

Low-Cost Hydrogen-from-Ethanol: A Distributed Production System

**Presented at the
Bio-Derived Liquids to Hydrogen Distributed Reforming
Working Group Kick-Off Meeting**

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Topics

- H₂Gen DOE Program
- Why convert ethanol to hydrogen?
- Hydrogen ICE Hybrid Electric Vehicles
- Renewable Hydrogen Comparisons
- 100-Year Vehicle Simulation: Hydrogen vs. Gasoline

DOE Program

Task 1 : Demonstrate \$3/kg DOE cost target with HGM-10,000

Task 2: Develop hydrogen-from-ethanol reforming capability

The H₂Gen HGM-2000



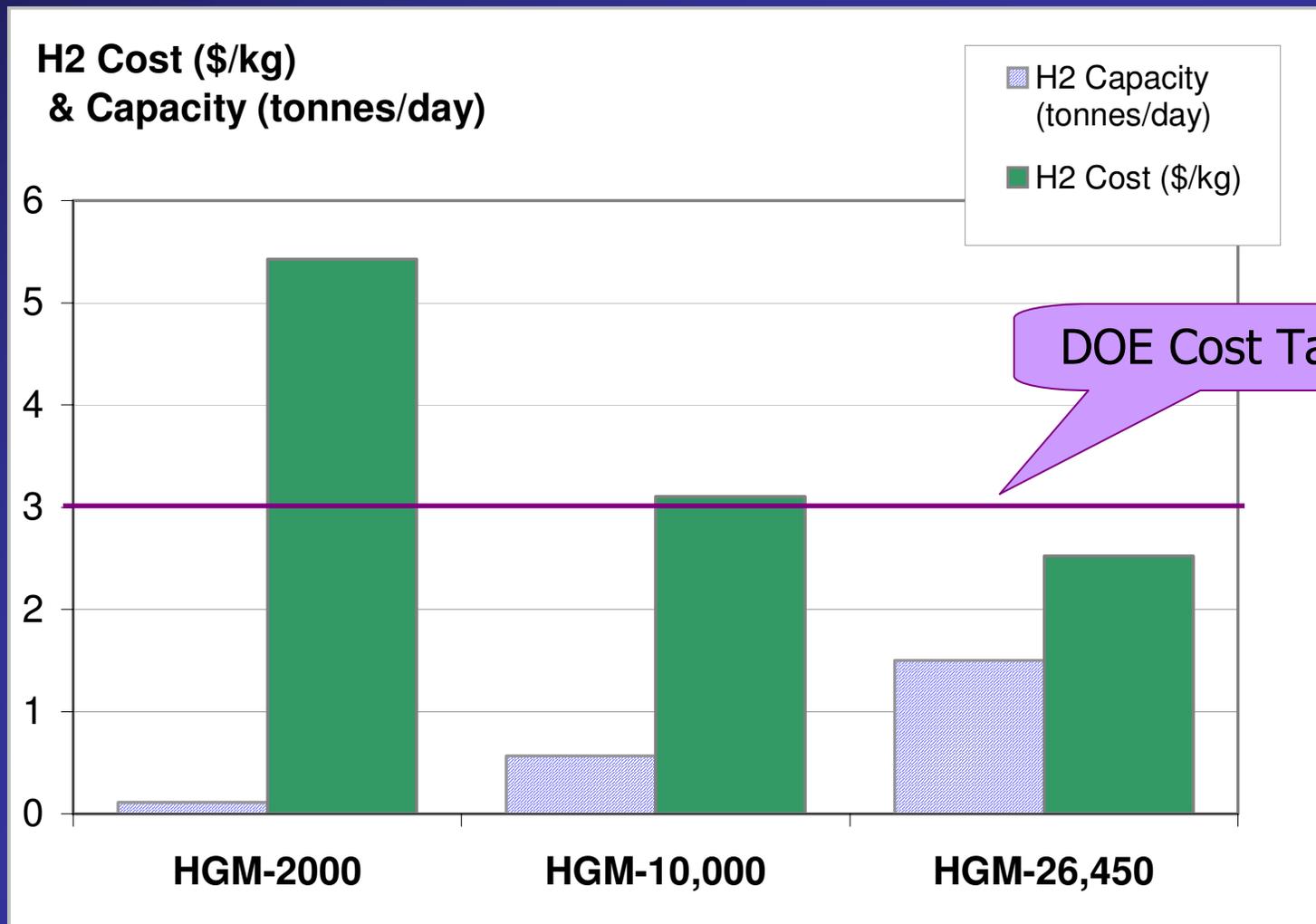
Plant Floor



Field Units

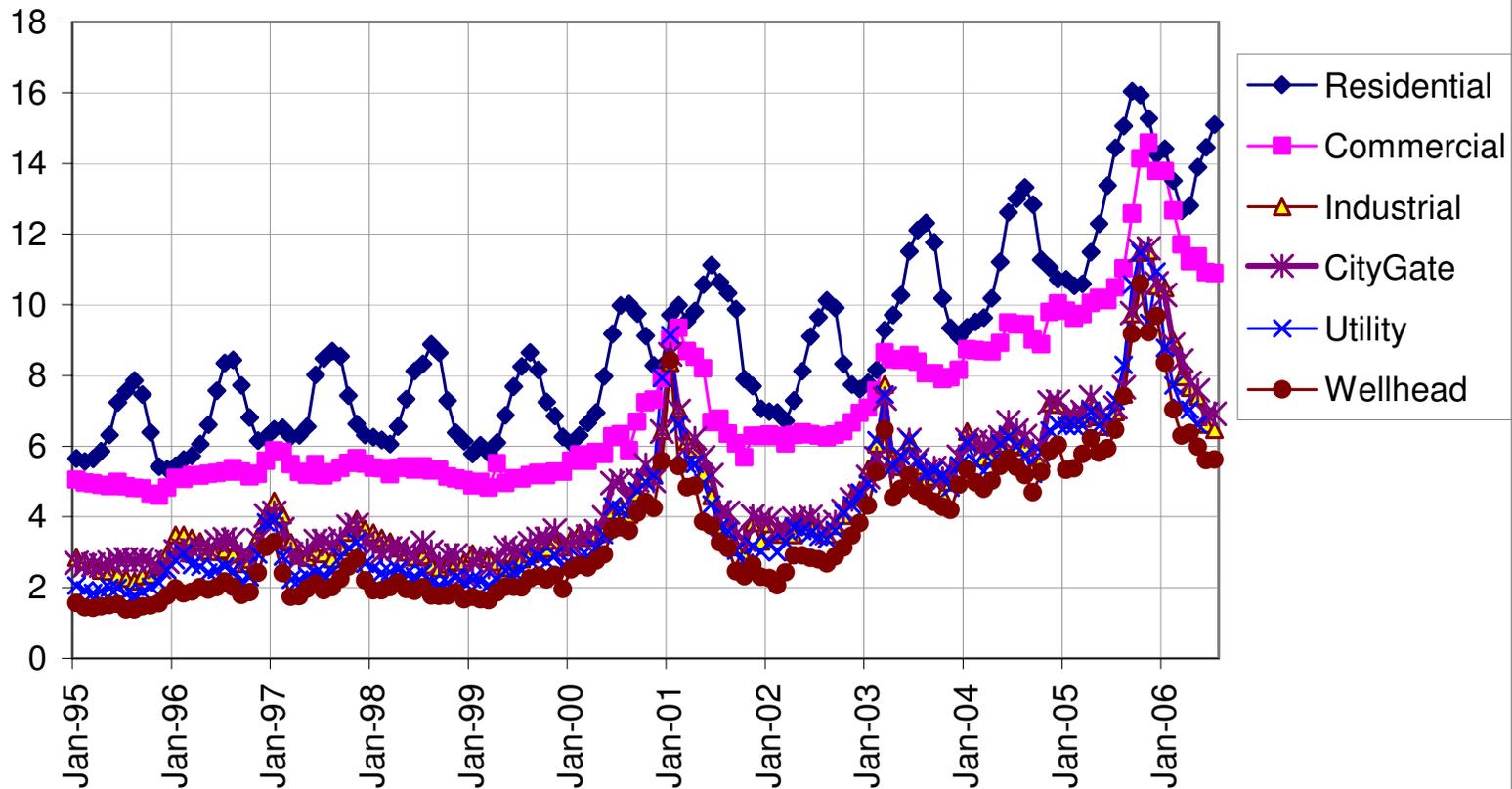


Compressed Hydrogen Cost Projections

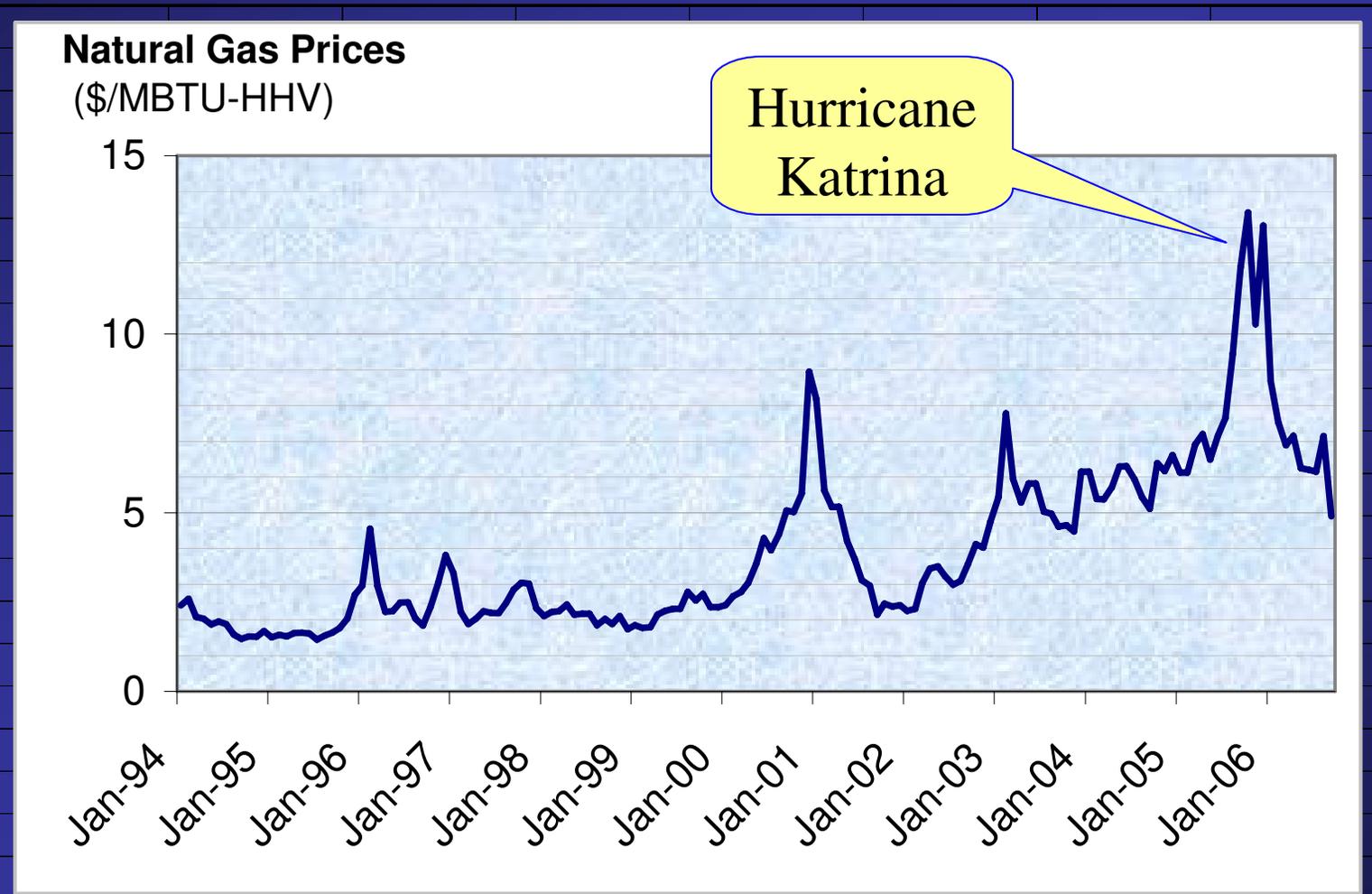


US Natural Gas Prices

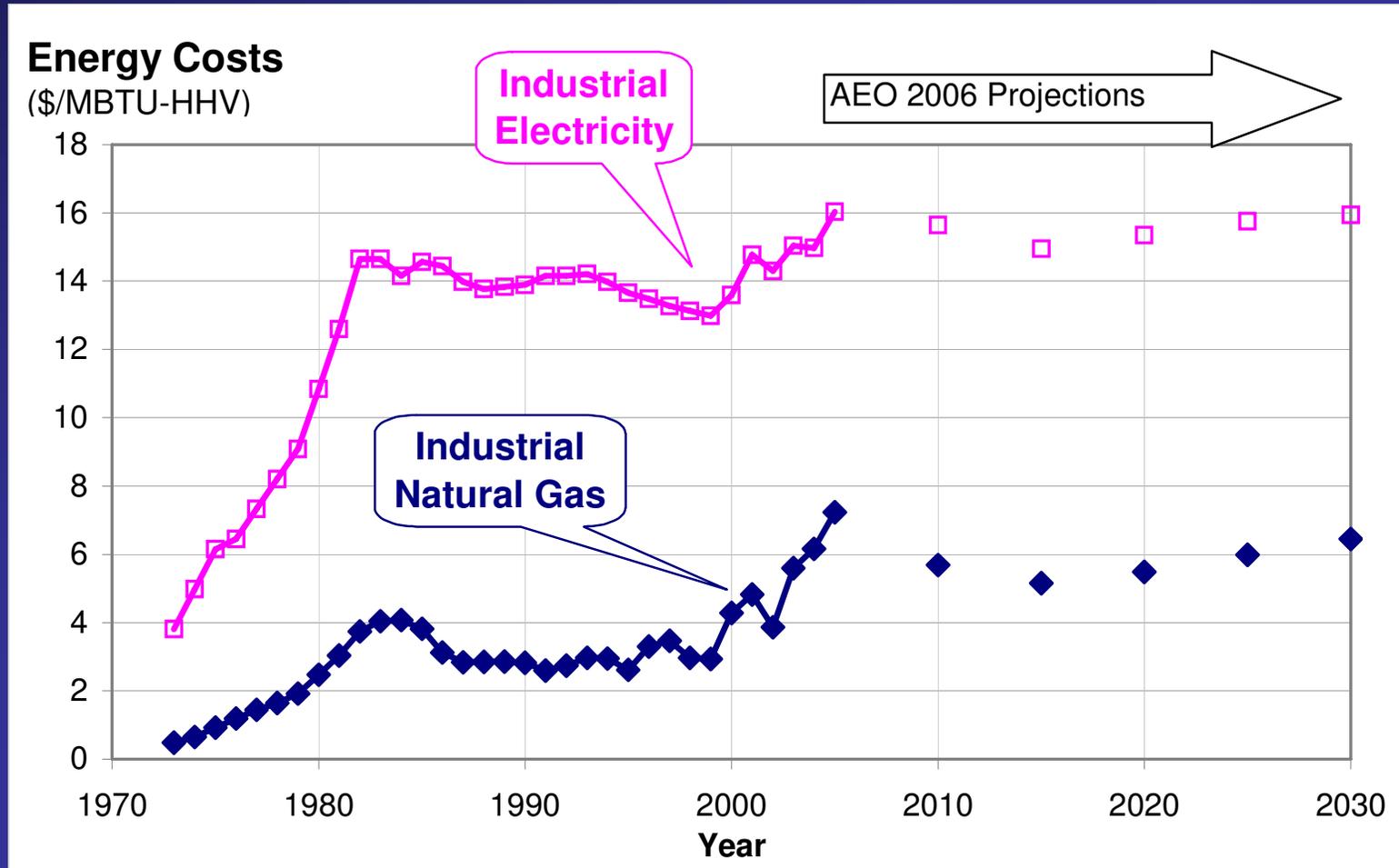
Natural Gas Prices
(\$/MBTU-HHV)



