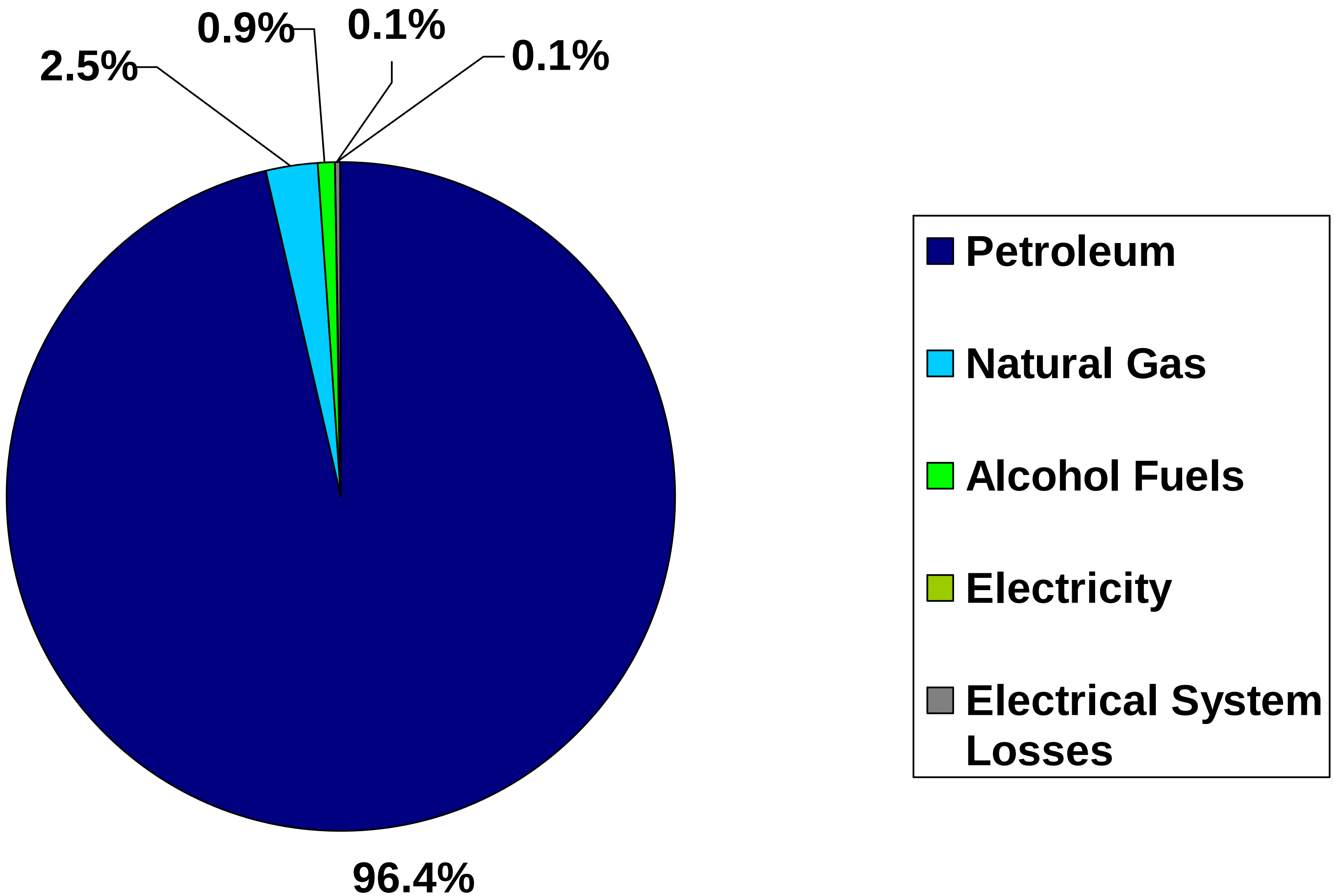
Preserving Mobility While Protecting the Environment: Hybrid Versus Hydrogen Vehicles

James Sweeney

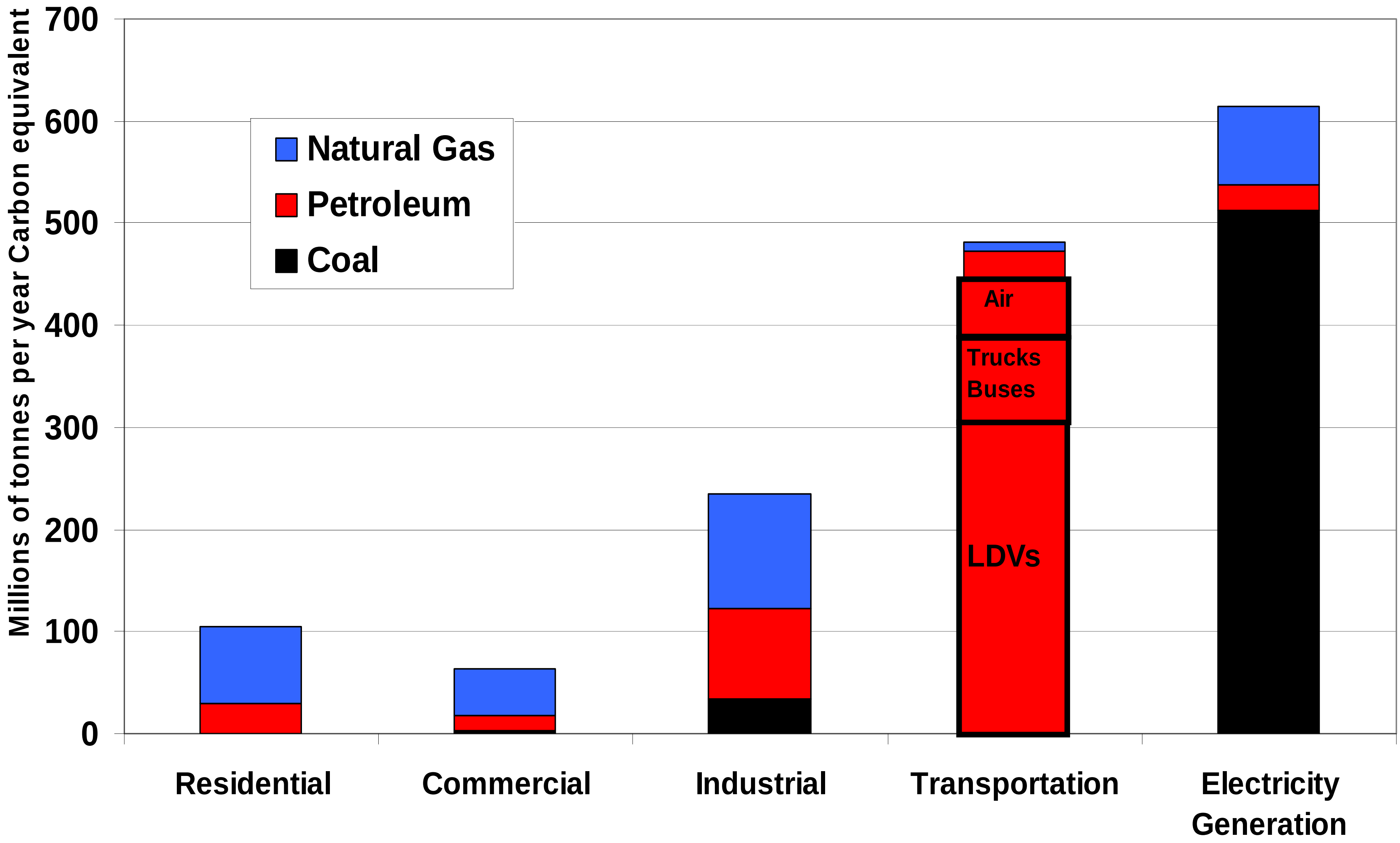
Stanford University

U.S. Transportation Energy, 2003



Crude Oil Futures Prices: Dec 2010 Delivery

United States CO_2 Emissions by Sector and Fuels 2003



Source: U.S. EPA Inventory of Greenhouse Gas Emissions, April 2005

The Challenge

- **Gradually transition away from oil in transportation**
- **Protect the environment**
- **Preserve mobility**

Two Technologies

- **Hybrid electric vehicles**
  - **Increased fuel economy relative to conventional**
  - **Somewhat larger capital costs**
  - **Use existing fueling infrastructure**
- **Hydrogen Fuel Cell Vehicles**
  - **Increased fuel economy relative to hybrids**
  - **Fundamental technical challenges**
    - **Fuel Cell Stack**
    - **Onboard Storage**
  - **Considerably larger capital costs**
  - **Need new infrastructure**
  - **Do not use any oil**

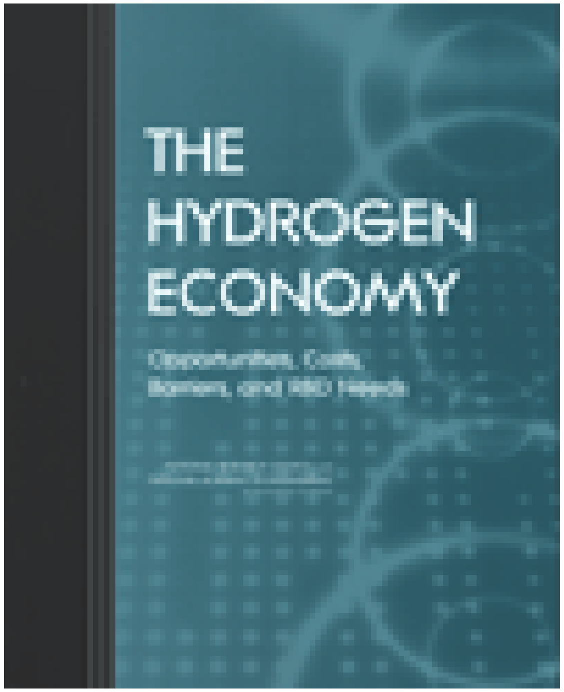
Basic Policy Question

- On which strategy should the U.S. focus its attention if it cannot do both as well as it could do either one alone?
  - Promote hybrid vehicles
    - Private sector now doing R&D
    - Encourage rapid near-term adoption
  - Hydrogen R&D
    - Solve problems of vehicle technology
    - Develop hydrogen infrastructure
    - Promote near-term FCV adoption
- Assume either strategy can be achieved. Here I ignore uncertainty. To account for uncertainty, scale down benefits based on probability of failure.
- Also, IF U.S. could simultaneously do both in near term, should it?

