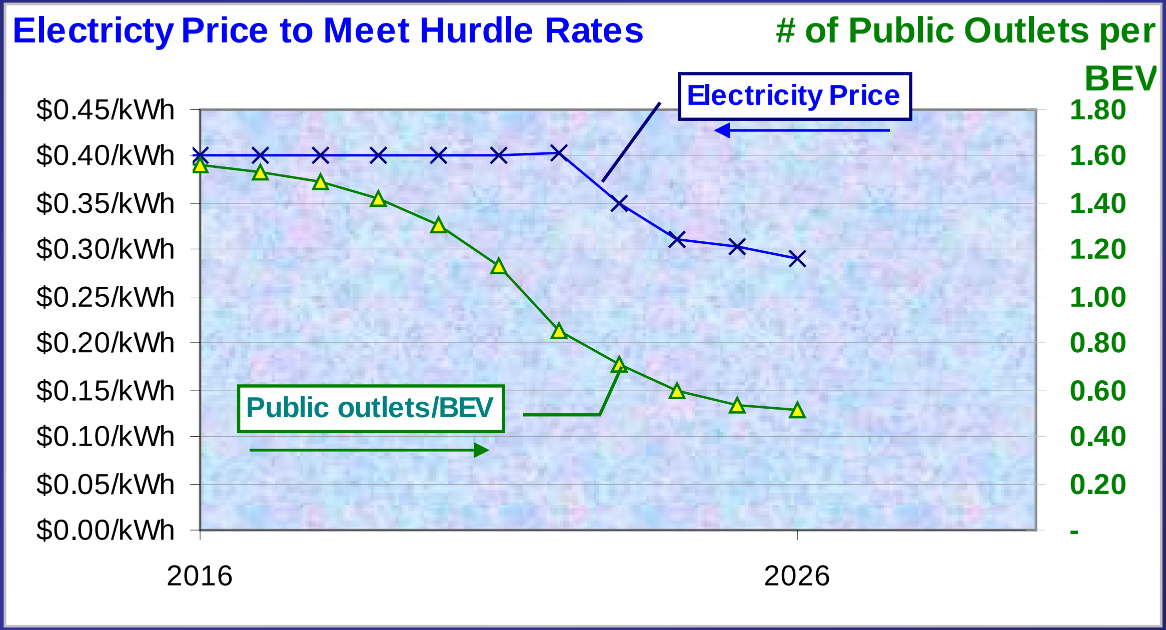


Hydrogen Price to make 25% IRR on capex



Graphs for Story Simultaneous.XLS; Tab 'Govt Incentives'; K 30 3/18 /2010

Electricity price @ public outlet to make 25% IRR



Capital & Installation Cost H2A Variances for natural gas reformer

(based on 1,500 kg/day systems in 500 production quantities)