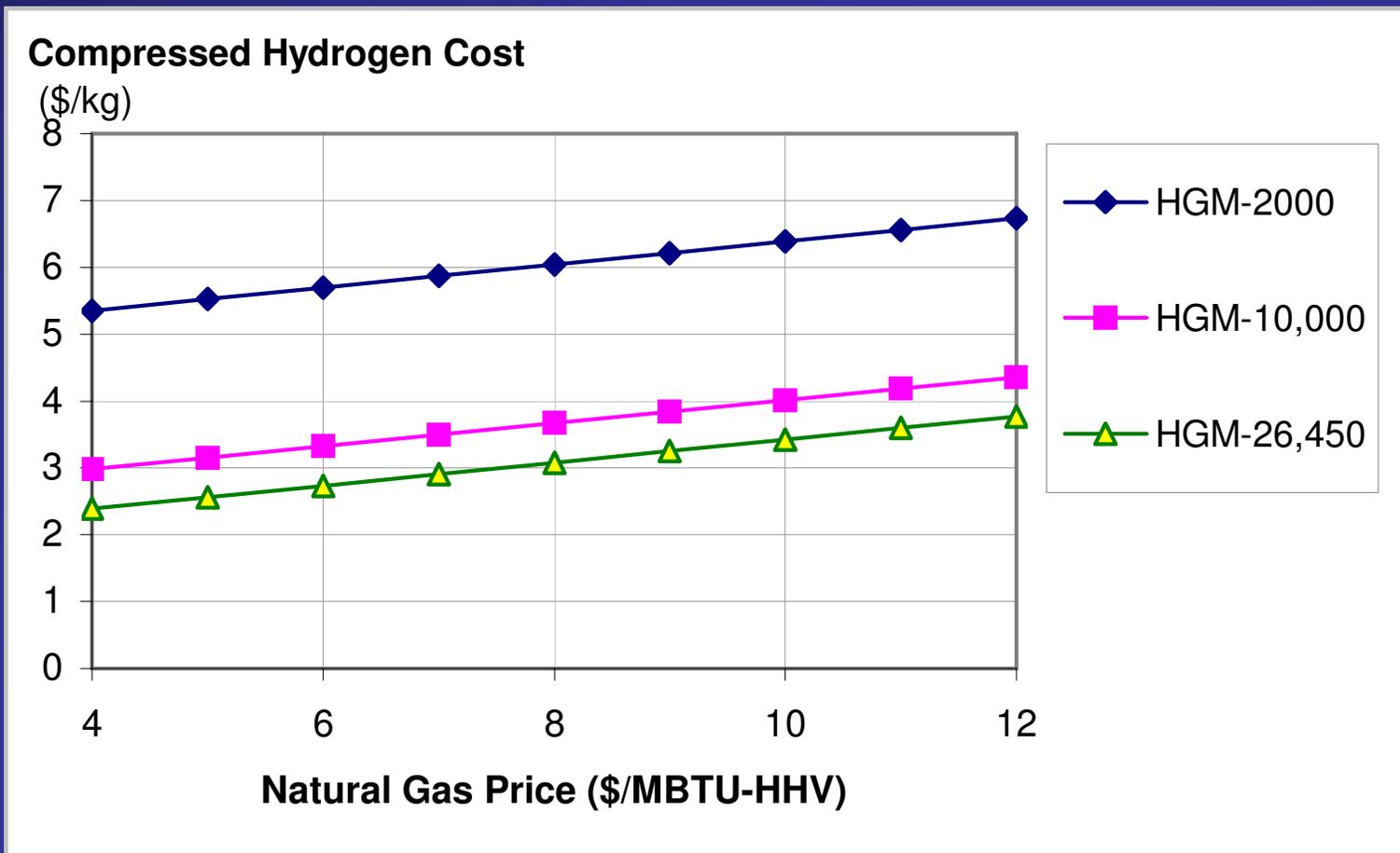
Natural Gas Price: Henry Hub



AEO Energy Price Projections



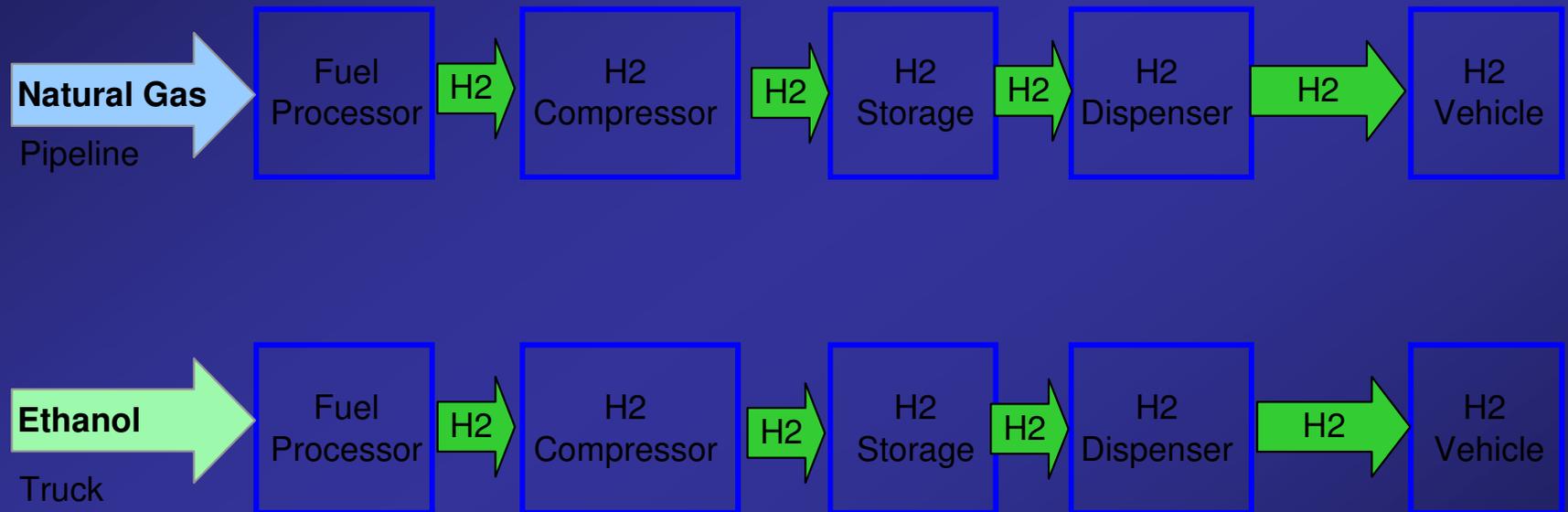
Natural Gas Price Impact on H2 Cost



Ethanol Plan

- Obtained samples from various points in ethanol still
- Begin lab scale long-term reformer tests
- Iterate
- Scale up to HGM-2000 if justified

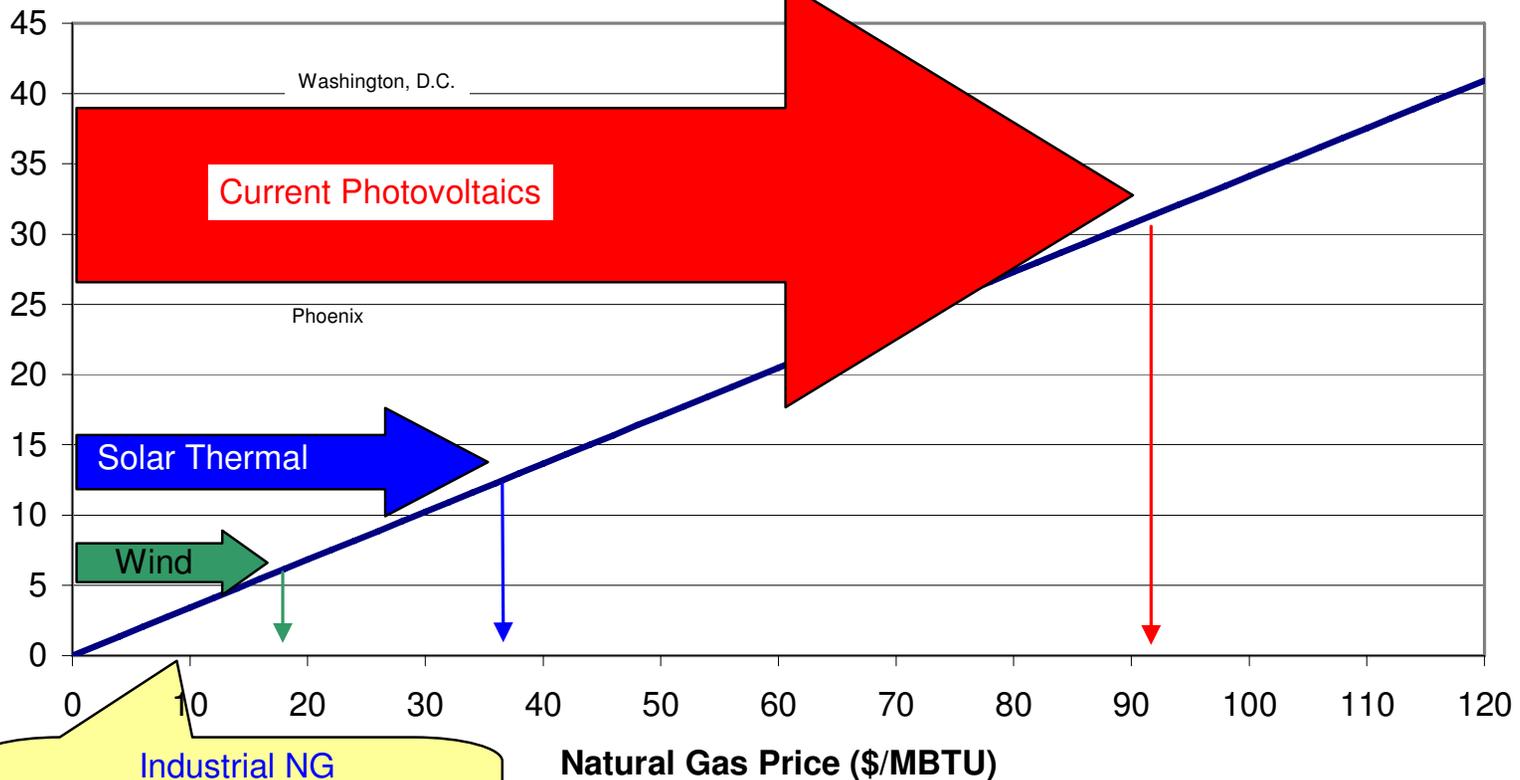
Renewable Ethanol to Hydrogen



Renewable Prices vs. Natural Gas Prices

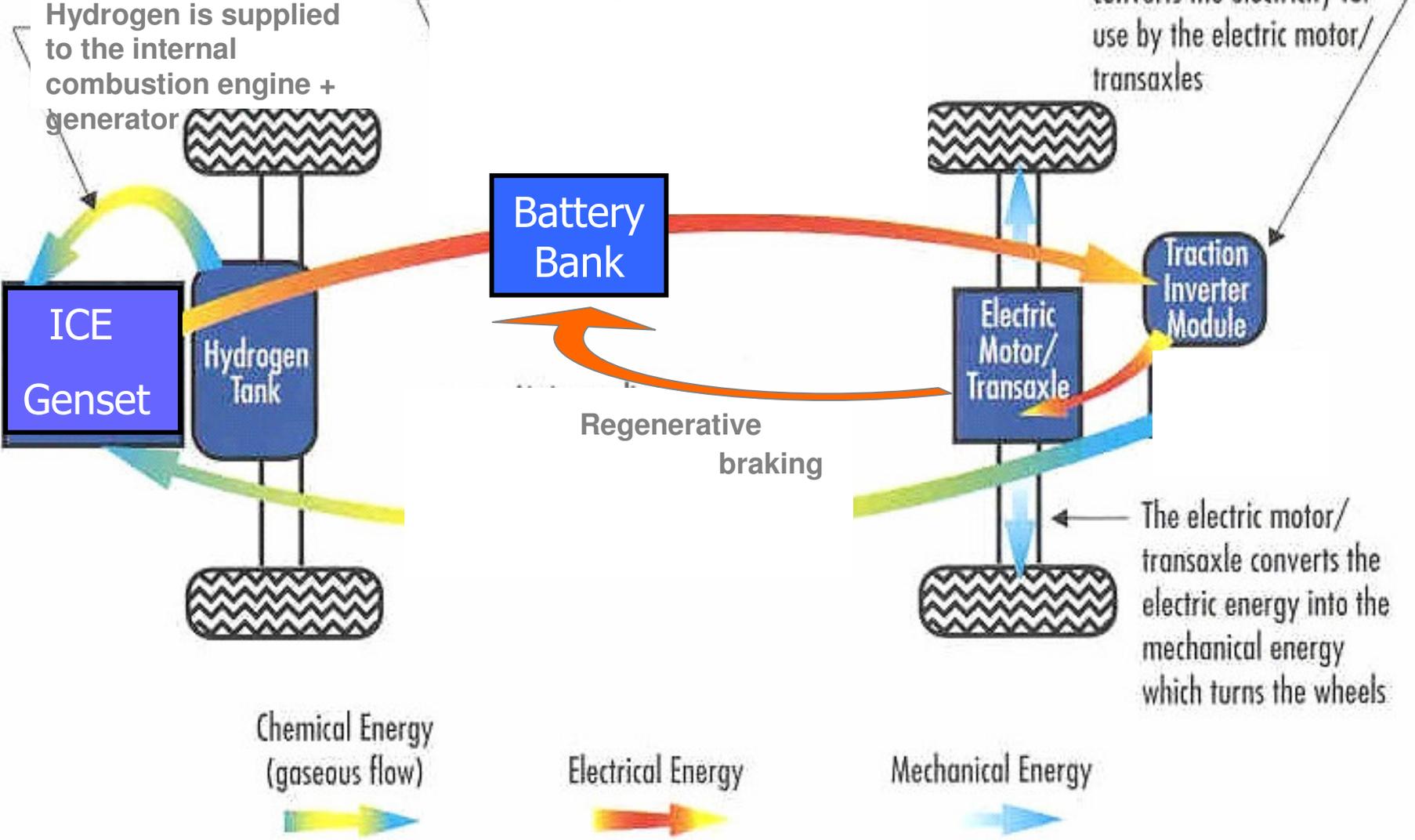
Electricity Price

(cents/kWh)



H₂ ICE HEV-

(Series Hybrid Shown)



Ford Model U

A direct hydrogen ICE hybrid electric vehicle (HEV)

Bill Ford, Jr.: “I believe that hydrogen-powered internal combustion engines are the bridge between today’s gasoline hybrids and tomorrow’s fuel cell vehicles.”