***The Hydrogen Economy*: Opportunities, Costs, Barriers, and R&D Needs**

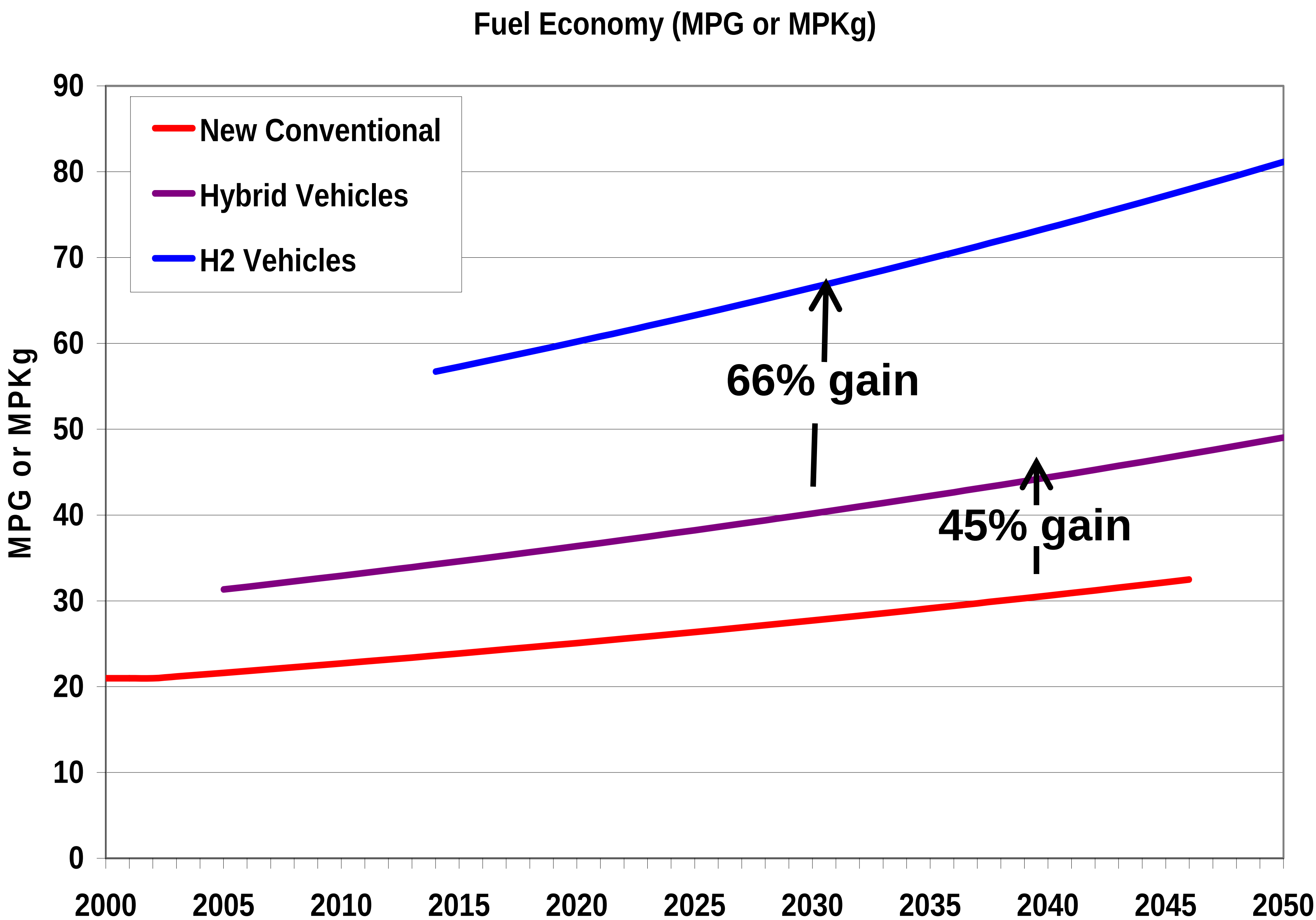
Committee on Alternatives and Strategies for Future Hydrogen Production and Use

National Research Council



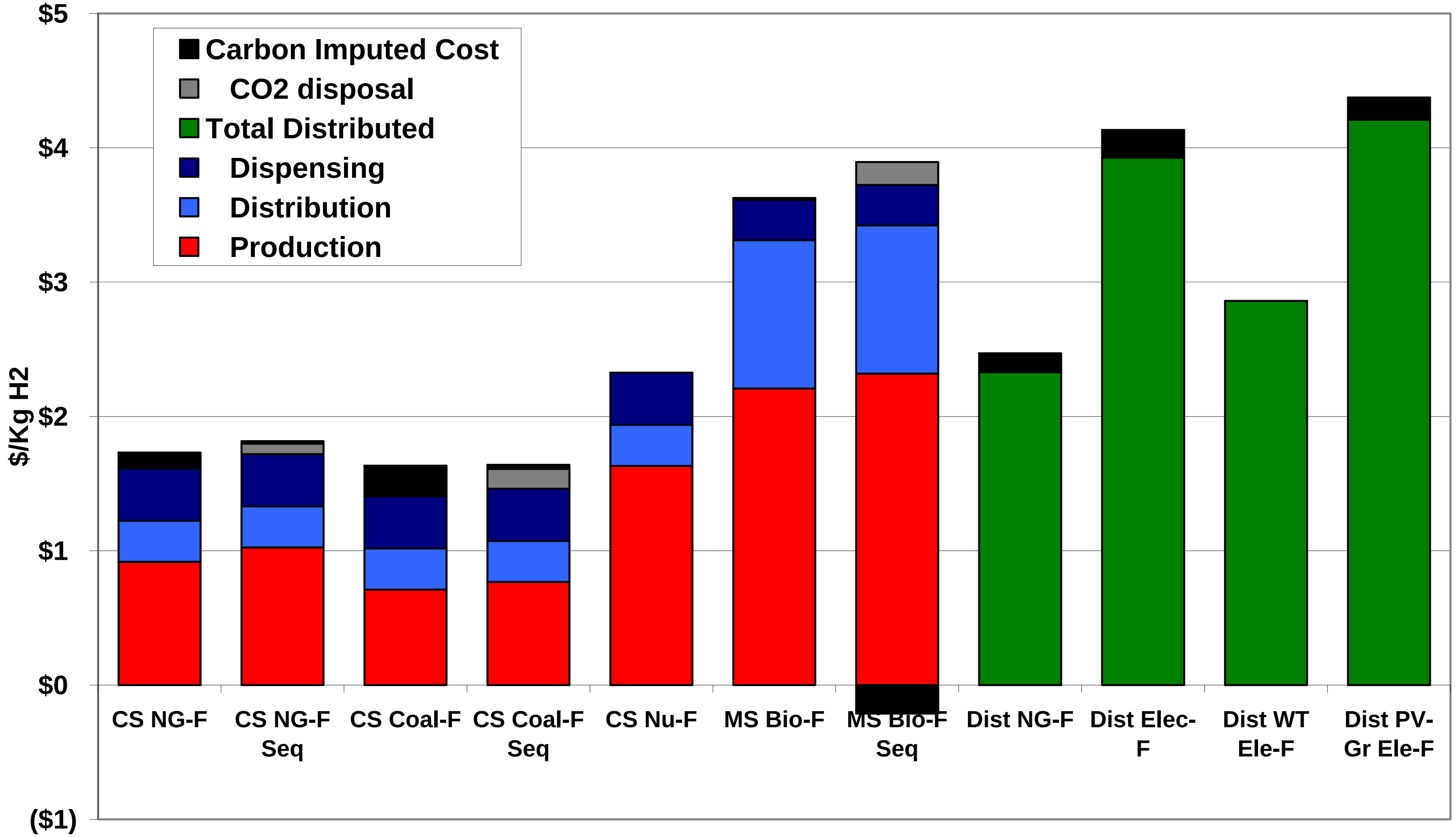
Final Report available (PDF or hard copy) from:

http://books.nap.edu/catalog/10922.html



Fuel Economy (MPG or MPKg)
MPG or MPKg
90
80
70
60
50
40
30
20
10
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
New Conventional
Hybrid Vehicles
H2 Vehicles
66% gain
45% gain

