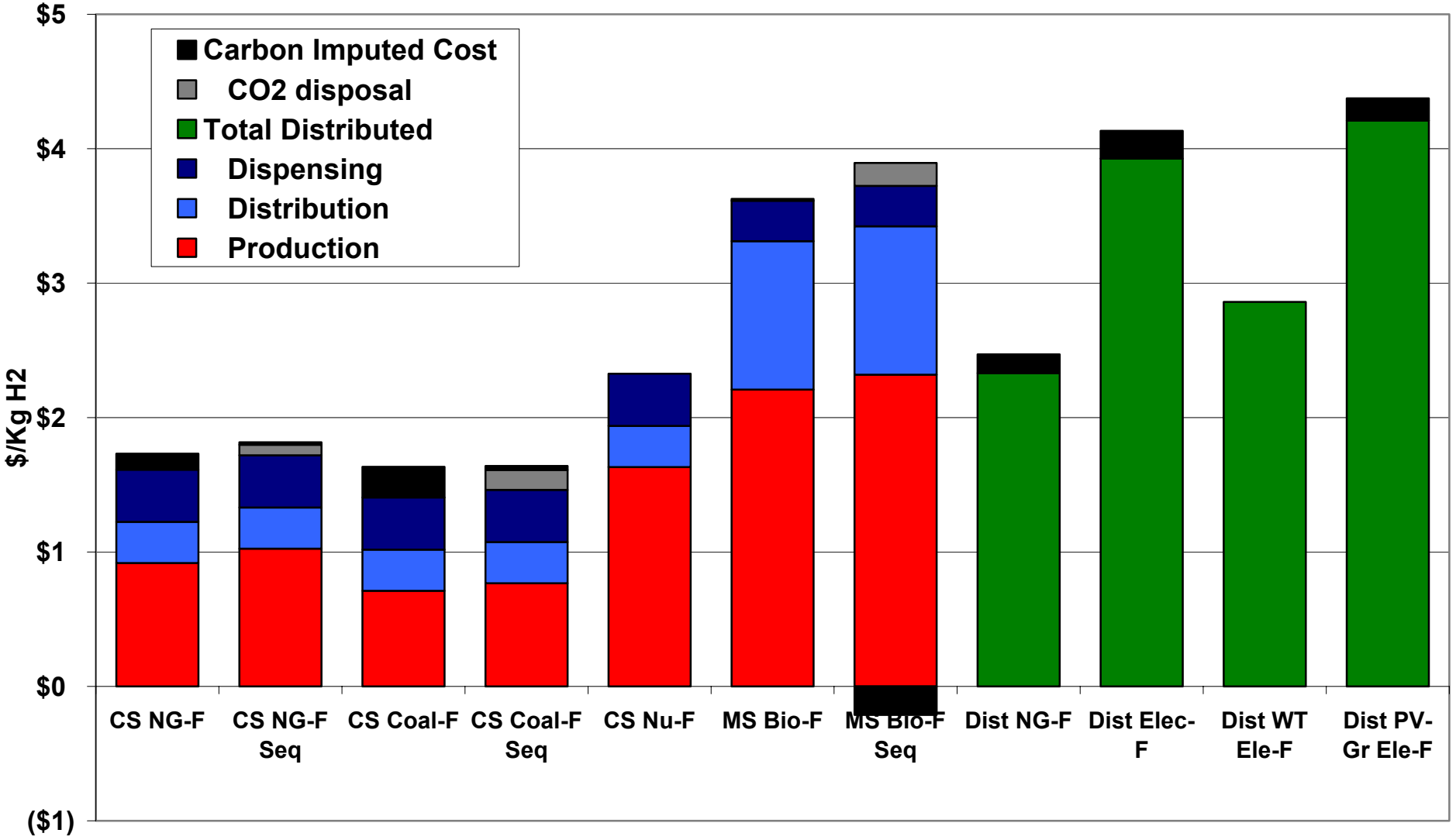
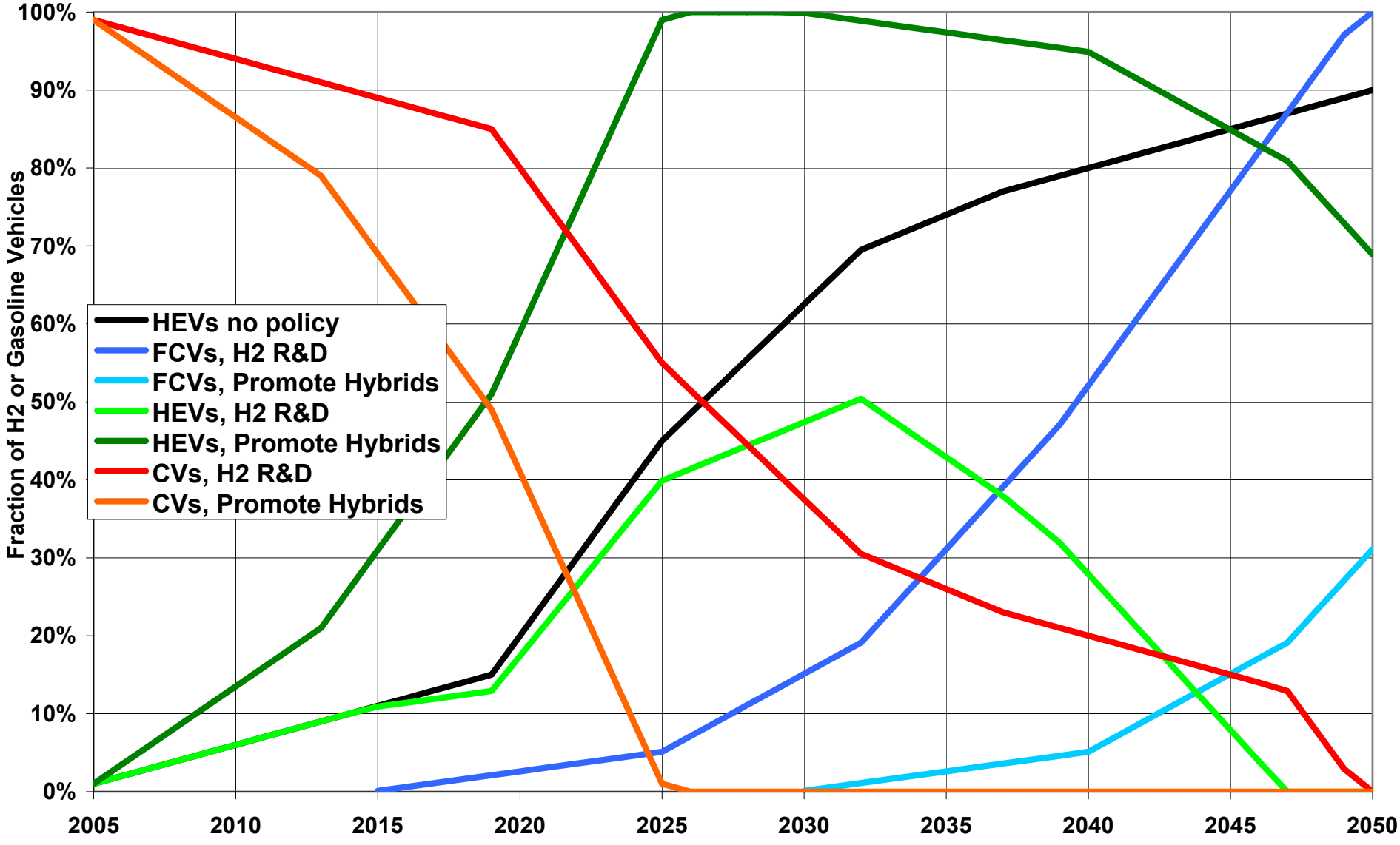
Hydrogen Supply Costs: With Technology Advance