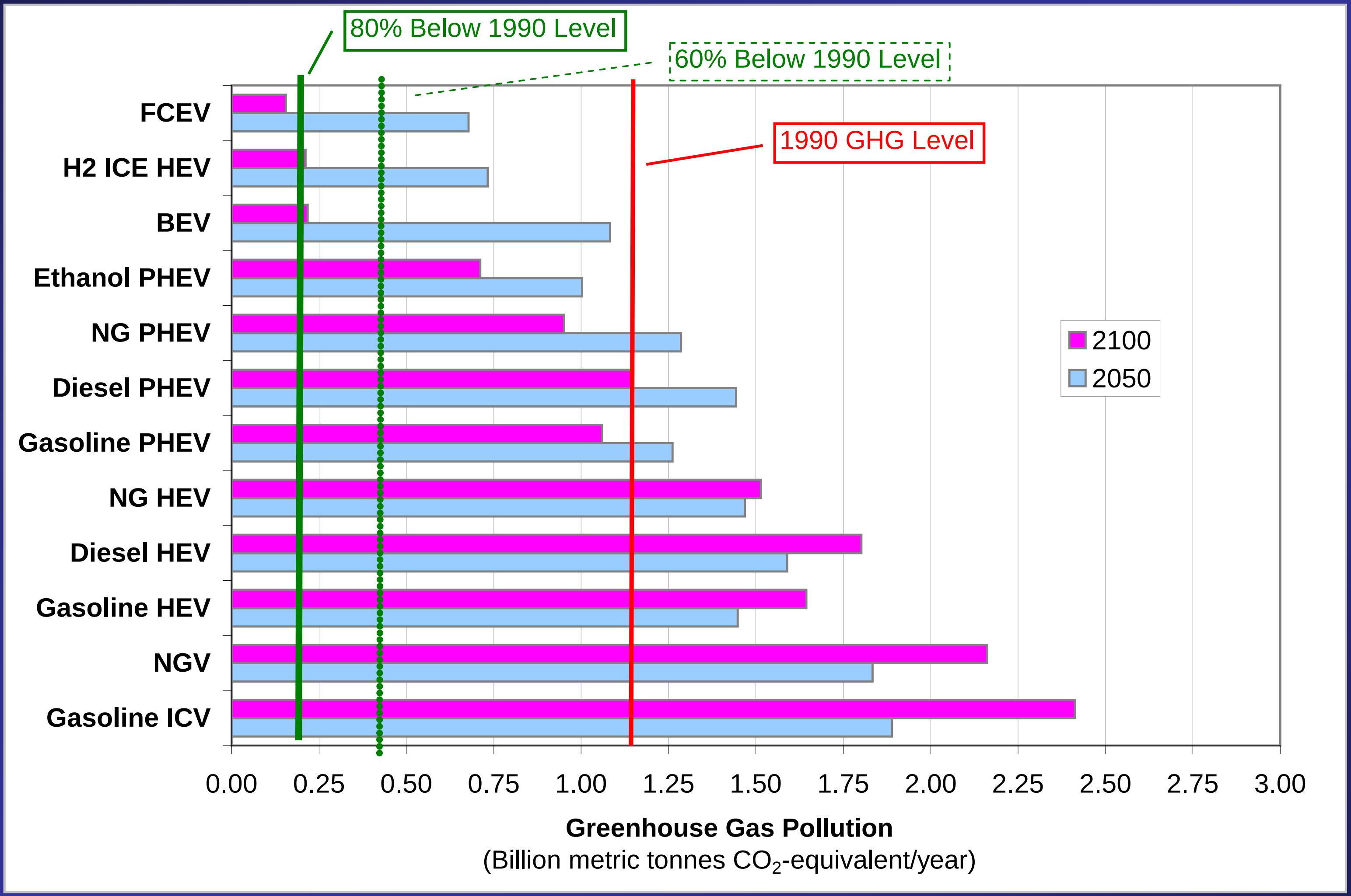
	H2A	H2Gen - NHA	Delta
SMR + PSA System FOB	**$1,172,478**	**$ 1,365,476**	**$ 192,998**
Installation Costs			
State Sales tax (5%)	$ 58,624	$ 68,274	$ 9,650
Unspecified (5%)	$ 58,624	$ -	$ (58,624)
Engineering Design	$ 30,000	$ -	$ (30,000)
Transportation & Insurance	$ -	$ 20,892	$ 20,892
On-Site Riggers	$ -	$ 16,200	$ 16,200
Site Preparation	$ 74,344	$ 81,993	$ 7,649
Utility Hook-ups	$ -	$ 26,714	$ 26,714
Permitting costs	$ 30,000	$ 30,000	$ -
Total Installation Costs	**$ 251,592**	**$ 244,073**	**$ (7,519)**
CSD	**$ 1,520,000**	**$ 1,563,000**	**$ 43,000**
Total Capital Costs	**$ 2,944,070**	**$ 3,172,549**	**$ 228,479**
Contingency %	*10%*	*2%*	
Contingency*	$ 294,407	$ 63,451	$ (230,956)
Total Costs with Contingency	**$ 3,238,477**	**$ 3,236,000**	**$ (2,477)**

H2Gen: HGM Cost Scaling size and quantity.XLS; Tab 'H2A Comparison';E21 - 3 / 16 / 2010

Excerpt from Electrification Roadmap

- “Early battery GEVs (grid-enabled electric vehicles…PHEVs and BEVs) “will have limited range, take hours to charge and will add significantly to vehicle cost.”

Greenhouse Gas Pollution Comparisons (2050 & 2100) The best NG option, the NG PHEV cannot approach the 80% GHG reduction target, even by 2100:



GHG = greenhouse gases

FCEV = fuel cell hybrid electric vehicle

HEV = hybrid electric vehicle

PHEV = plug-in hybrid electric vehicle

NG = natural gas

NGV = natural gas vehicle

ICV = internal combustion engine vehicle

Based on AEO 2010 data

Story Simultaneous.XLS; Tab 'Graphs'; BJ 464 5/15 /2009