Hydrogen Supply Costs: With Technology Advance

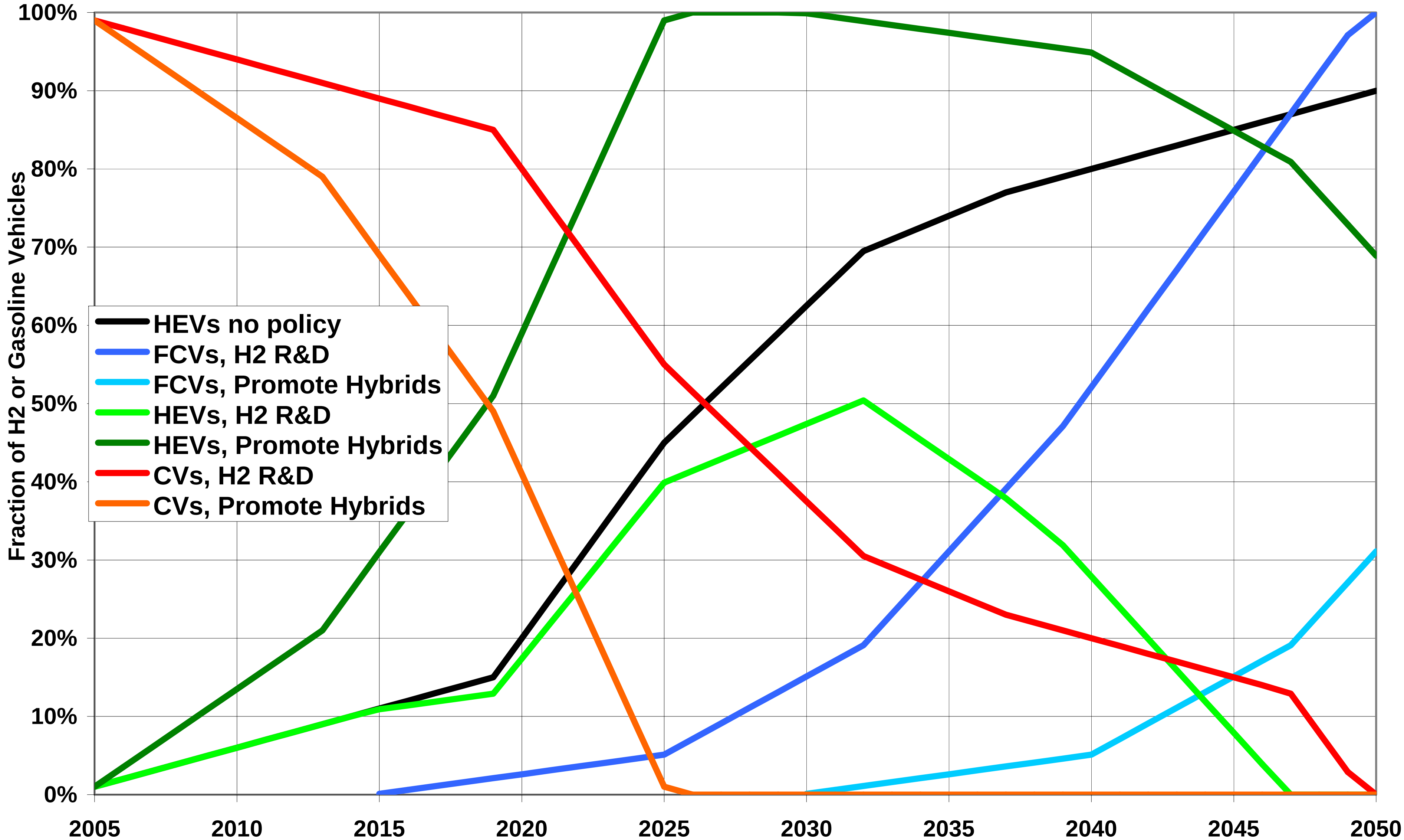


Source: NRC Hydrogen Study

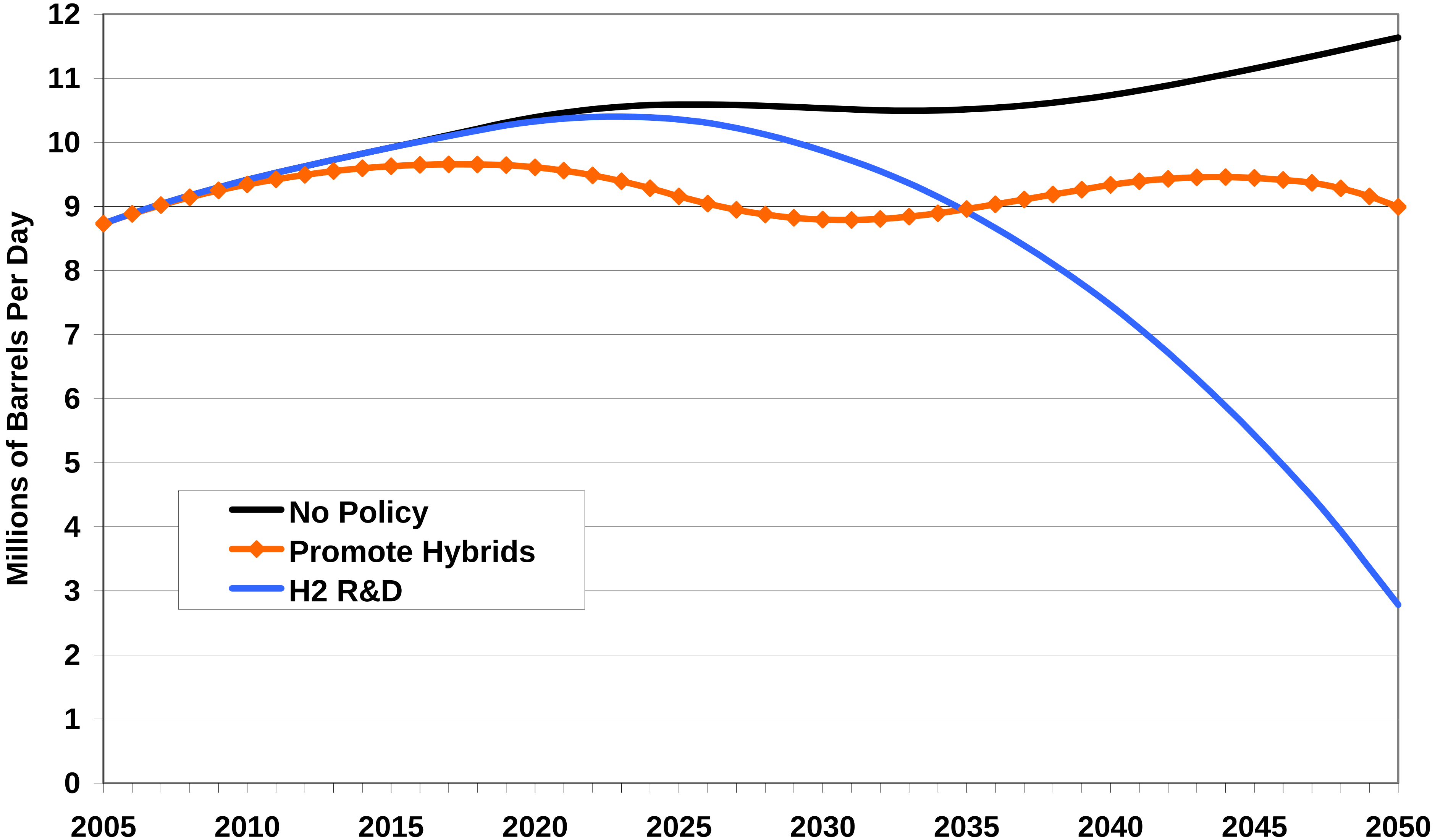
Two Technology Policy Scenarios (Illustrative; Not definitive)

- **No Policy**
  - Medium rate of hybrid introduction
  - No hydrogen vehicles
- **Promote Hybrids: Accelerate Hybrid Penetration**
  - Economic incentives to accelerate market penetration of HEVs
  - Hydrogen FCVs introduced later, here assumed 2030
- **H2 R&D: R&D on Hydrogen Fuel Cell Vehicles**
  - Successful R&D on FCVs massively reduces costs
    - Fuel Cell Stack
    - Onboard Storage
  - Economical hydrogen FCVs introduced in 2015
  - Hybrid penetration slower