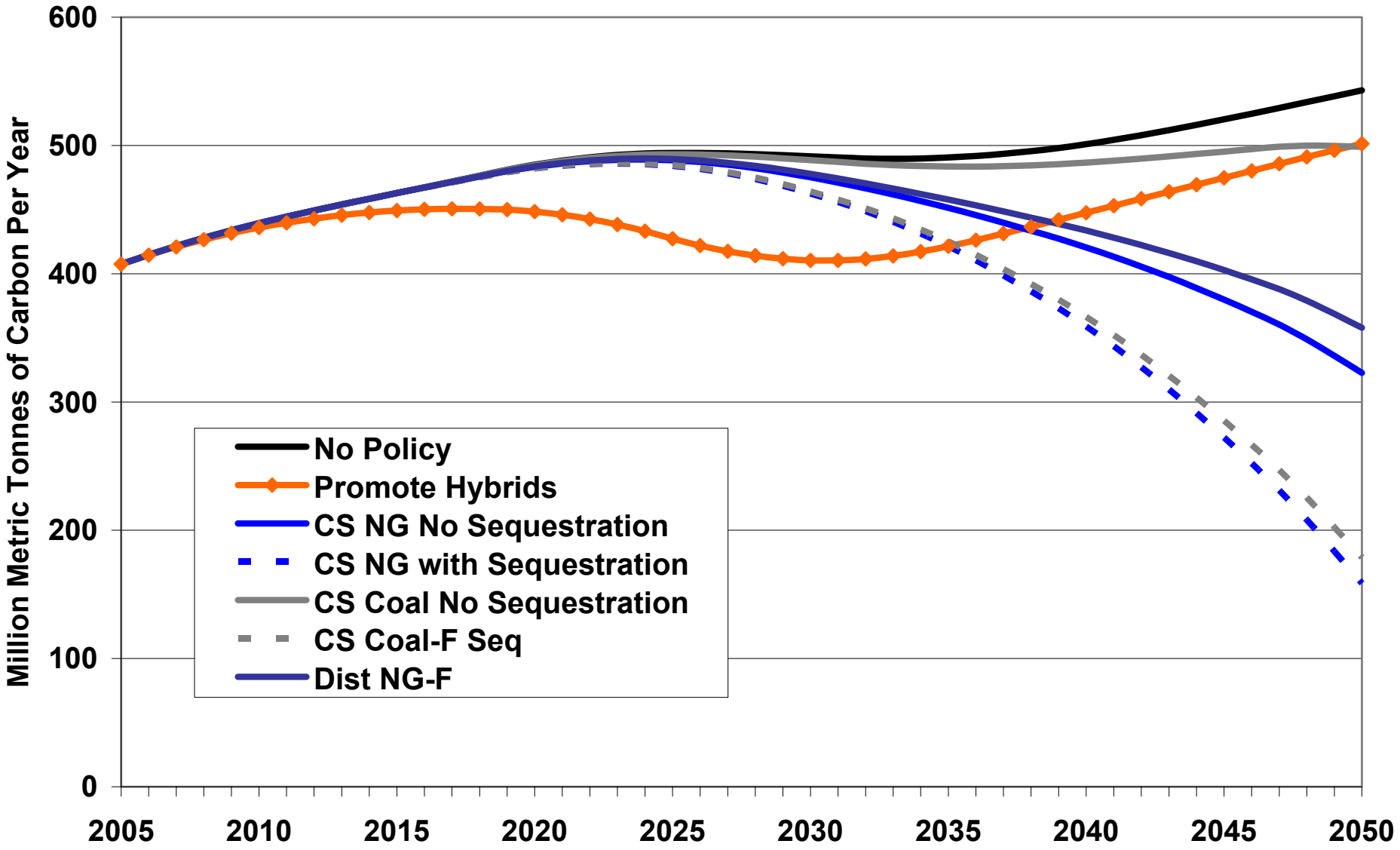


Source: NRC Hydrogen Study

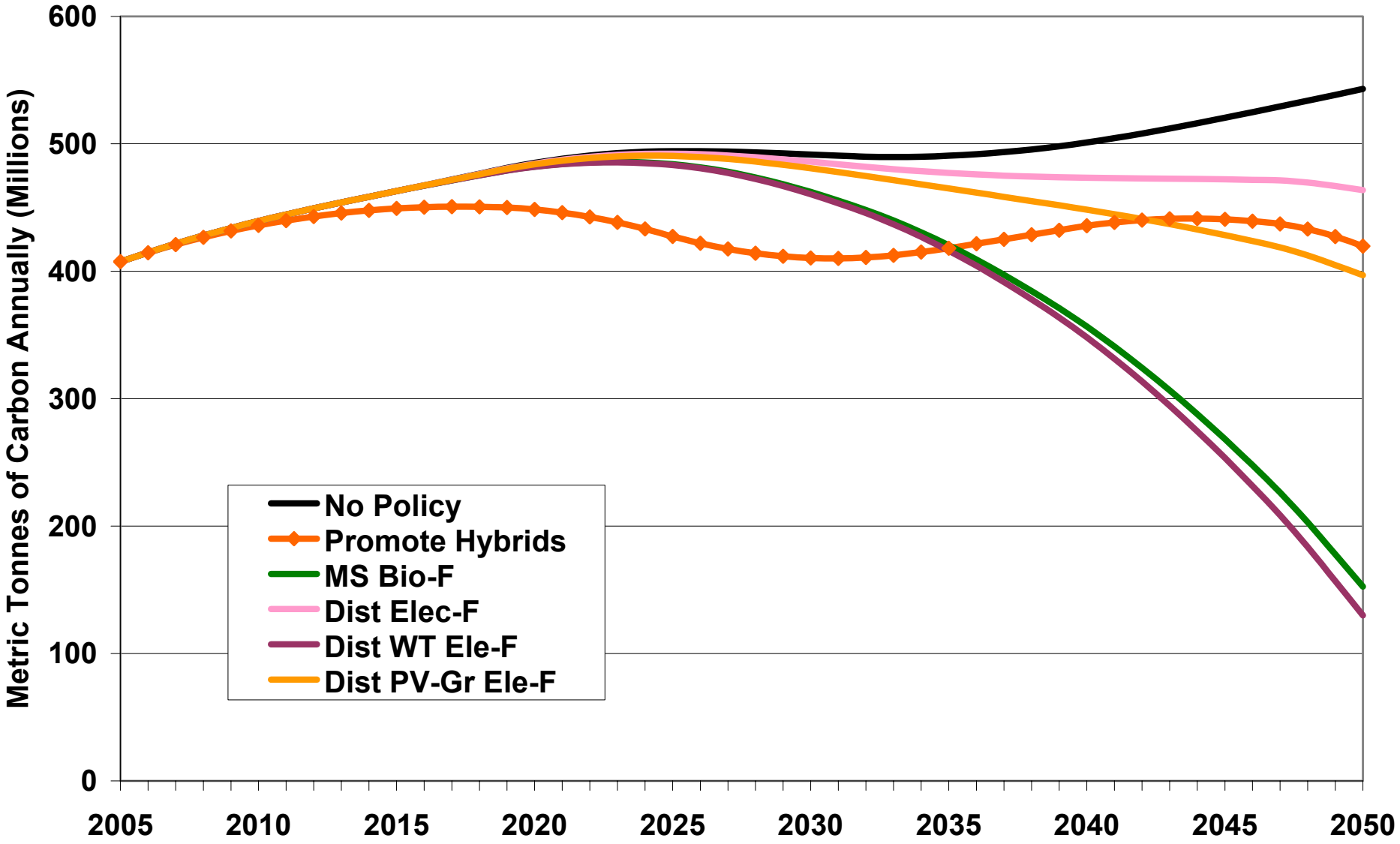
Assumed New Vehicle Fractions



Carbon Releases (Fossil Fuel)



Carbon Releases (Renewables, Electrolysis)



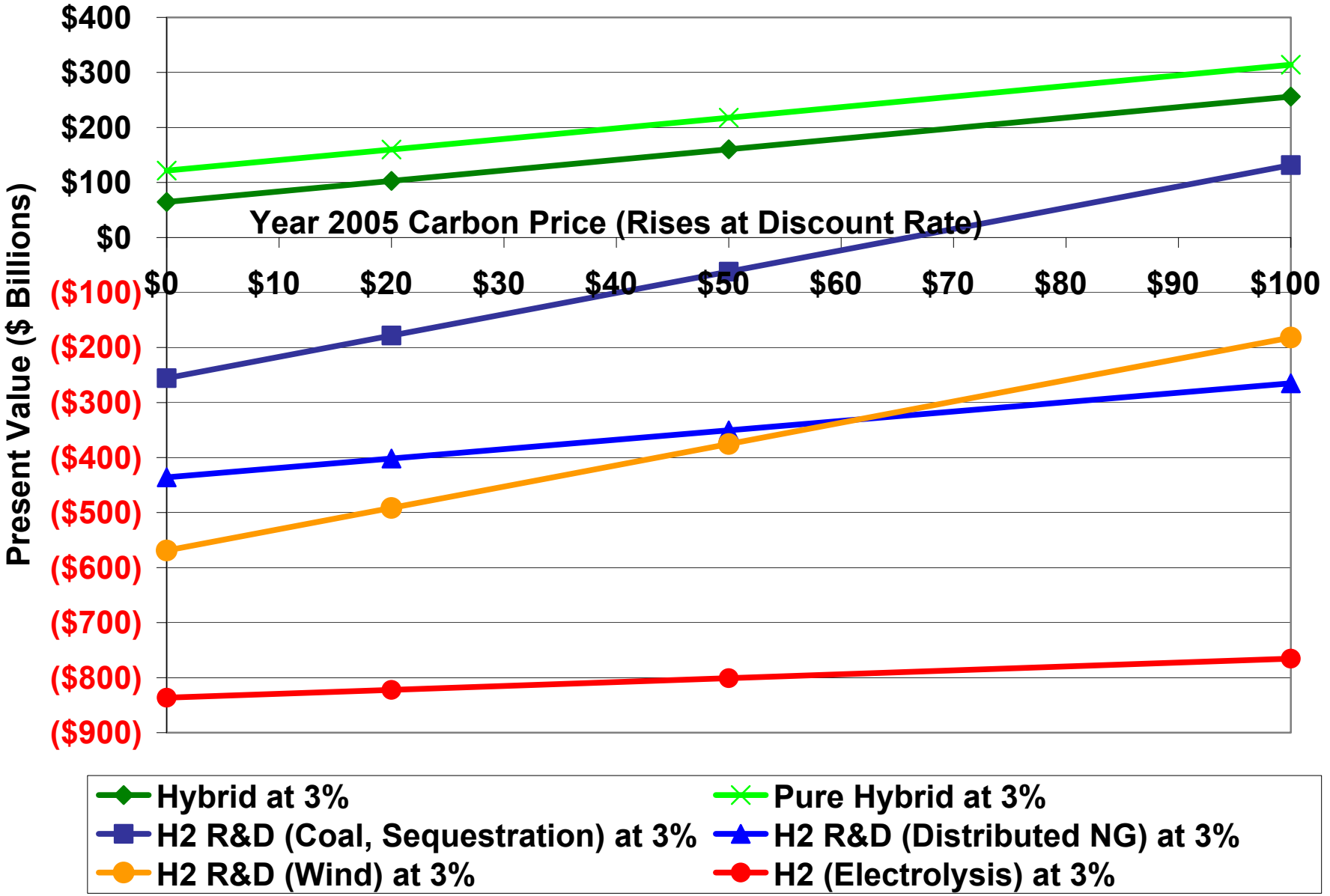
Estimated Damages Criteria Pollutants Plus CO_2: Conventional Gasoline Light Duty Vehicles (20 mpg)

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
CO_2	150 C	$50/ T C	22.5	$1,125
Total				$2,700
Gasoline Cost	20 mpg	$2.50/gal	7,500 gal	$18,750