2.3-liter supercharged
4-cylinder ICE

Range: 300 miles

H₂: 7 kg @ 10,000 psi

Fuel Economy: 45 mpgge

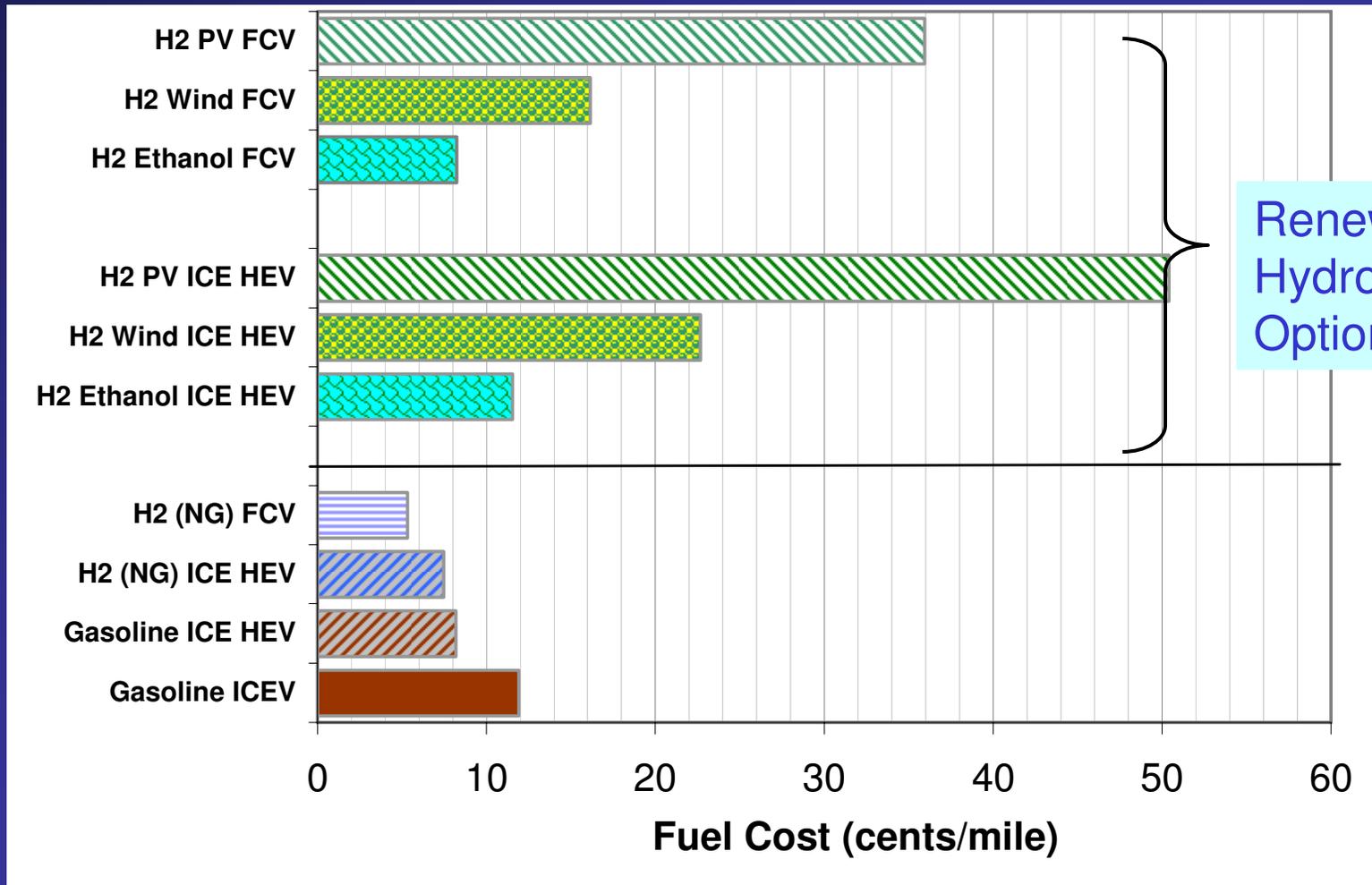
H₂RV – hydrogen hybrid
research vehicle



Hydrogen ICE Hybrid vs. Fuel Cell Vehicle

- Hydrogen Hybrid is much lower cost today
 - (\$50,000 vs. \$500,000 to \$1,000,000 or more)
- Hydrogen Hybrid depends on 100+ year old ICE technology
 - (Fuel cell vehicle durability still lacking)

Fuel Costs per Mile

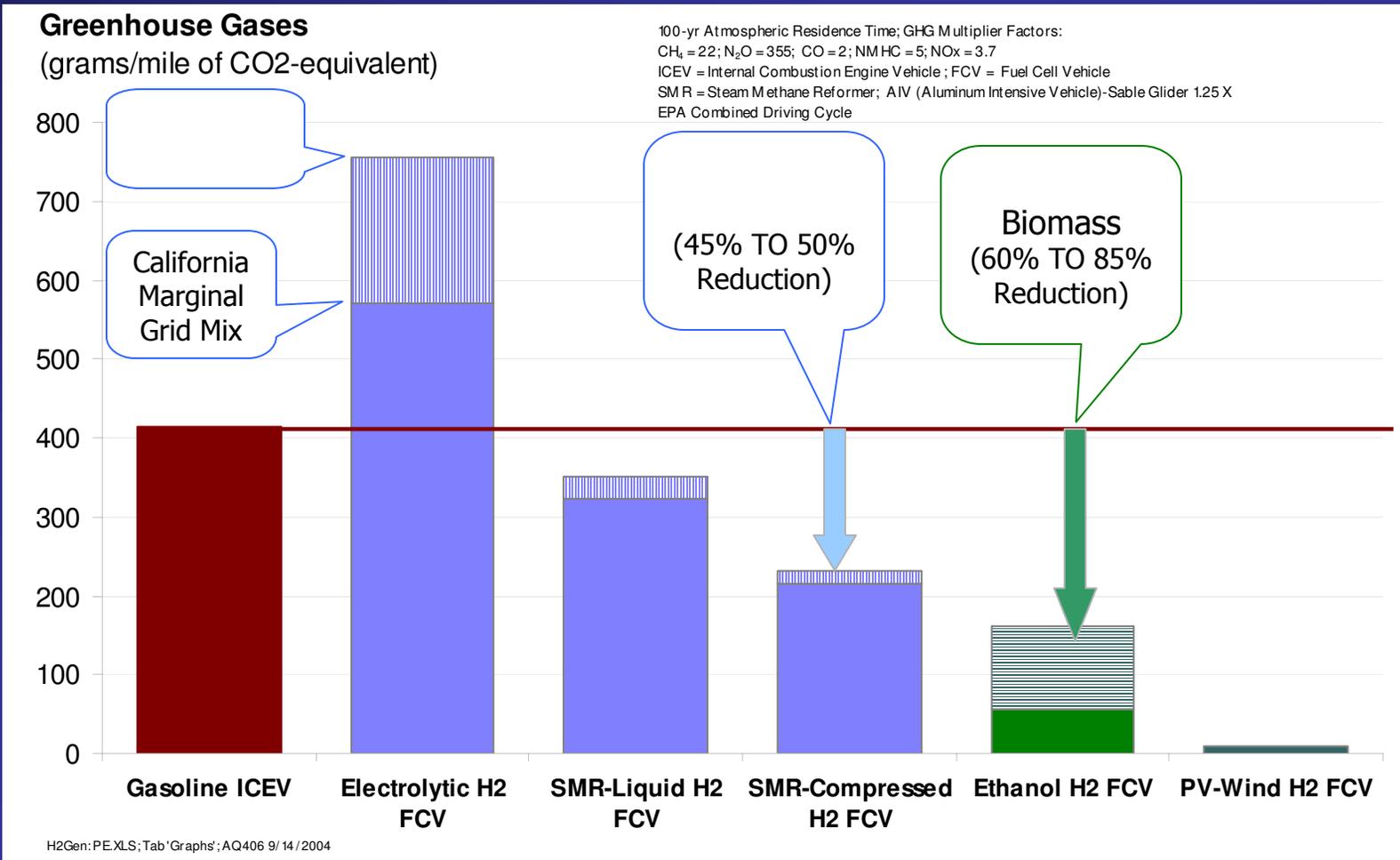


Renewable Hydrogen Options

H2Gen:Ethanol vehicles.XLS; Tab 'Charts';H 75 10/22 /2006

Assumptions: gasoline = \$2.5/gal; Ethanol = \$1.5/gal; PV =20c/kWh for 7 hrs/day; Wind = 5 c/kWh for 8.4 hrs/day
 Gasoline HEV fuel economy = 1.45 X ICEV; H2 HEV = 1.71 X ICEV; FCV = 2.4 X ICEV
 Annual capital recovery (NRC) = 0.16; Capacity factor = 0.9; Natural gas = \$ 8.98/MBTU; Electricity = 7 cents/kWh