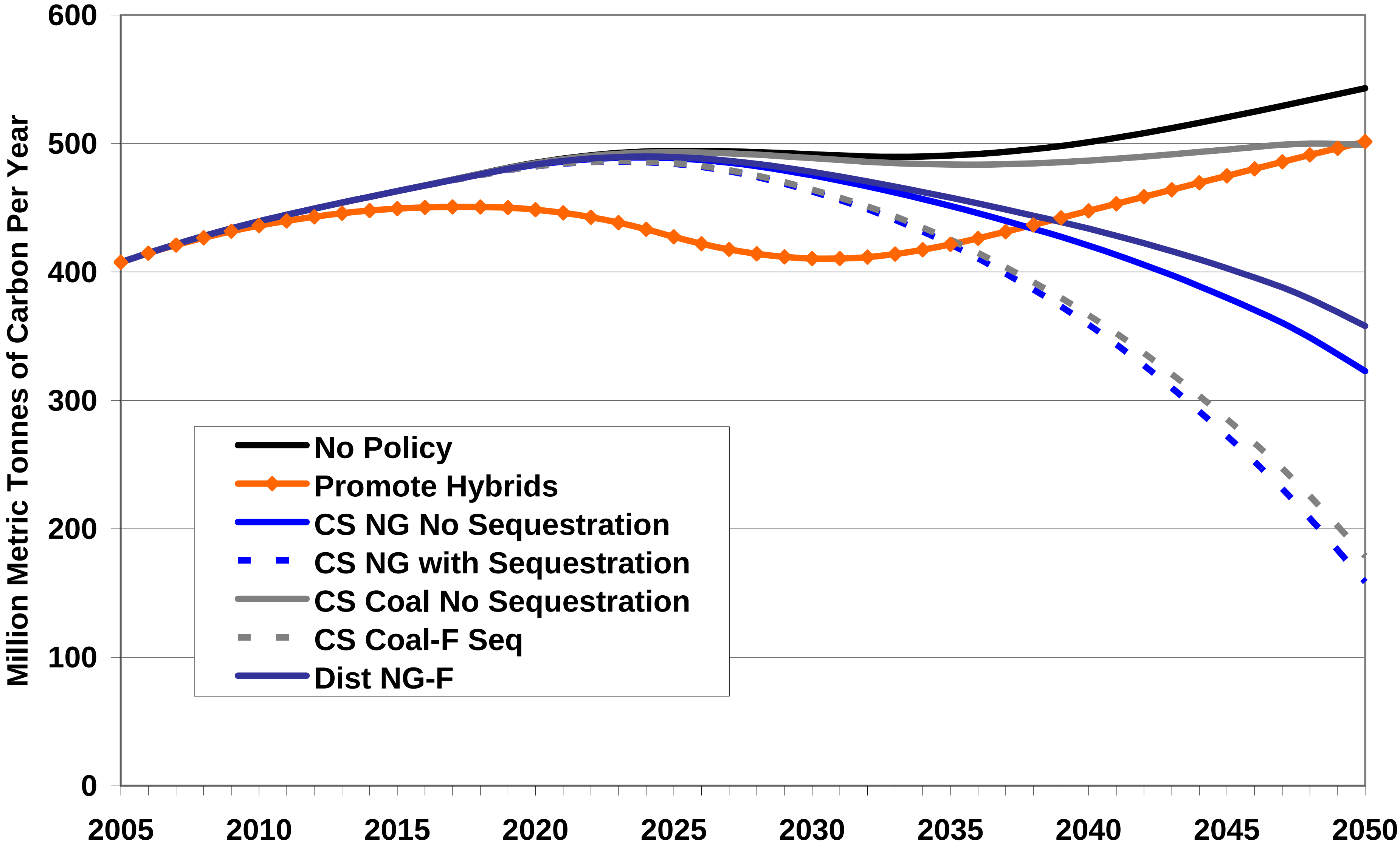
Assumed New Vehicle Fractions



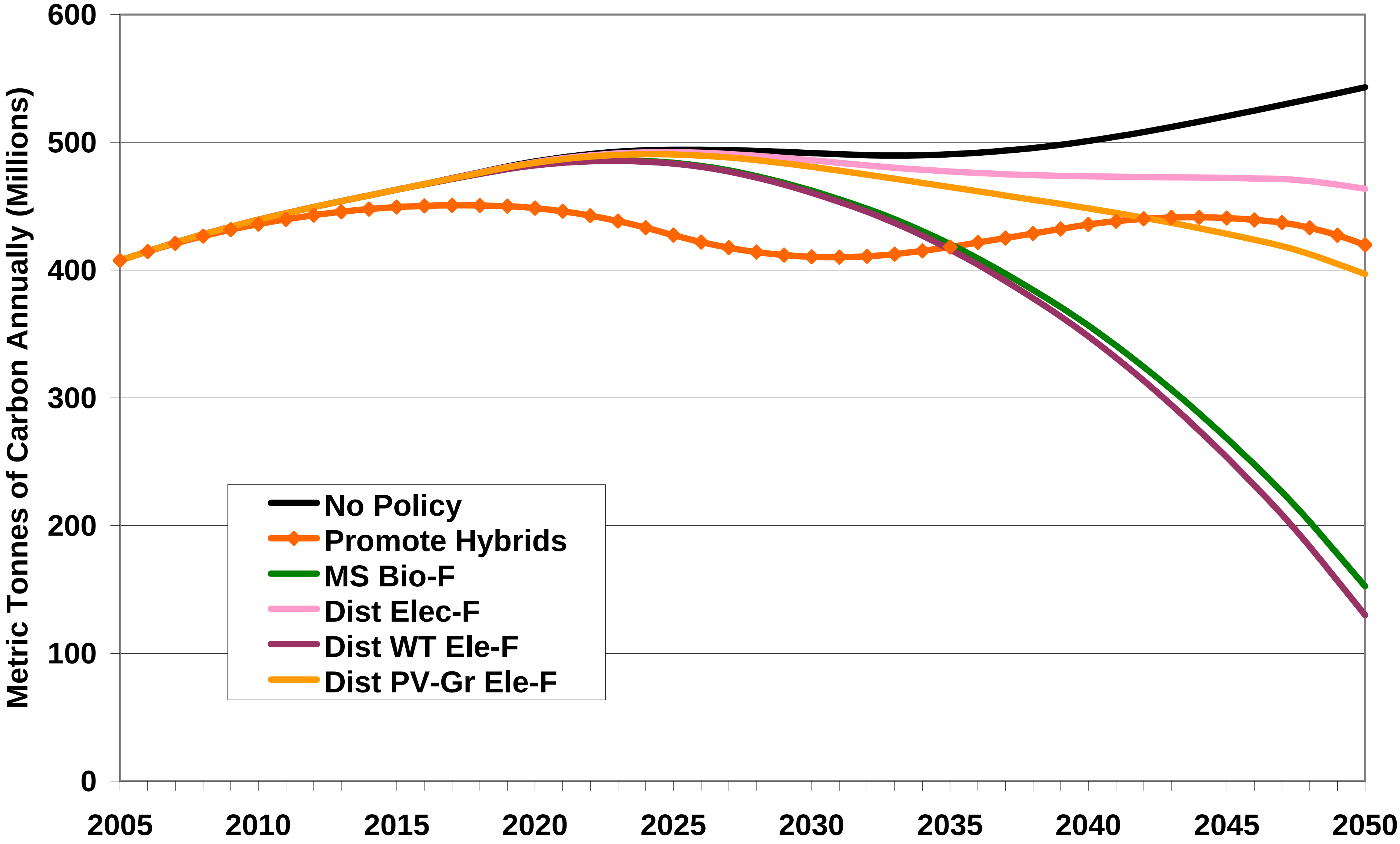
Gasoline Use



Carbon Releases (Fossil Fuel)



Carbon Releases (Renewables, Electrolysis)



Valuation of Outcomes: Assumptions

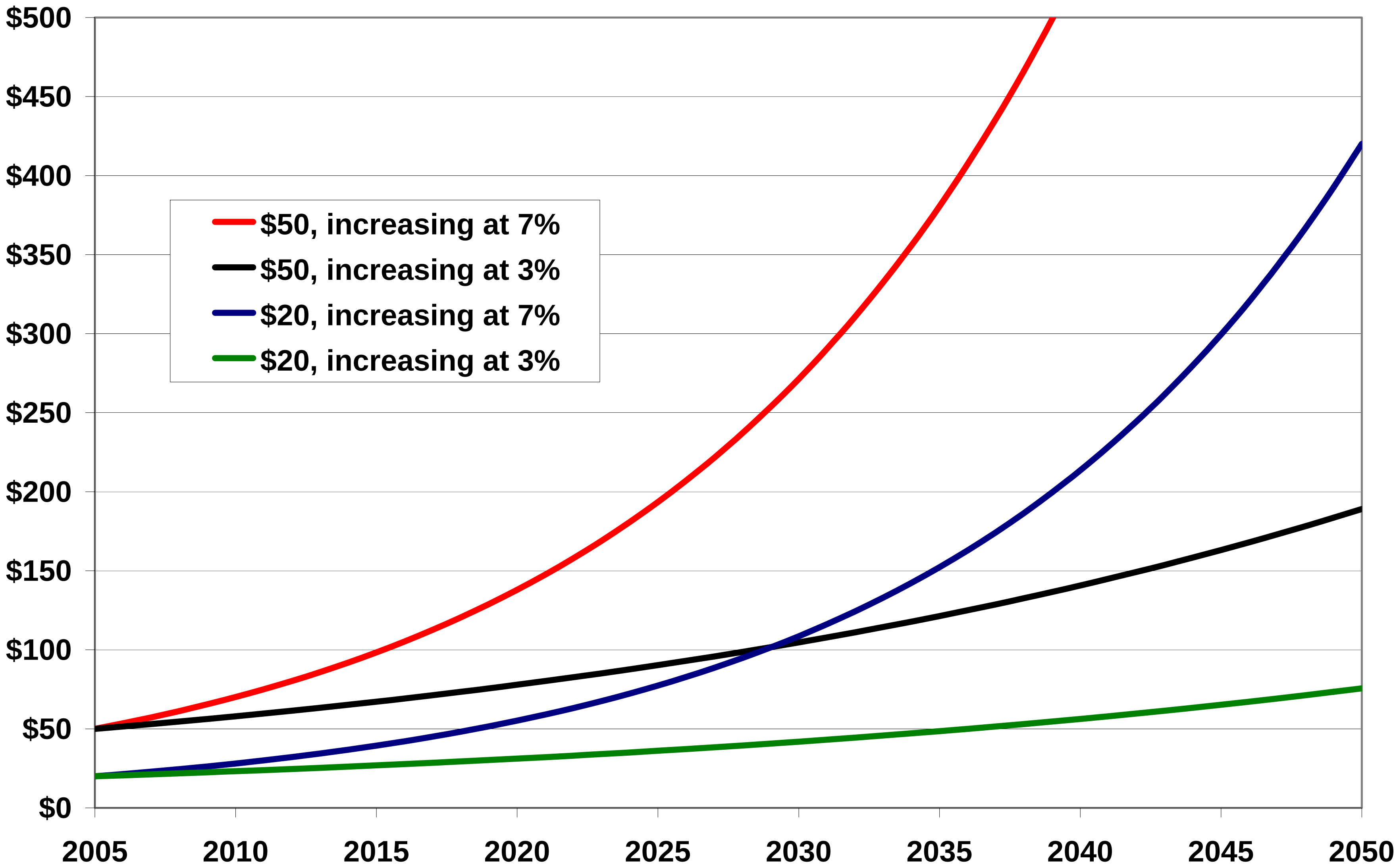
- **Social Discount rate: 3% (7% sensitivity)**
- **Carbon Price:**
  - **\$50/ton carbon base in 2005**
  - **Show carbon price as central variable for analysis**
  - **Assume carbon price rises at discount rate**
- **Crude oil Price**
  - **\$50/barrel**
  - **Sensitivity analysis to this variable**
- **Criteria Pollutants**
  - **See Table**
- **Incremental Vehicle Costs: Net of reduced criteria pollutant damages**
  - **HEV: \$2,000 per vehicle (lower than current costs)**
  - **FCV: \$5,000 per vehicle (radically lower than current)**

Estimated Damages From Criteria Pollutants: Conventional Gasoline Light Duty Vehicles

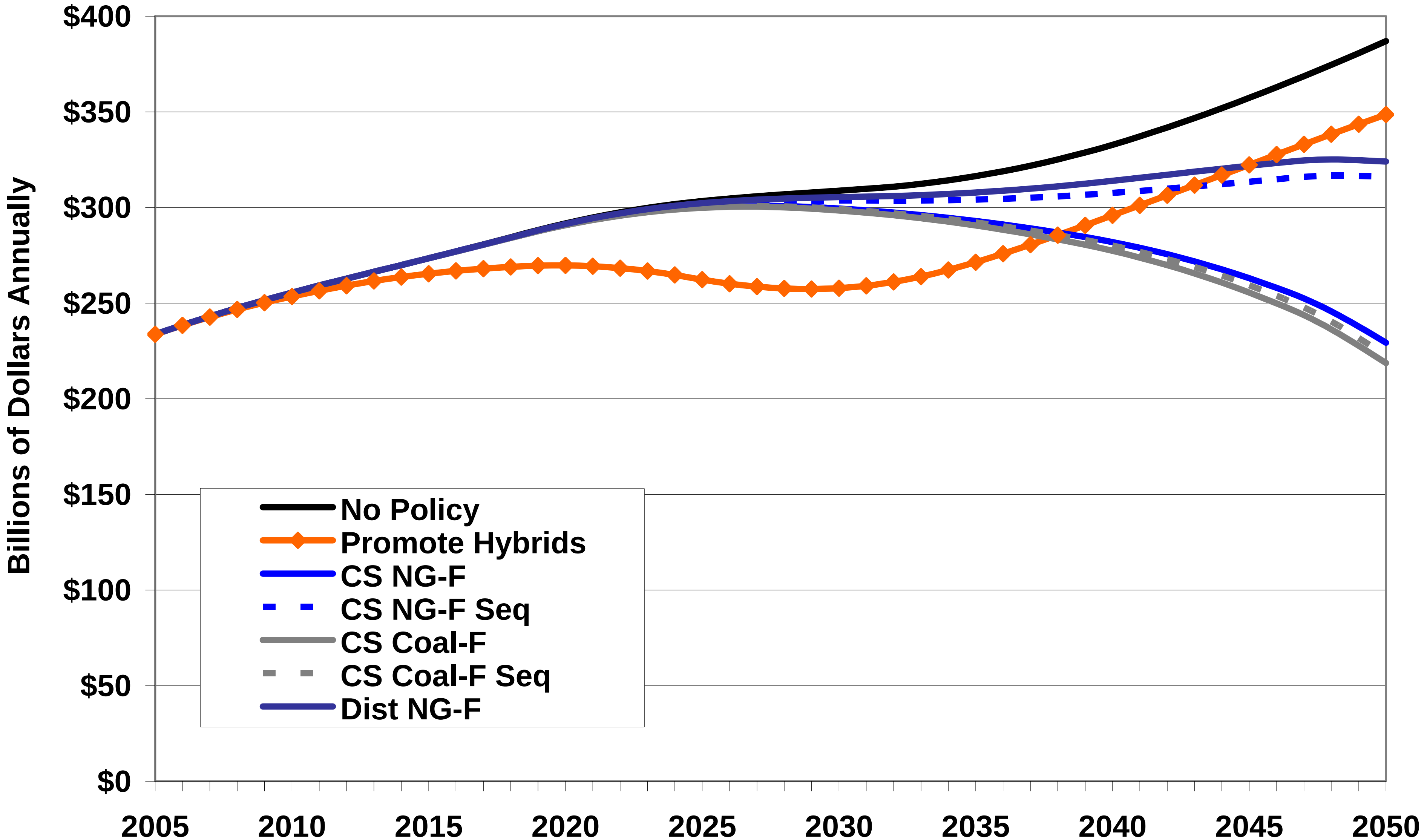
(Damage Estimates from Hydrogen Highway Blueprint)

Pollutants	CA LEV II Standards (gm/mile)	Assumed Damages Per Tonne	Tonnes during 150 K miles	Lifetime Pollution Damages (Not discounted)
CO	3	$220	0.45	$99
NOx	0.1	$88,000	0.015	$1,320
VOCs	0.07	$5,000	0.0105	$53
PM	0.01	$48,000	0.0015	$72
Total				$1,544