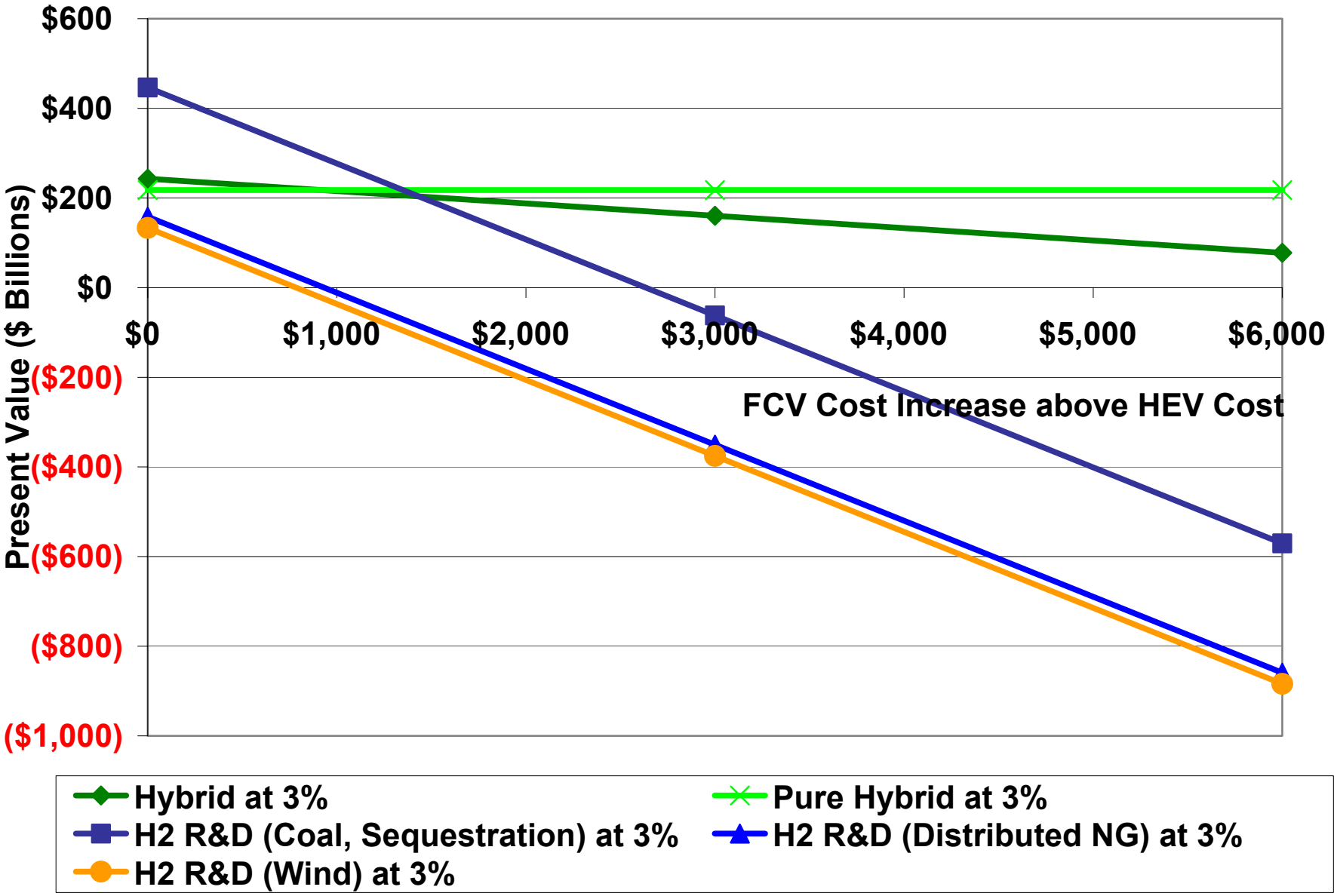
DPV Total System Costs, through 2050 ($Billions). $50 2005 Carbon Price, Rising at Discount Rate