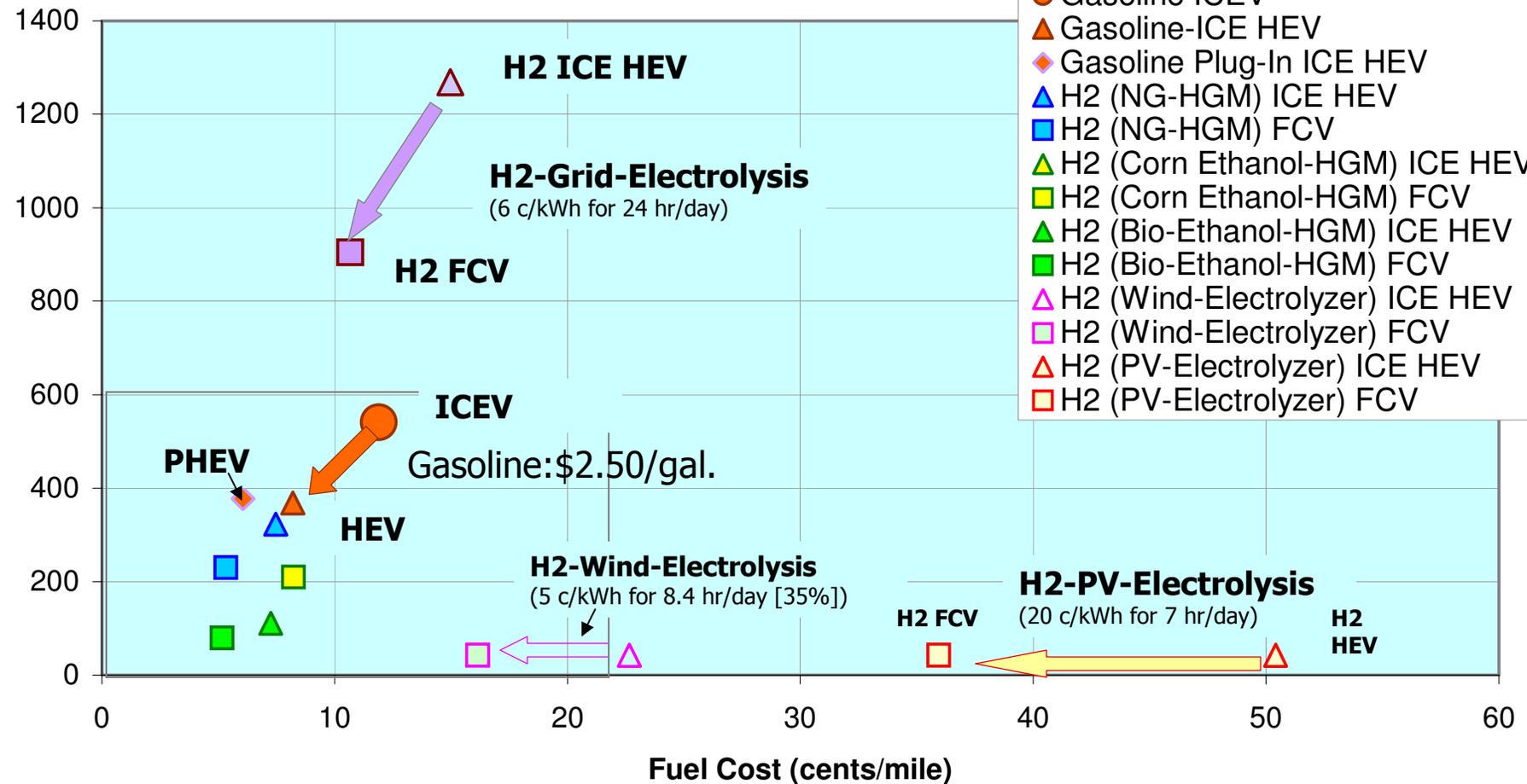
Greenhouse Gas Emissions



GHGs vs. Fuel Cost

Greenhouse Gas Emissions

(g/mile)

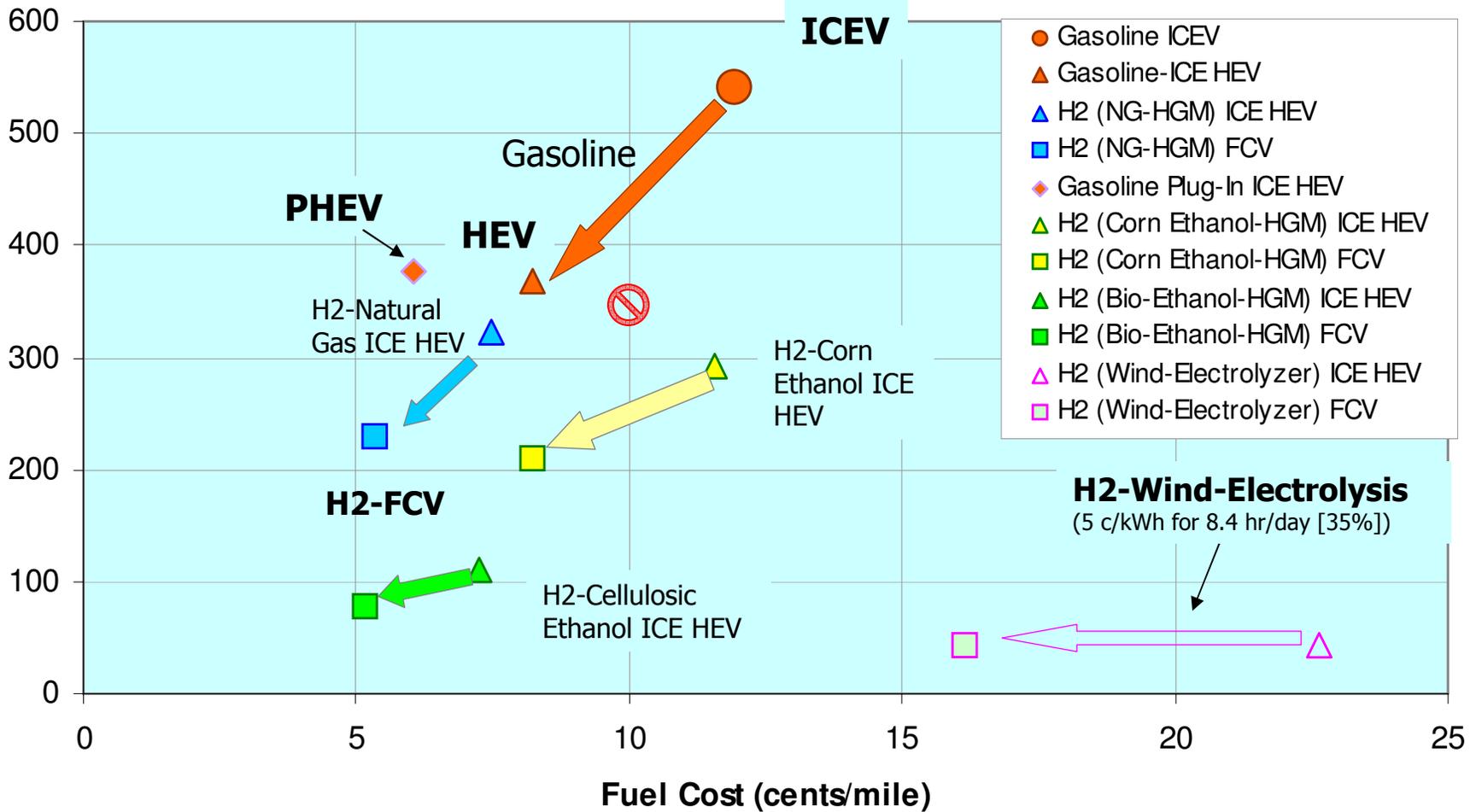


PHEV = Plug-in hybrid; 40% on electricity at 8 cents/kWh.

H2 = hydrogen; HEV = hybrid electric vehicle; FCV = fuel cell vehicle; ICEV = internal combustion engine vehicle; PV = photovoltaic (solar cells)

GHG vs. Fuel Cost (Scale change)

Greenhouse Gas Emissions
(g/mile)



Electricity = 8 cents/kWh; PHEV electricity 40%

H2Gen:Ethanol vehicles.XLS; Tab 'GHG vs Fuel Cost'; AC 51 4/5/2006

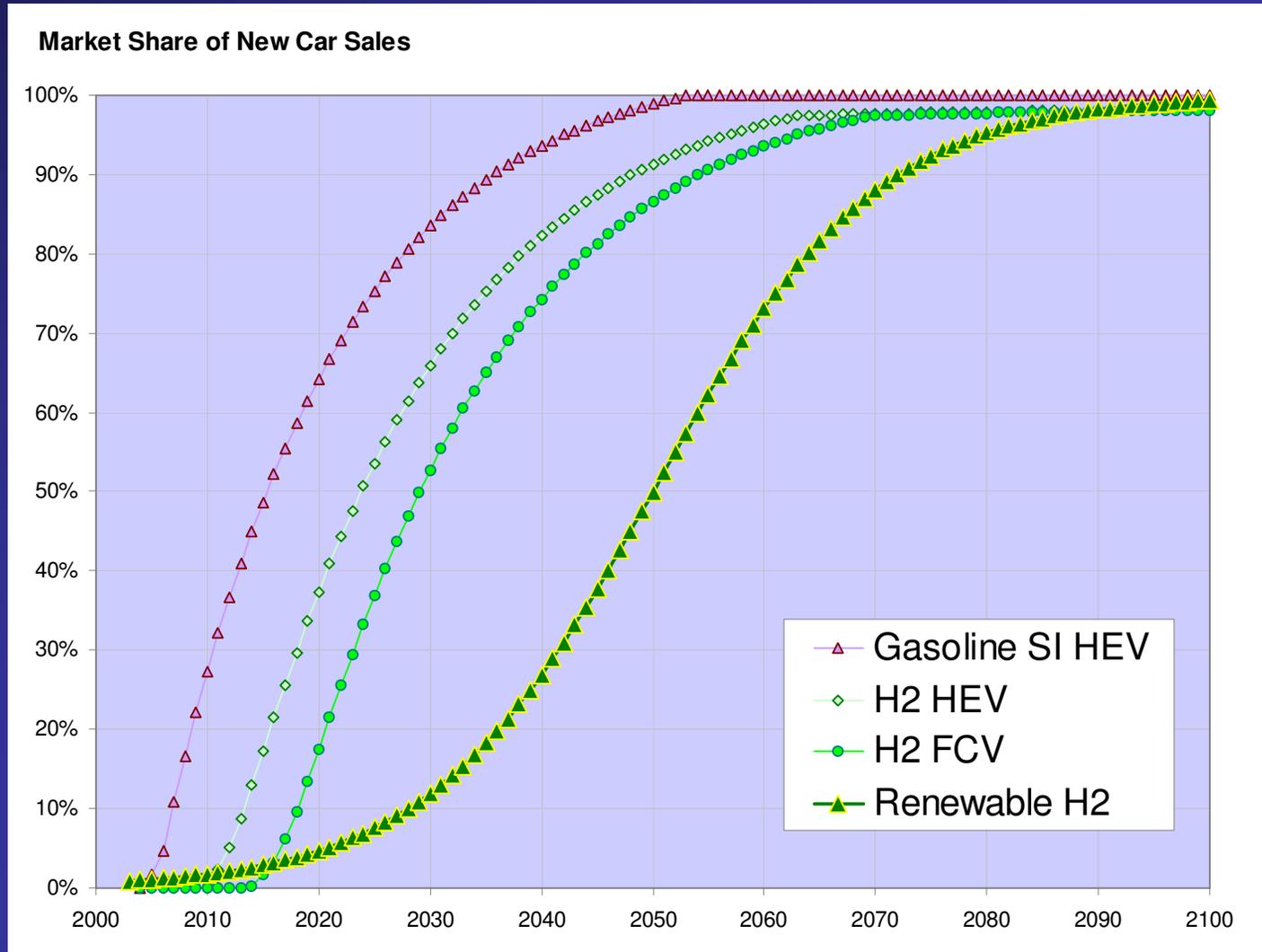
Corn Ethanol = \$1.5/gallon Cellulosic Ethanol = \$0.75/gallon Natural Gas = \$8.98/MBTU Gasoline = \$2.5/gallon

Note: these charts are based on the NRC/NAS capital recovery assumptions (16% annual capital recovery & 90% capacity factor)