Carbon Prices Over Time ($/tonne Carbon)



Fuel plus Carbon Cost: $50/Bbl Oil, $50/TC in 2005, Growing at 3%



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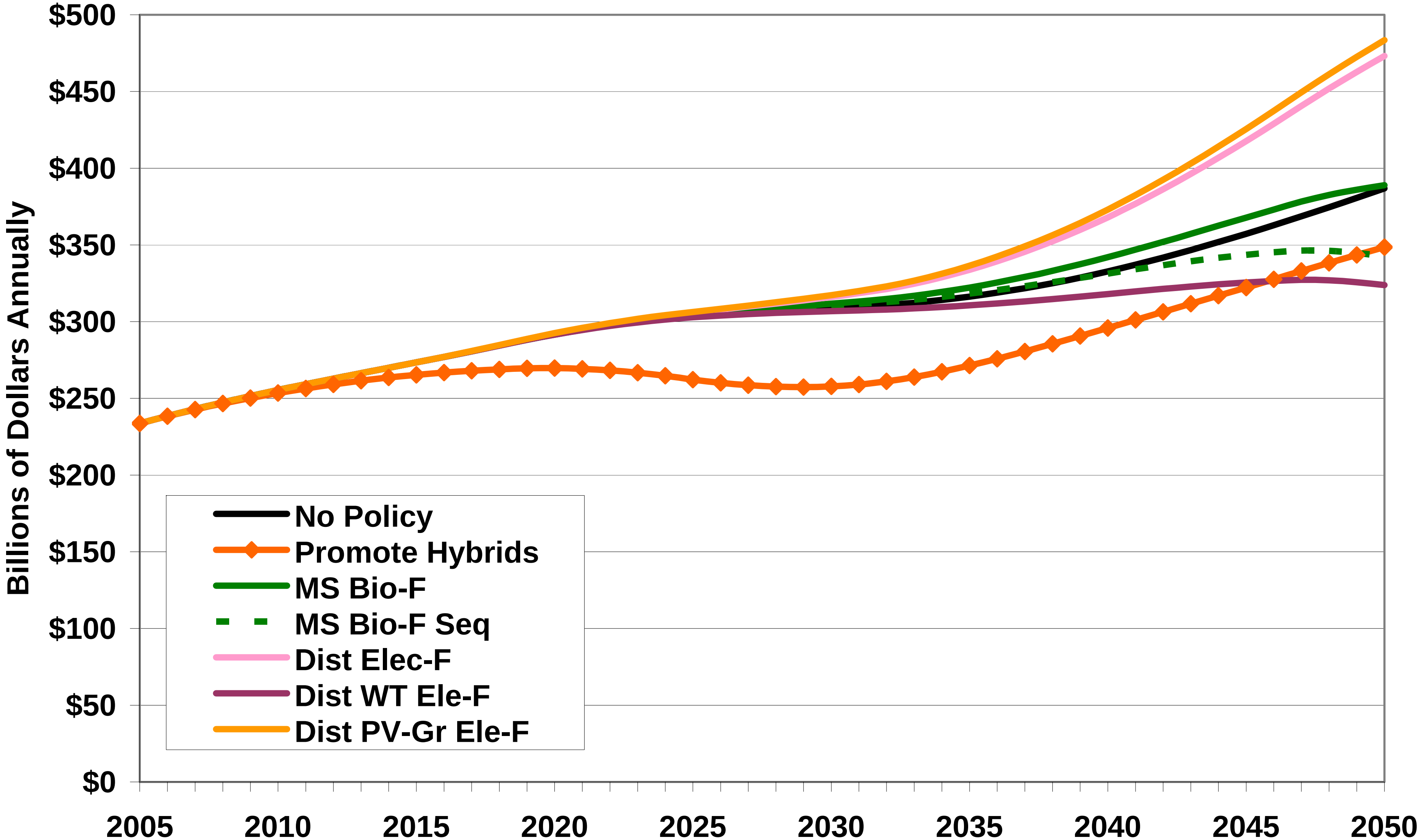
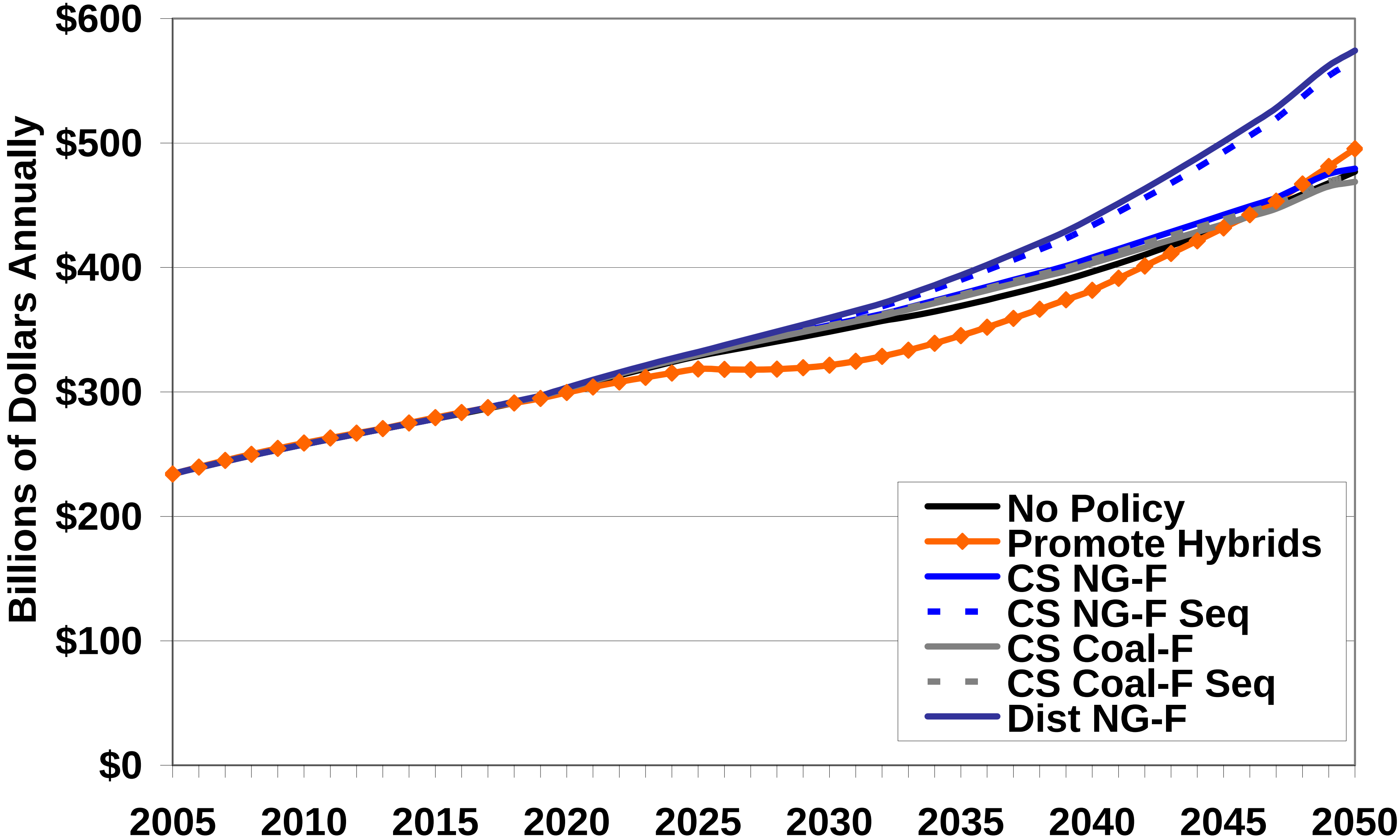


DPV Fuel System Costs, through 2050 ($Billions)
$50 2005 Carbon Price, Rising at Discount Rate

Carbon Price in 2005 ($/TC)	$50		$50	
Discount rate	3.0%		7.0%	
	NPV	Saving	NPV	Saving
No Policy	$7,429		$4,625	
Hybrid Focus	$6,843	$586	$4,334	$291
Hybrid Focus w/o any H2	$6,868	$561	$4,339	$286
Hydrogen Scenarios				
Natural Gas, Central Station	$6,993	$436	$4,383	$242
Coal, Central Station, Seques.	$6,977	$453	$4,366	$258
Natural Gas, Distributed	$7,265	$164	$4,520	$105
Electrolysis, Grid Derived	$7,716	($286)	$4,670	($45)
Electrolysis, Wind Turbine	$7,290	$139	$4,445	$180
Electrolysis, PV, Grid Backup	$7,755	($326)	$4,656	($31)

Fuel + Carbon + Additional Vehicle Cost: $50/Bbl Oil, $50/TC, +$2,000 HEV, +$5,000 FCV