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



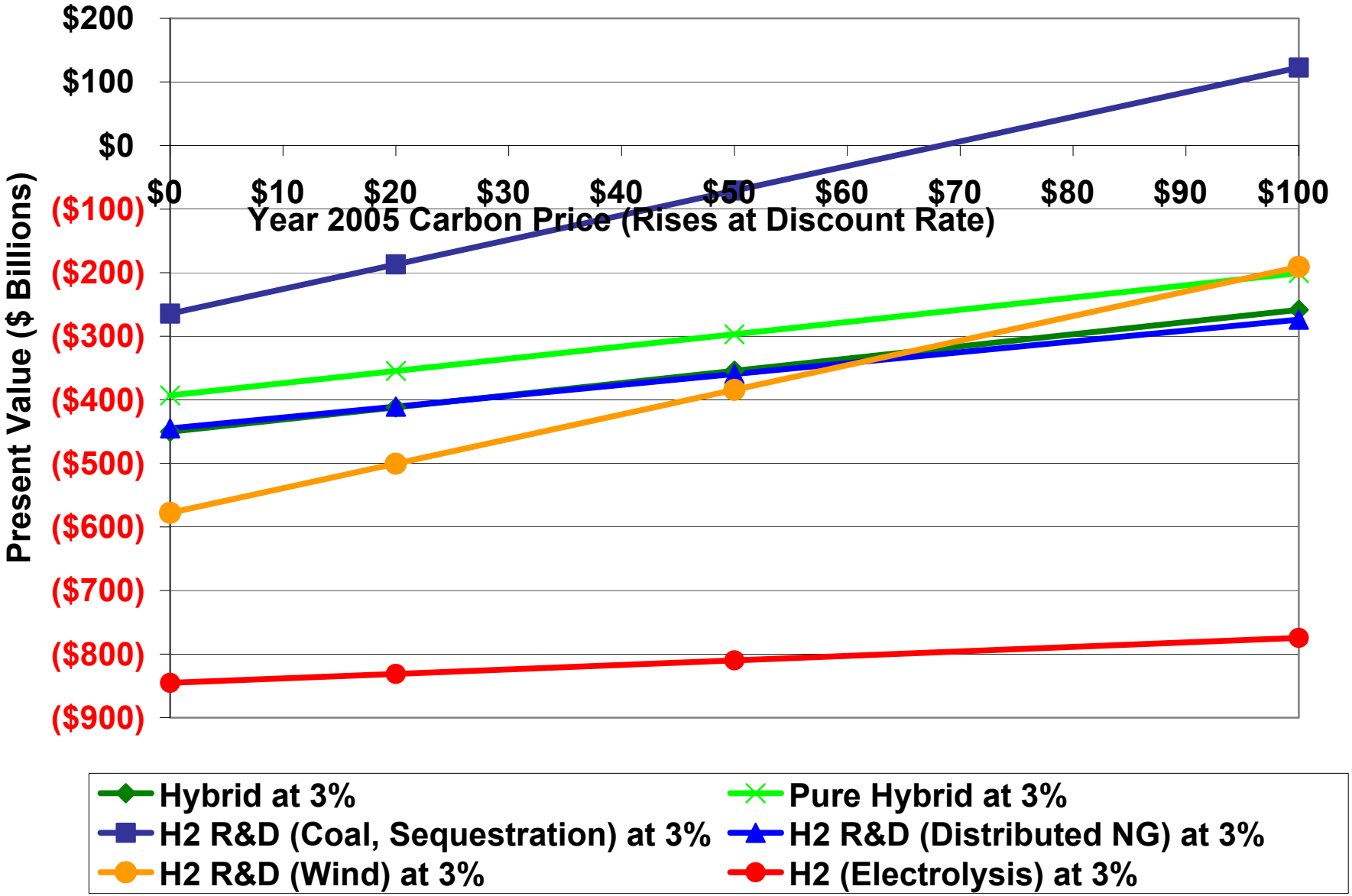
Total Cost Savings vs FCV Cost