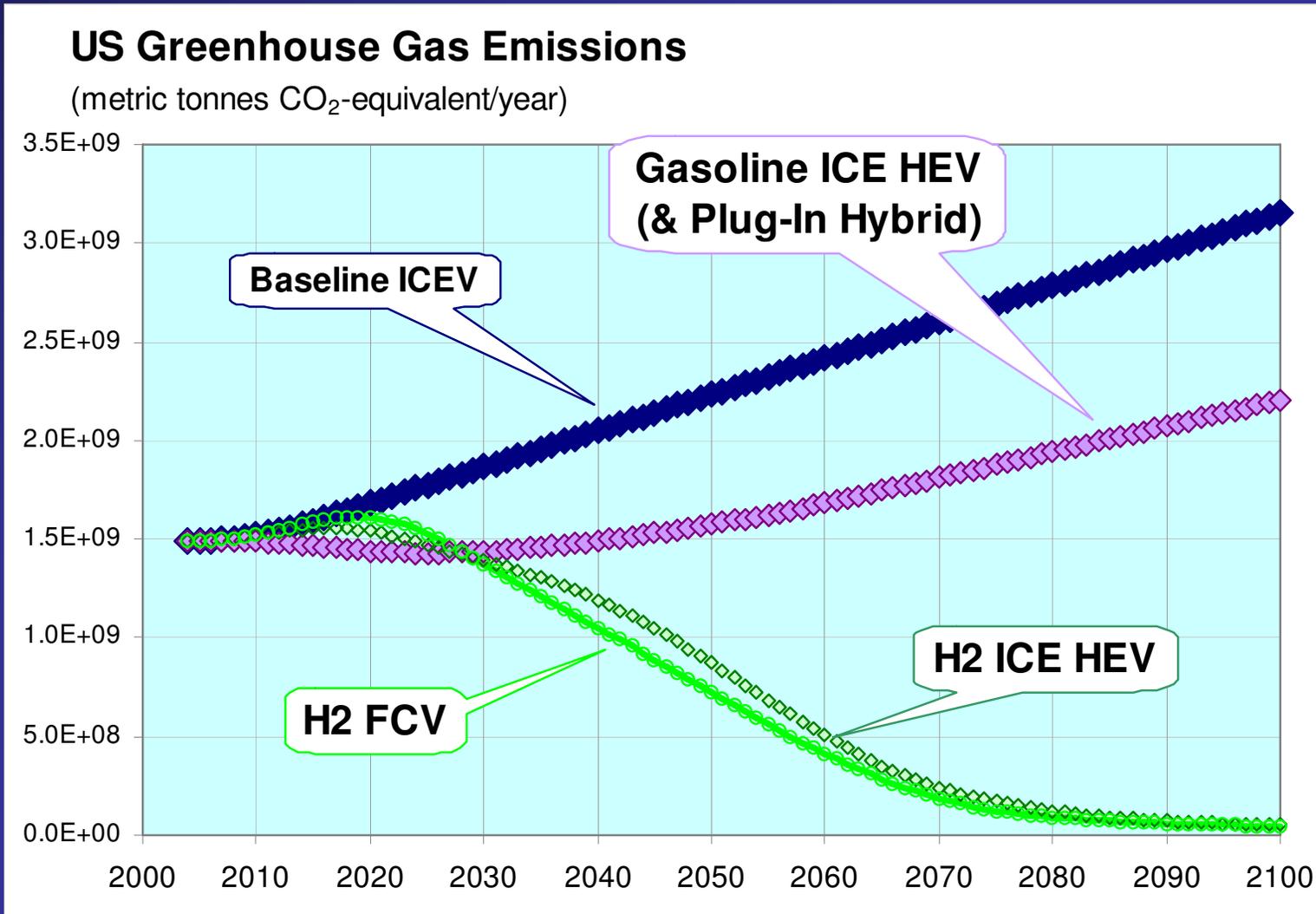
Vehicle Options Considered for 100-year Computer Simulation

- Conventional Gasoline ICEVs
- Gasoline ICE HEVs (Prius, Insight, etc.)
- Gasoline Plug-In HEVs
- Hydrogen ICE HEVs
- Hydrogen FCVs

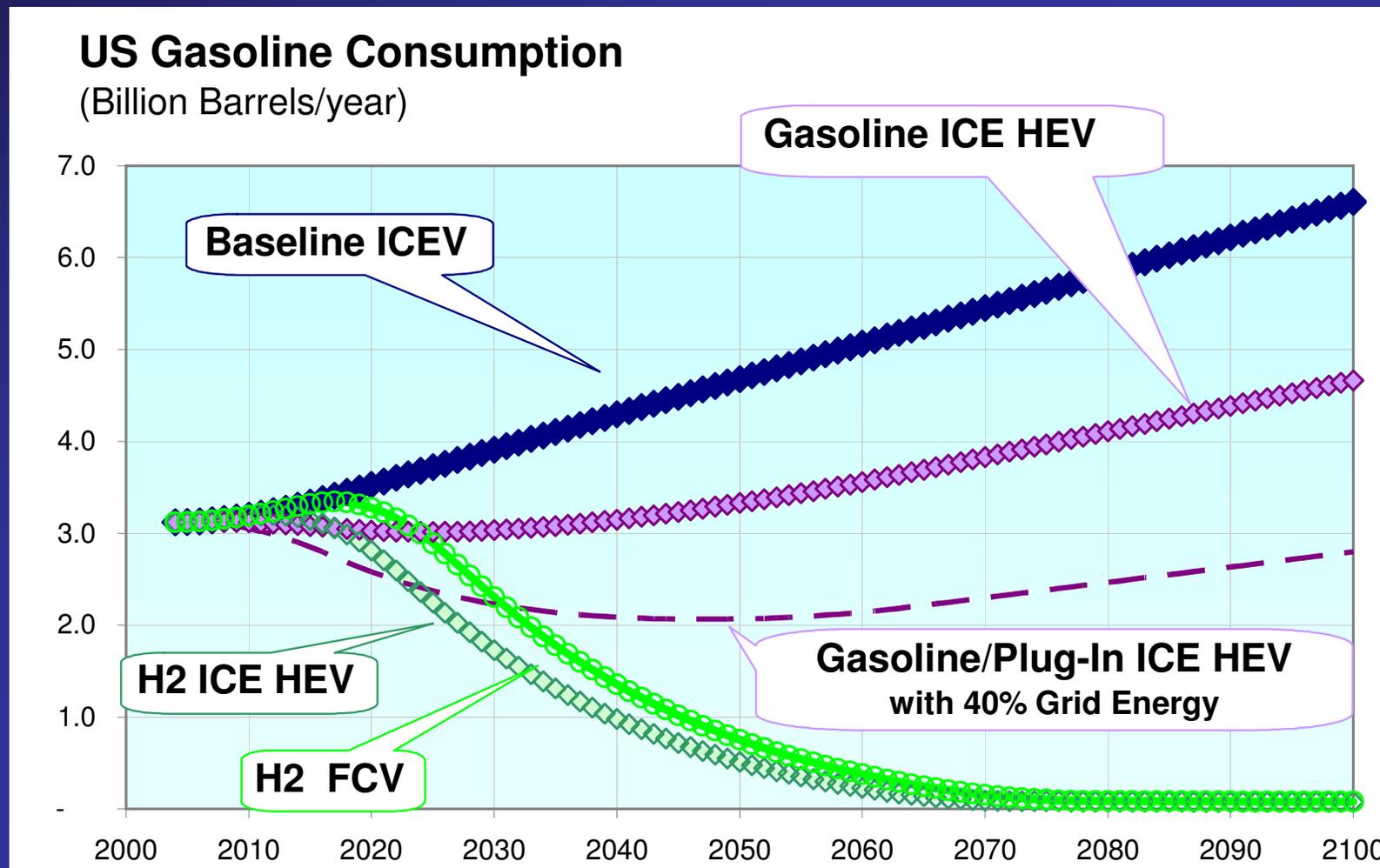
Renewable Hydrogen Fraction



Greenhouse Gases (US)

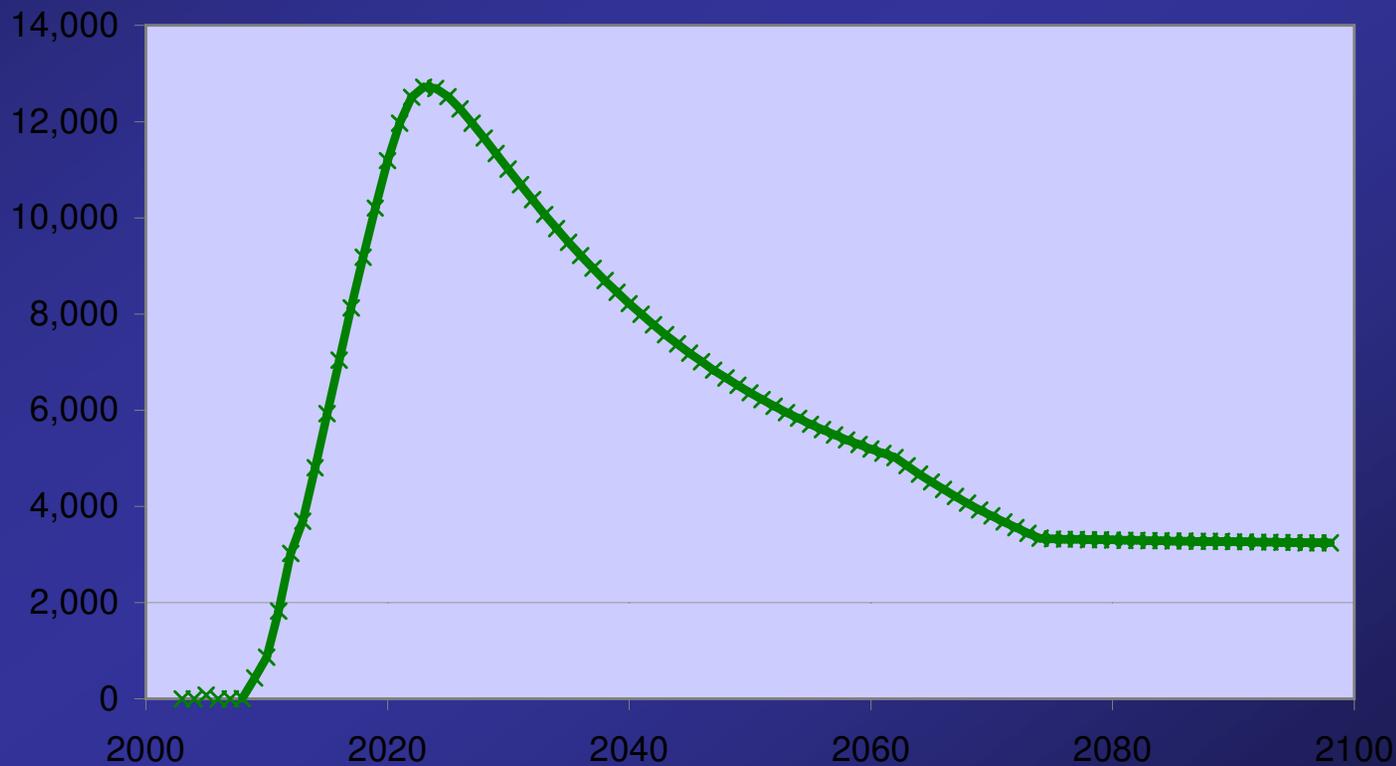


Oil Consumption (US)