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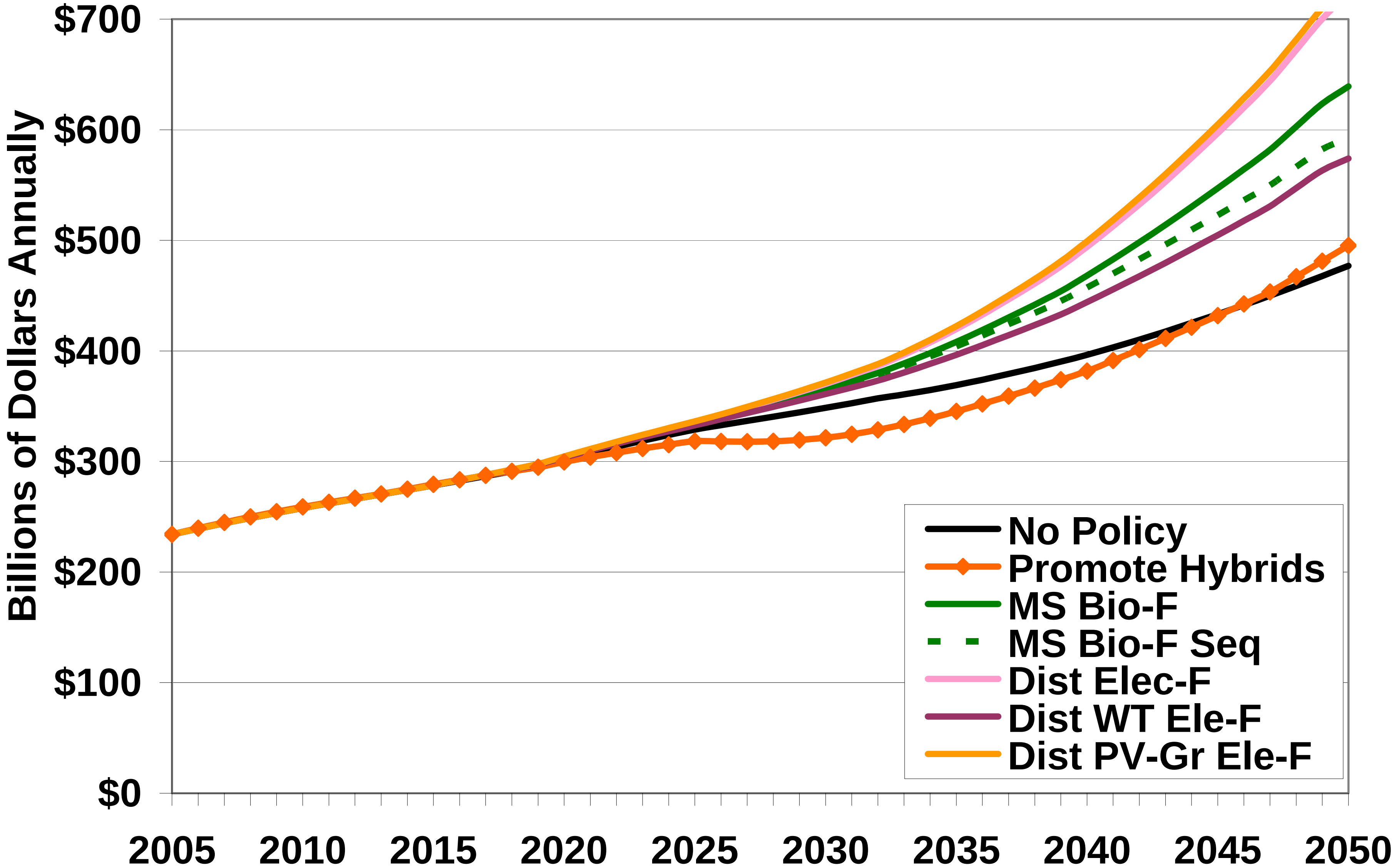
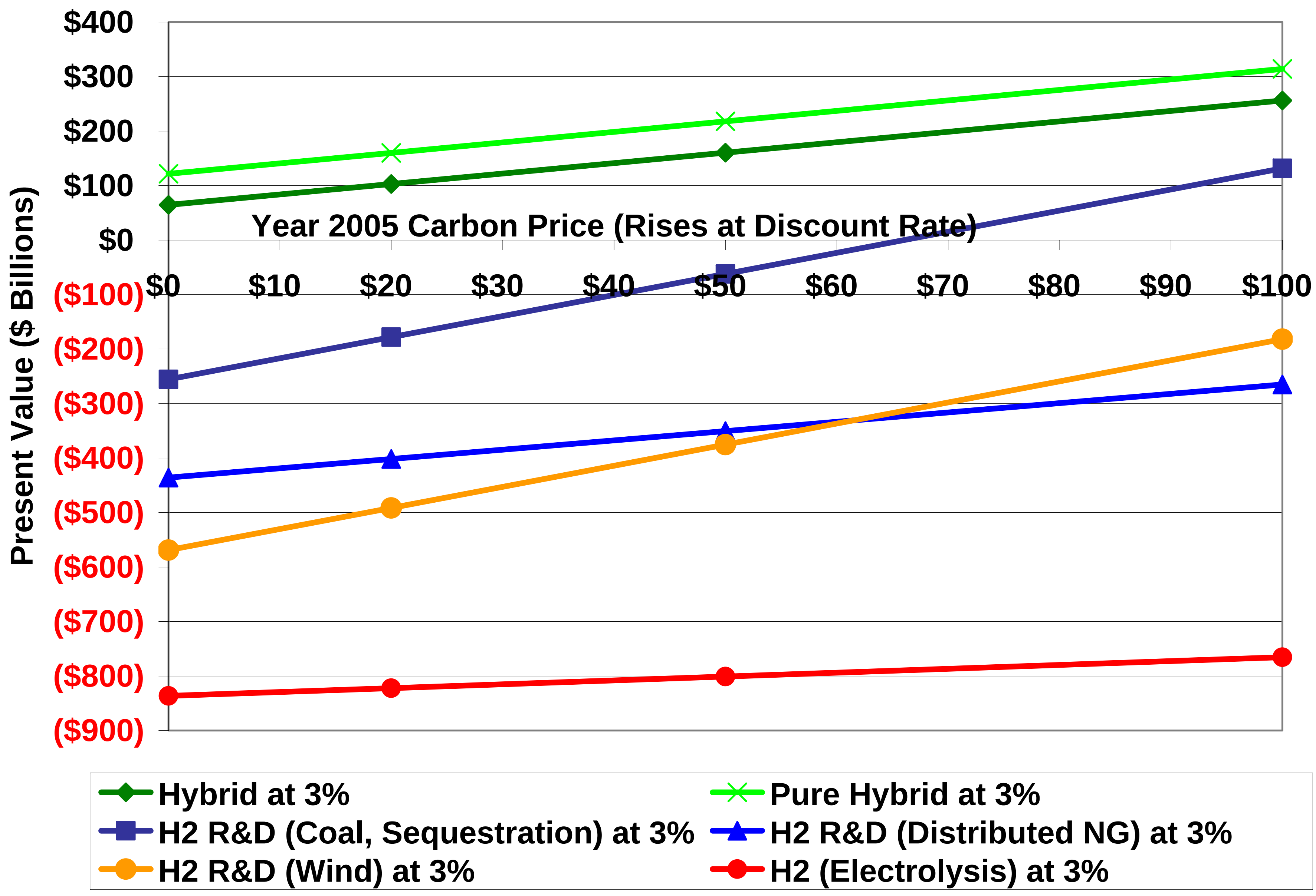


DPV Total System Costs, through 2050 ($Billions). $50 2005 Carbon Price, Rising at Discount Rate

Carbon Price in 2005 ($/TC)	$50		$50	
Discount rate	3.0%		7.0%	
	NPV	Saving	NPV	Saving
No Policy	$8,067		$8,067	
Hybrid Focus	$7,907	$160	$7,907	$160
Hybrid Focus w/o any H2	$7,849	$218	$7,849	$218
Hydrogen Scenarios				
Natural Gas, Central Station	$8,146	($79)	$8,146	($79)
Coal, Central Station, Seques.	$8,129	($62)	$8,129	($62)
Natural Gas, Distributed	$8,418	($350)	$8,418	($350)
Electrolysis, Grid Derived	$8,868	($801)	$8,868	($801)
Electrolysis, Wind Turbine	$8,442	($375)	$8,442	($375)
Electrolysis, PV, Grid Backup	$8,907	($840)	$8,907	($840)

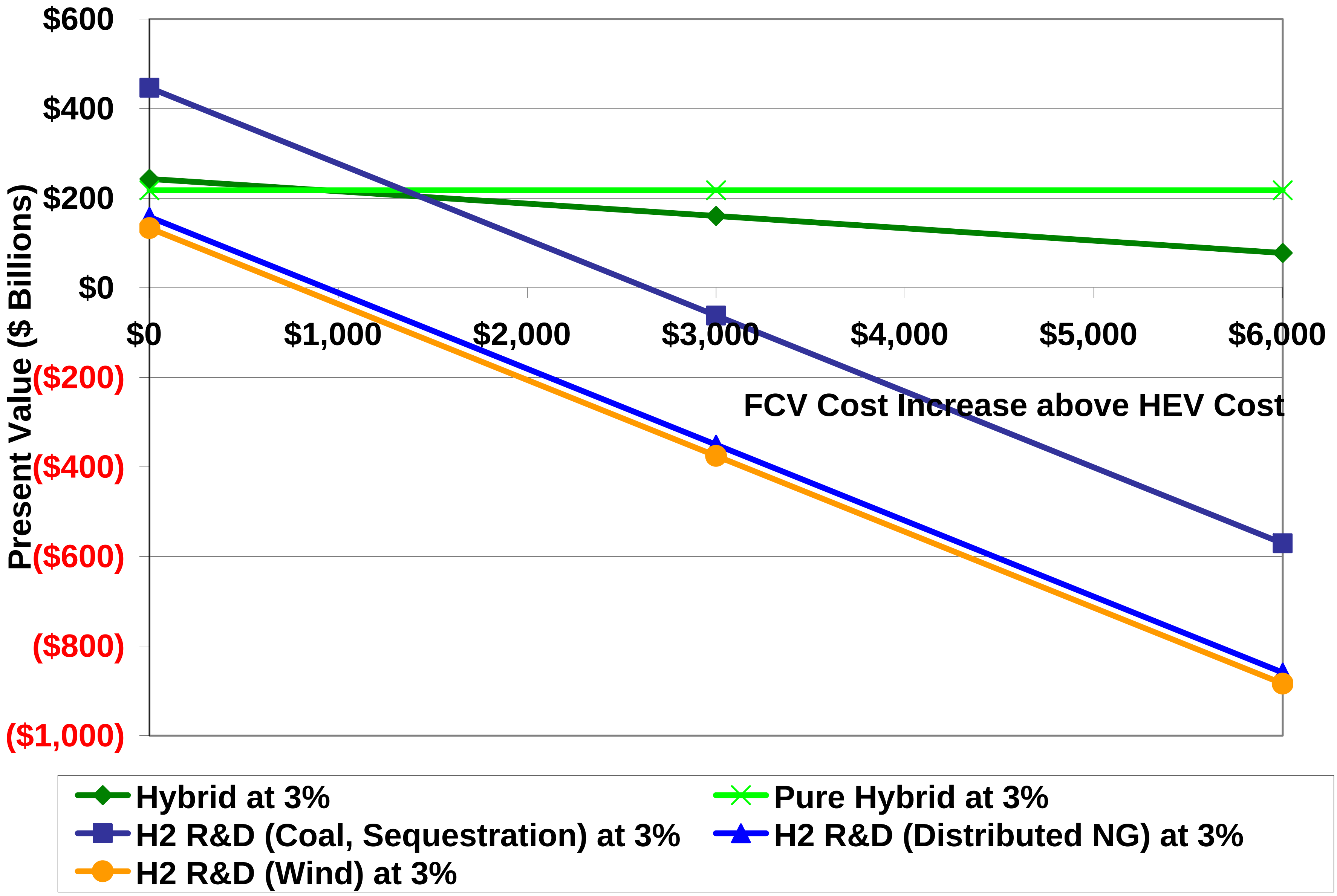
Total Cost Savings from Technology Programs: 3% Carbon Price Growth Rate and Discount Rate



At 3% growth rate of CO_2 damages (and 3% discount rate):

- **Promoting hybrids provides greatest savings for CO_2 prices (or damages) up to over $100/TC**
- **Fuel system costs:**
  - **All strategies except grid-based electrolysis reduce fuel system costs unless very low carbon damages**
  - **Grid-based electrolysis increases fuel system costs**
- **Total system costs:**
  - **Hydrogen FCVs, using distributed generation (grid-based electrolysis, distributed NG, renewables) increases total costs, relative to no policy.**
  - **Hydrogen FCVs, using central station coal, with CO_2 sequestration, reduces costs if very high CO_2 prices.**