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.**

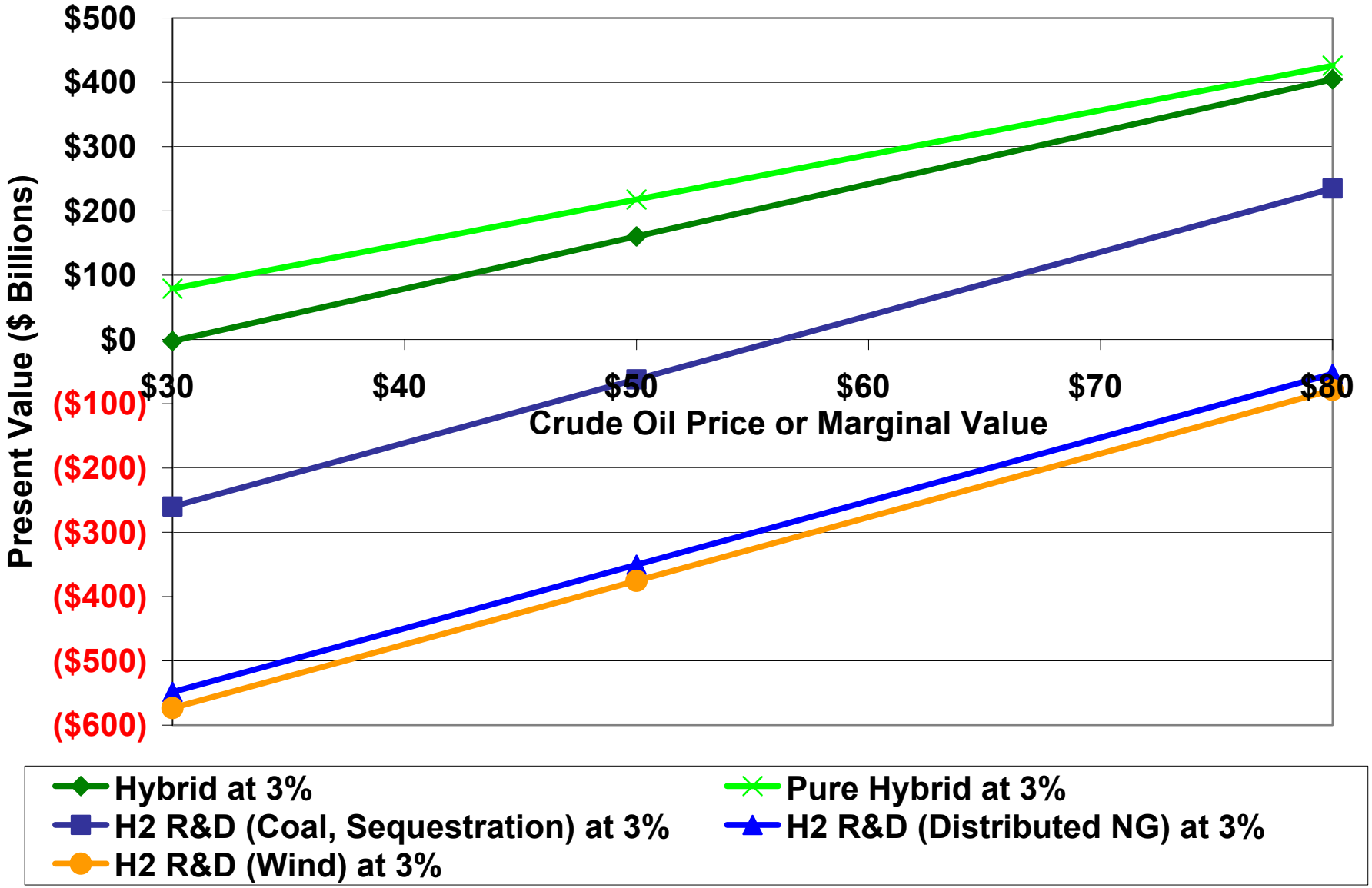
Total Cost Savings at $5,000 Incremental HEV Cost and $8,000 Incremental FCV Cost