Hydrogen Infrastructure Costs (US) (Distributed Hydrogen Generators at Fueling Stations)

Annual Hydrogen Infrastructure Investments
(\$US Millions)

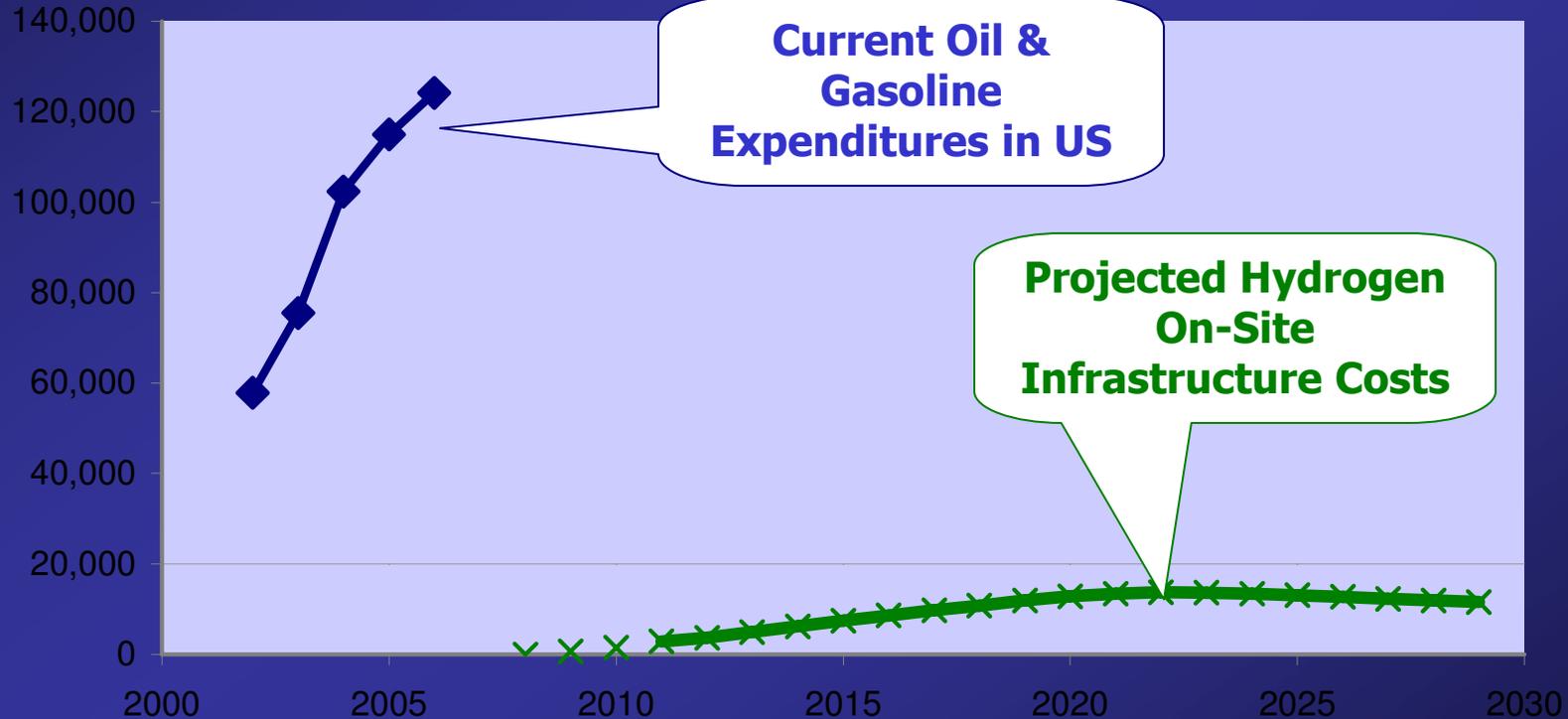


Average = \$5.8B/yr

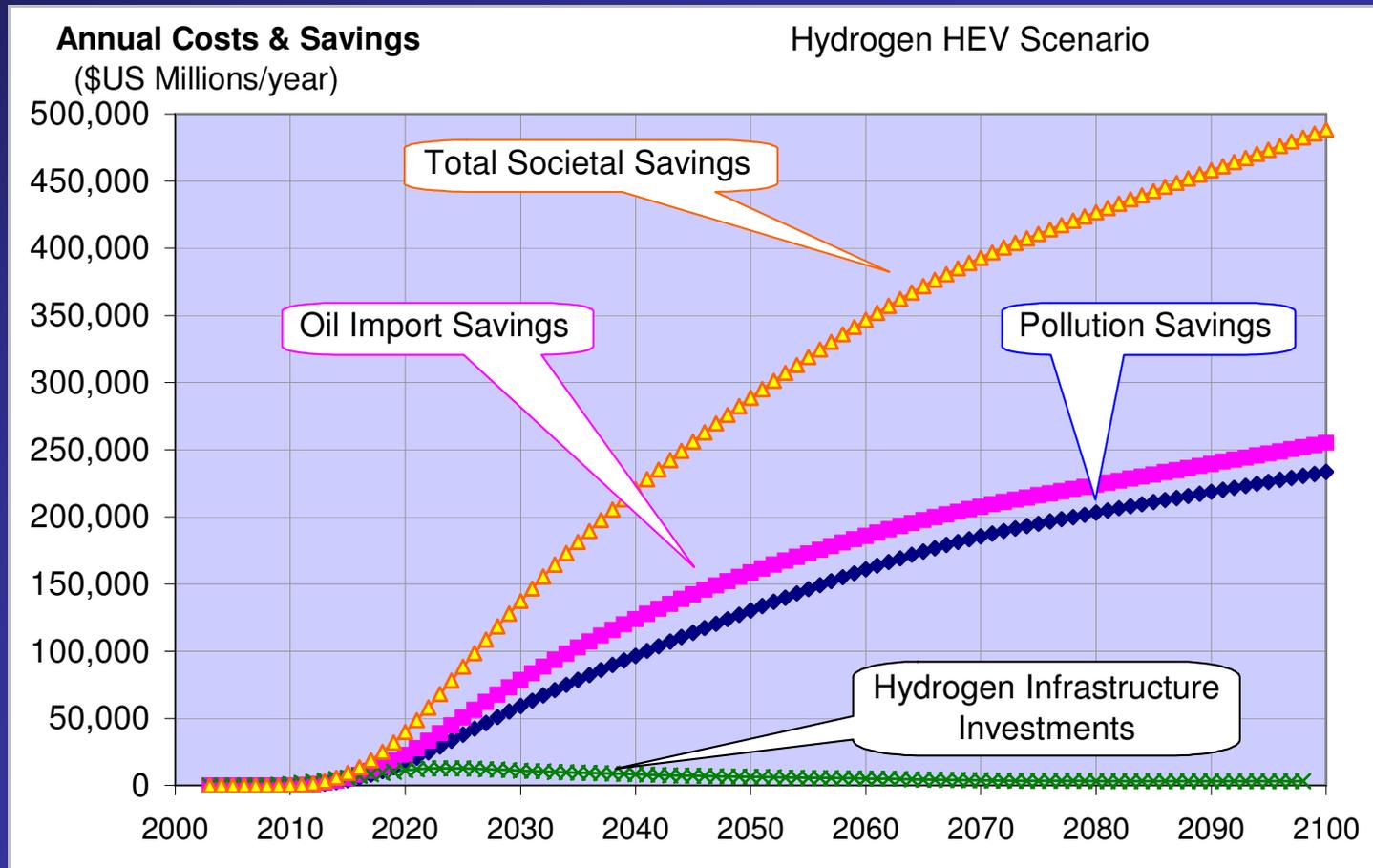
Infrastructure Costs

Annual US Fuel Infrastructure Capital Expenditures

(\$US Millions)