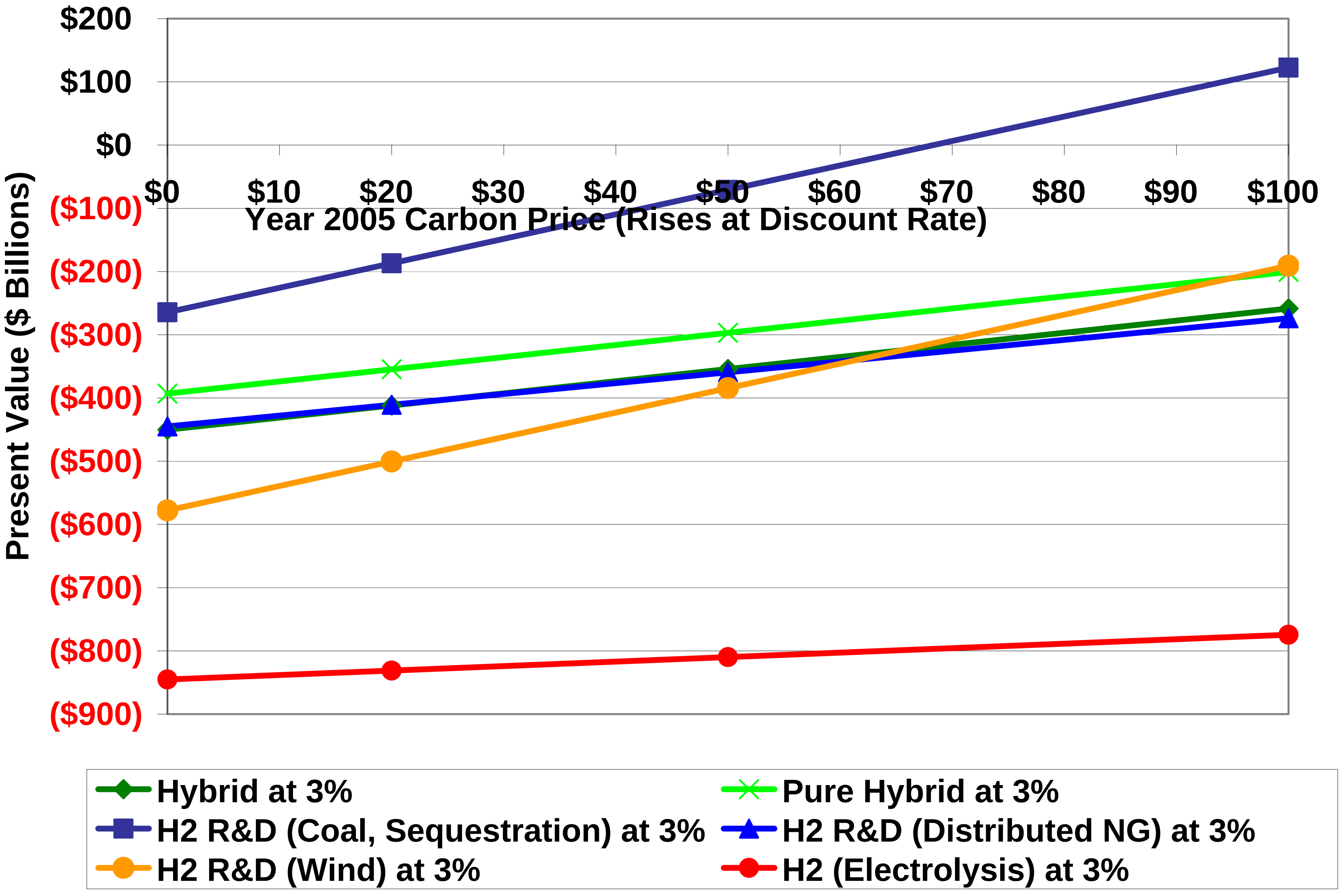
Total Cost Savings vs FCV Cost



Differential Cost of FCVs

- **Relative ranking of hybrid strategies vs. hydrogen R&D strategies depends greatly on differential cost of hydrogen FCVs relative to hybrid vehicles (including criteria pollutant damages.)**
- **If FCV costs are no higher than HEV costs, then hydrogen R&D, with coal-based hydrogen and CO_2 sequestration gives greatest savings (for $50/TC).**
- **If FCV costs are $1,500 or more higher than HEV costs (at 3% discount rate; $3,000 at 7%), then promoting hybrids gives greatest savings (for $50/TC).**
  - **Note: These are costs net of criteria pollutant savings. If criterion pollutant damages are reduced by $1,544 for FCVs, then $1,500 higher FCV cost implies $3,044 additional cost of the FCV itself.**

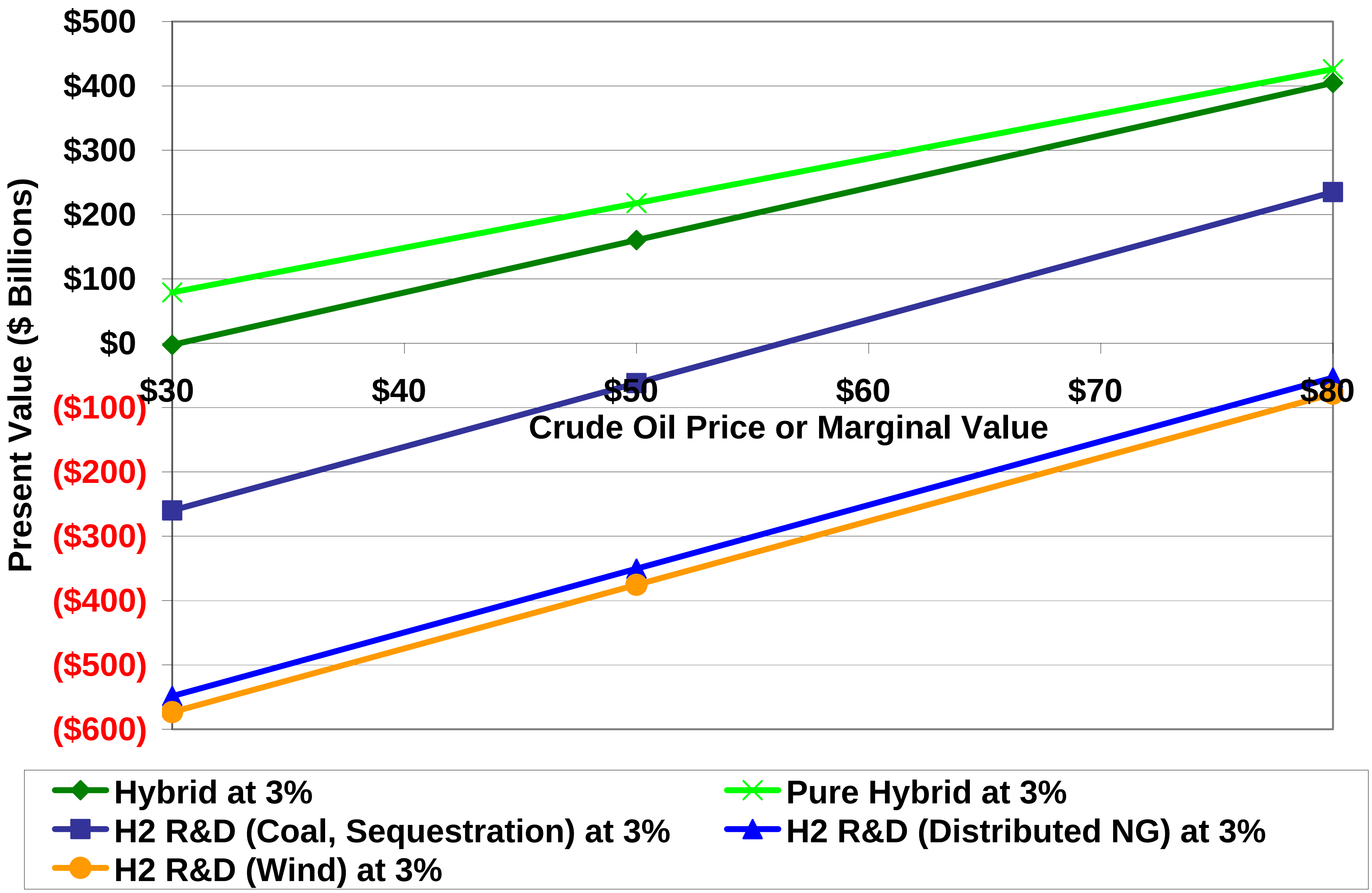
Total Cost Savings at $5,000 Incremental HEV Cost and $8,000 Incremental FCV Cost



Incremental Vehicle Costs are Crucial

- Scenario
  - $5,000 incremental HEV Cost
  - $8,000 incremental FCV Cost
  - $50 Crude oil Price
- None of the strategies have net positive benefits unless carbon price exceeds $40 per tonne of carbon in 2005, at 3% discount rate
- Hybrid strategies do not have net positive benefits.