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.**

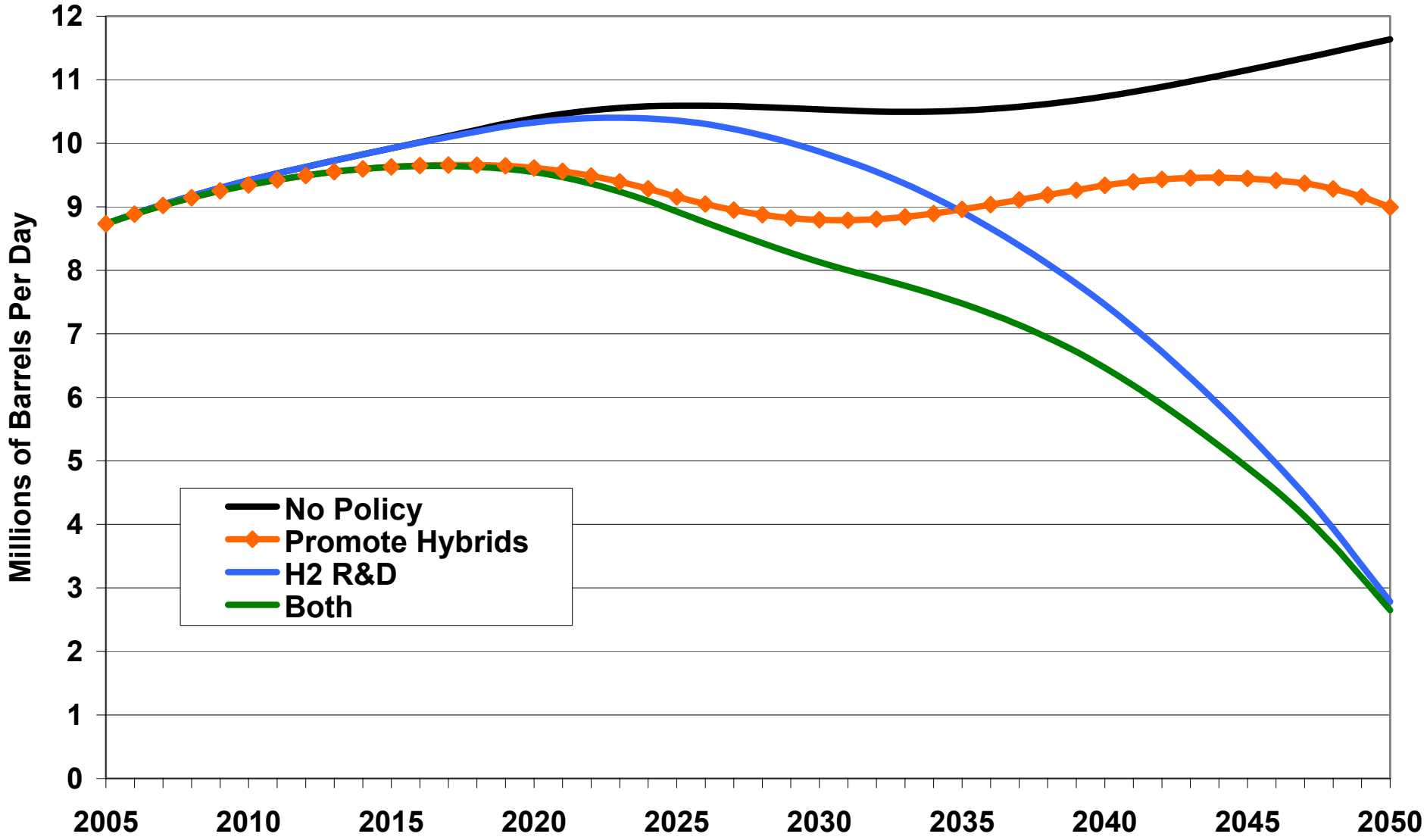
Total Cost Savings vs Crude Oil Price



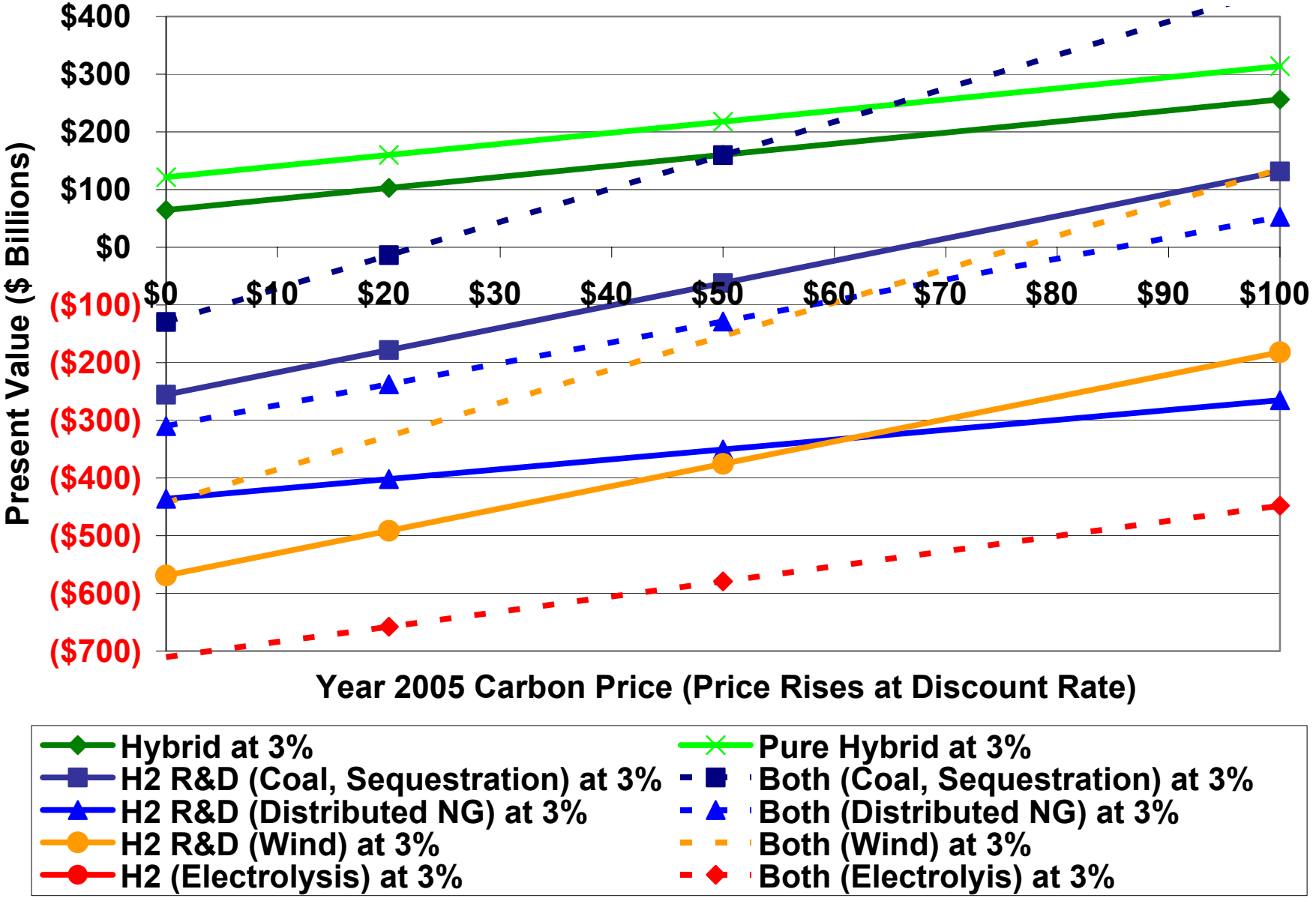
Oil Price Uncertainty

- **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.**

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.**