H₂ Costs & Societal Savings

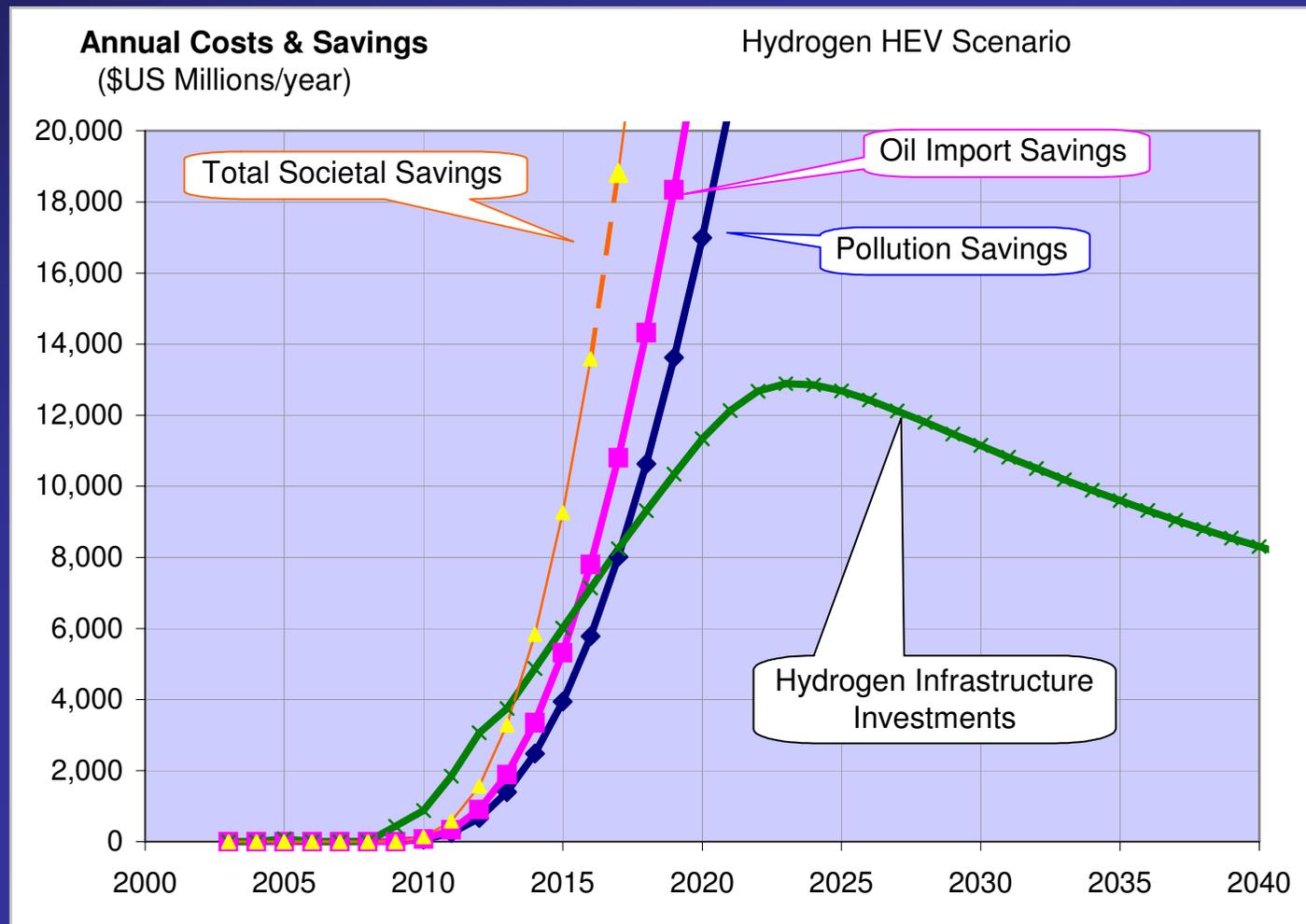


Damage Costs of Pollution: (\$/metric tonne)	VOC	CO	NO _x	CO ₂
	2,660	2,990	5,300	25
Crude Oil Price	\$40/bbl			

H2Gen: H2 ICE HEV.XLS; Tab 'Annual Sales' EE 26 9/14/2004

H₂ Costs & Societal Savings

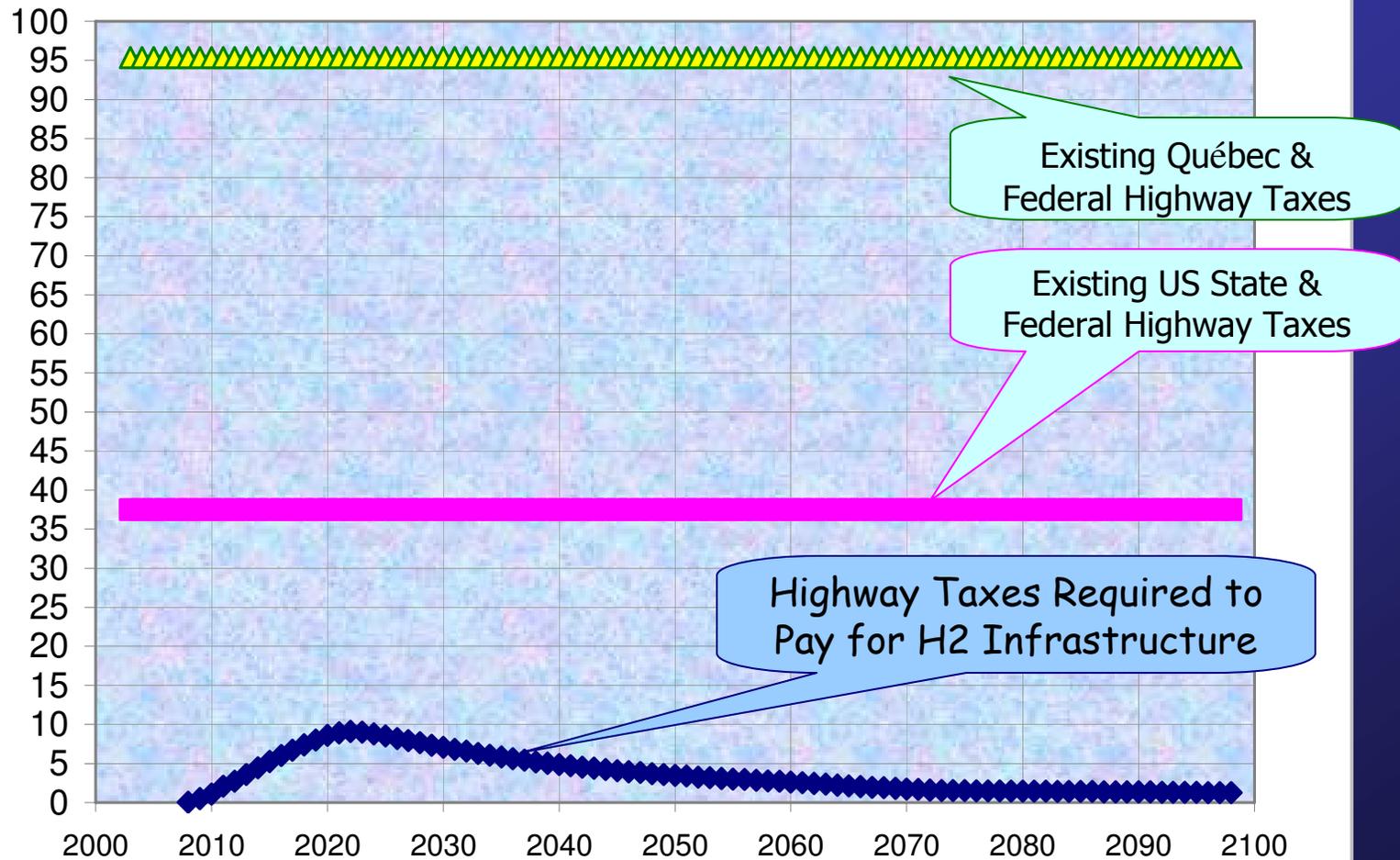
(scale change)



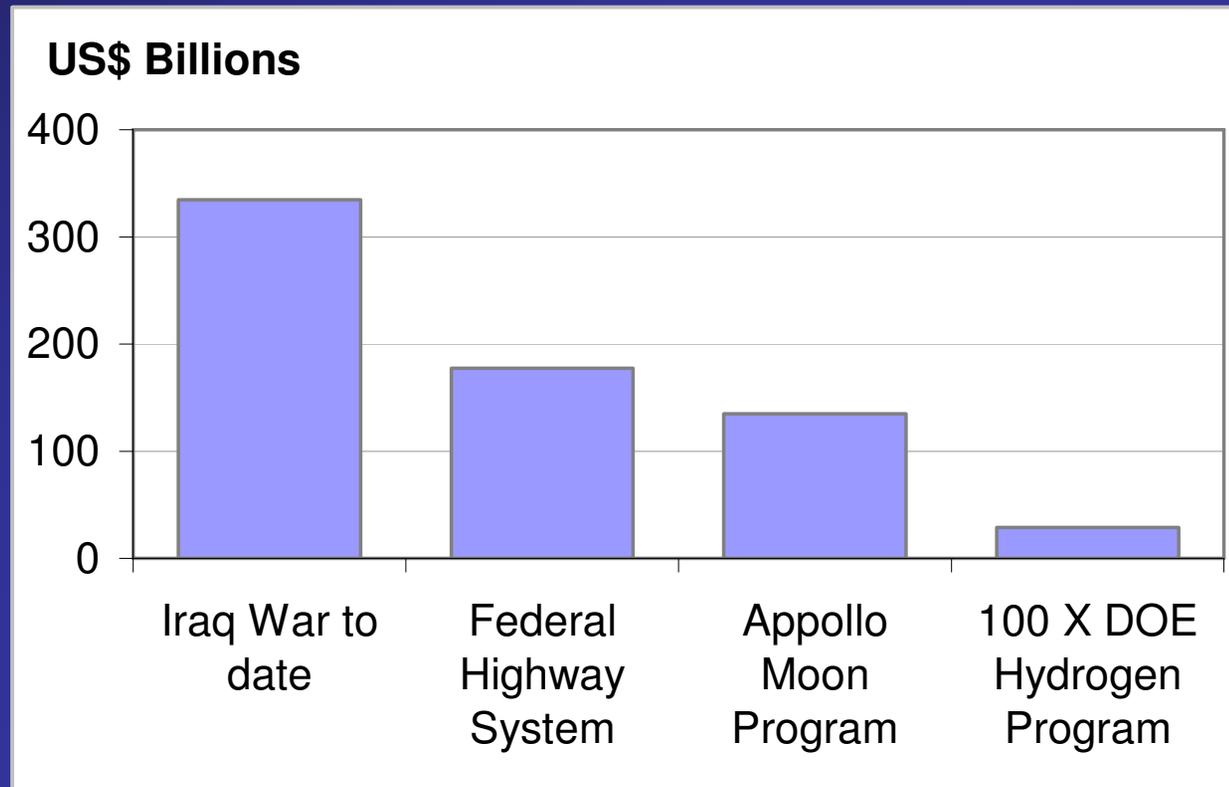
Crude Oil Price \$40/bbl

How would we pay for it?

Fuel Tax Required to Pay for H2 Infrastructure
(cents/gallon)



DOE Hydrogen Program Spending Compared to Prior Projects



H2Gen: H2 ICE HEV.XLS; Tab 'Cost';J 21 10/18 /2006

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

Transition Strategy

H₂Gen

Today:

Hydrogen ICE
Hybrid Electric
Vehicles



Tomorrow:

Hydrogen
Fuel Cell
Vehicles

Hydrogen
Made from
Natural Gas



Renewable
Hydrogen

Hydroelectric, Ethanol, Wind,
Solar Thermal, PV,
Geothermal, Biomass, MSW,
Landfill gas

Why not use ethanol directly in ICEVs? (Instead of converting to hydrogen for FCVs)

- Substantially reduced criteria pollutants
- 45% lower greenhouse gases
HGM efficiency = 75% X FCV 2.4X efficiency = 1.8 longer range/gallon of ethanol
- Direct ethanol in ICEVs & H₂ from ethanol are not mutually exclusive
- When many vehicles run on hydrogen, ethanol is preferred feedstock over natural gas

Conclusions

- Hydrogen will cost less than \$1.50/gallon of gasoline (on a range-equivalent basis)
- Gasoline Hybrids are a dead-end street (with respect to GHG & Oil reductions)
- Hydrogen from ethanol is the least costly renewable hydrogen option

Thank You

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