Total Cost Savings vs Crude Oil Price



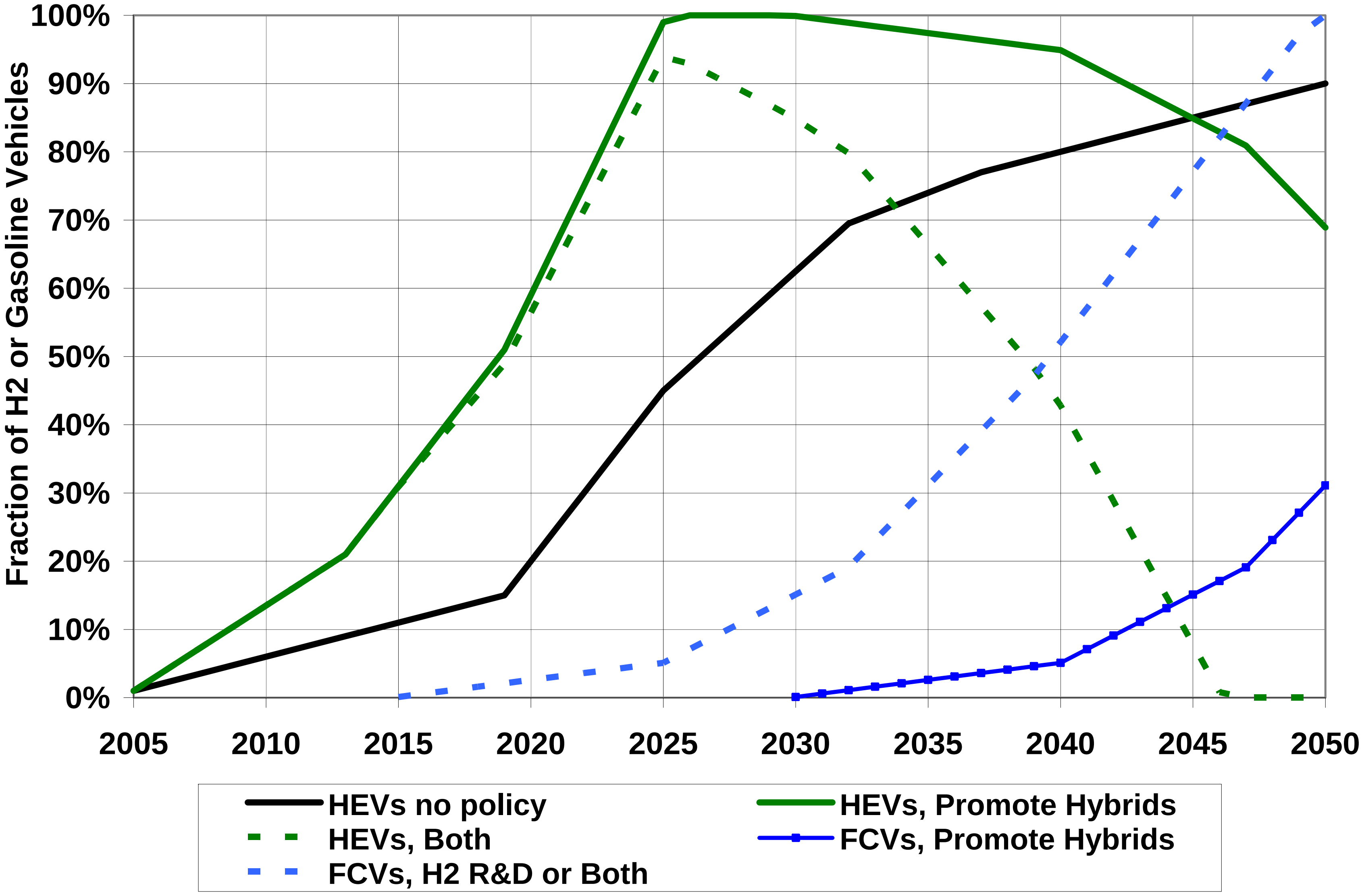
Oil Price Uncertainty

- **Future oil price level not crucial in determining which strategies have greatest benefits and which have the least benefits.**
- **Higher expected future oil price makes either strategy more attractive.**
- **Pattern of low oil prices through 2030s and much higher oil prices later would favor hydrogen R&D.**
- **The opposite pattern would favor promoting hybrids.**

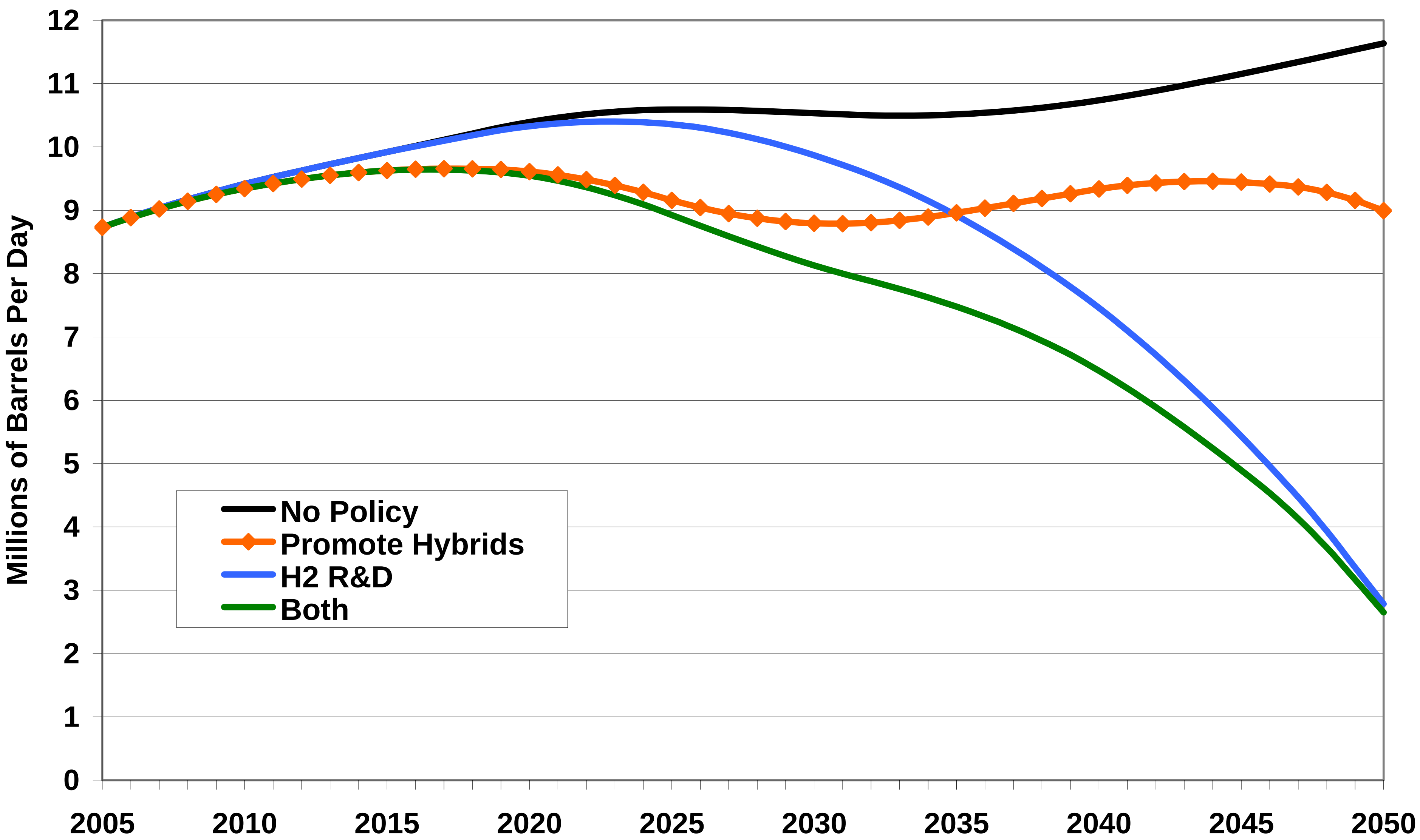
Both Policies Together

- **What if auto companies and government agencies pursued both strategies together: accelerate hybrids and maximum development of hydrogen FCVs?**
- **Assume same path of conventional vehicles as in “promote hybrids” case, but market share of hydrogen FCVs substitutes for HEVs.**

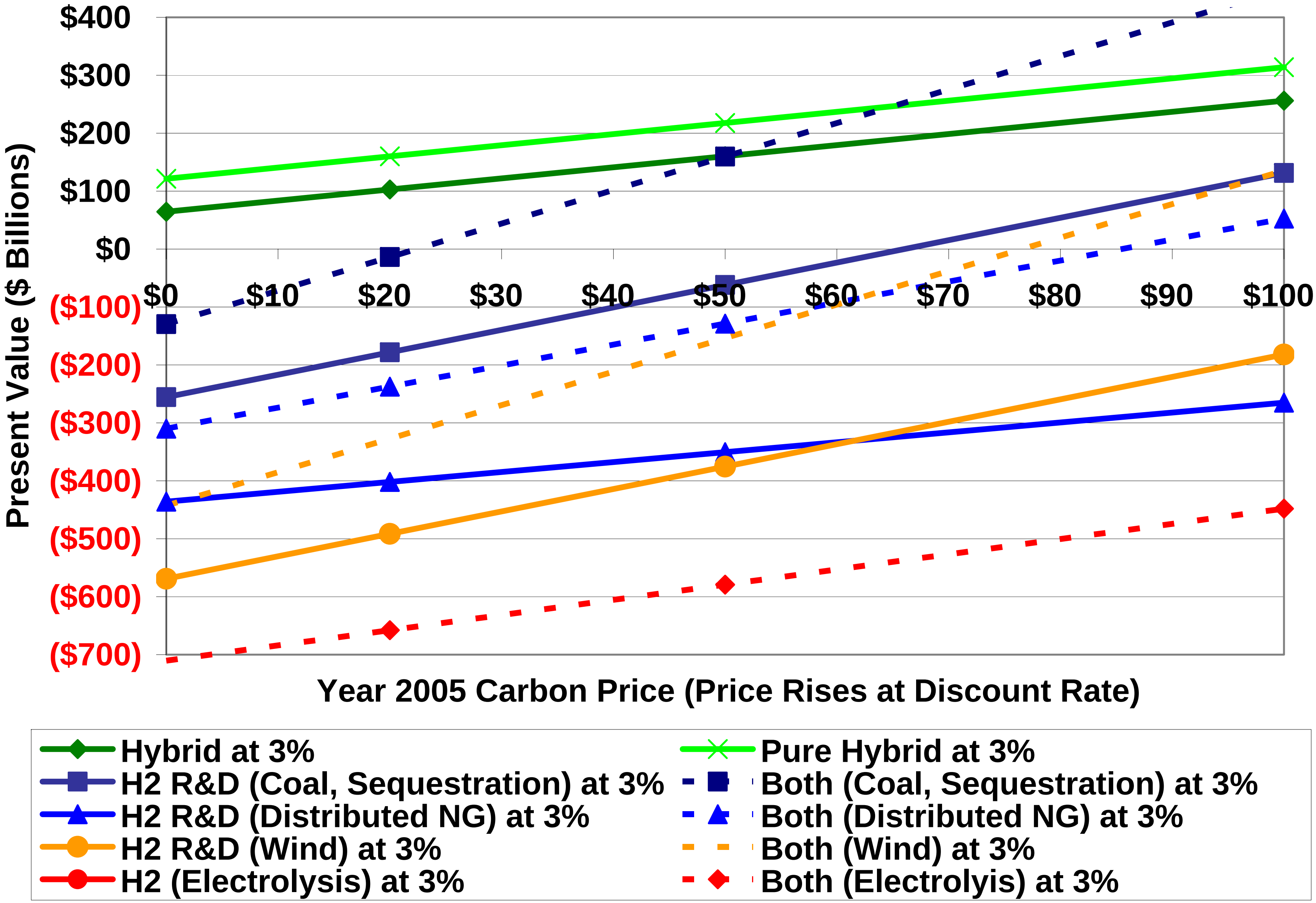
New Vehicle Assumed Market Shares



Oil Use Scenarios



Total Cost Savings from Technology Programs: 3% Carbon Price Growth Rate and Discount Rate



My Current Conclusions

- **Public policy should put attention on promoting hybrid vehicles for the near term (say, next 20-30 years) unless one assigns a high probability to very low costs of FCVs and very high and rapidly growing carbon prices.**
- **Public policy should continue R&D on hydrogen fuel cell vehicles and supply technology, with the idea of implementing hydrogen in the longer term (after say, 30 years) if technology advances sufficiently.**
- **Short term emphasis on hydrogen implementation is appropriate only if very high carbon taxes are expected, either very high immediate taxes or very high rate of growth of the carbon tax.**