Multi-Path Transportation Futures Study --

Lessons for the Transportation Energy Futures Study

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LDV Workshop, July 26, 2010

What have we learned that might be useful to TEF?

- **Do LOTS of sensitivity analysis – in this time frame, uncertainties about fuel price, technology costs, consumer behavior are very large, and effect of changed assumptions on outcomes can be huge**
- **Focus on *marginal* costs and performance -- Advanced technologies may look good against today's technologies, but that's really not what people will be judging them against…..the best "reference vehicle" is one customers will be seeing on showroom floors, in that year.**
- **Understand your model! -- Some of your "key results" may be coming from your model's quirks, not robust analysis. So be skeptical of your results, and be prepared to short-circuit your model's problems.**
- **Your scenario should align with the type of modeling you use -- e.g., define outcomes if you're using an optimization model, but avoid outcomes if you're using an equilibrium model (unless you want to do LOTS of expensive trial-and error runs!)..in other words, include a technology penetration goal for an optimization model, but not for an equilibrium model.**
- **Comparing alternative vehicle pathways – based on "equal performance" or "best for that pathway"? -- tendency to compare on equal performance…but this may shortchange some pathways.**

More insights:

- **We should be seeking pathways that are robust across scenarios and across assumptions about fuel prices, technology costs, etc….and looking very carefully at fallback positions if something goes wrong -- in other words, we need to ask questions like "Just how much money will we have invested before we know for sure things are working out…..and would this investment be totally lost if things went wrong, or would it have residual value?"**
- **As an addendum to the above….make sure to do some "reality checking" for your scenarios…..**
  - **Cash flow analysis…how long are we expecting people to wait before they turn a profit?????**
  - **Critical path analysis: how many potential roadblocks are out there, what are their probabilities?**
  - **Etc.**

A new area for study:

- **Examine the range of tasks a transportation system undertakes in a specific area, and then reimagine that system using a very different fuel such as electricity and hydrogen….then stress that system (with an earthquake, grid blackout, etc.) and ask the following questions:**
  - **What differences are there between the gasoline-based system and the altfuel-based system in their ability to respond?**
  - **How might the new system compensate for any shortcomings in its ability to respond to an emergency?**

Study Purpose

- Responded to a DOE EERE Senior Management request for an **integrated analysis of EERE's vehicle-and-fuel-related technologies,** and
- A **National Academy of Sciences review of the DOE Hydrogen Program** that asked DOE to assess **pathways *other than hydrogen* that can yield similar outcomes (low oil use and low GHG emissions)**
- Study **compares alternative ways** to achieve significant reductions in oil use and GHG emissions in **light vehicles** from now to **2050**
- **Underlying vision: Reduction of GHG emissions and oil use has become central to national policy!**

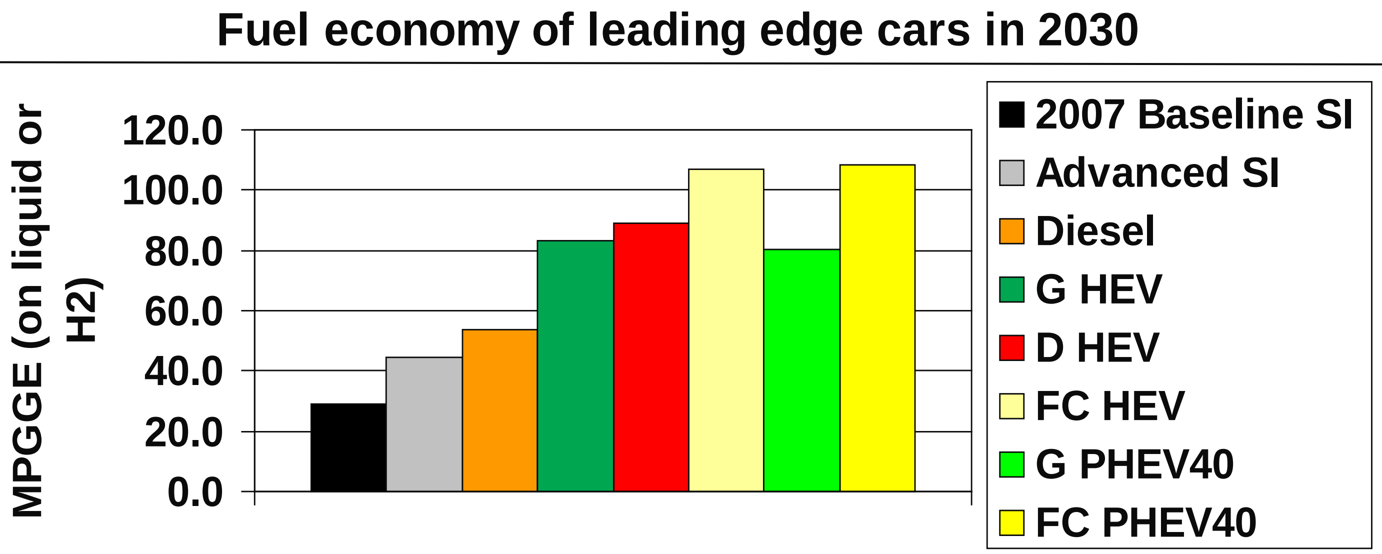
VEHICLE CHARACTERIZATION

Vehicle characterization: How do the vehicles improve over time?

- **Load reductions for leading edge midsize cars, for 2030:**
  - **30% glider weight (21% total vehicle weight) reduction**
  - **0.22 Drag coefficient (~0.3 today)**
  - **0.006 Rolling resistance (~0.9 today)**
- **40% peak efficiency for DI gasoline engines**
- **45% peak efficiency for DICI engines**
- **65% peak efficiency for fuel cells (now viewed as too high)**
- **No change in vehicle size or acceleration performance (contrary to trends of past 20 years)**

Updated Vehicle Fuel Economies

- Vehicles evaluated with ANL's PSAT model
- Vehicle performance requirements uniform across technologies
- 2010, 2015, 2030 and 2045 "leading edge" vehicles
- Estimates developed for one car and one light truck



Some key conclusions of the fuel economy analysis:

- **For 2030 leading edge vehicles, 50% fuel economy improvement is possible *without* hybrids or diesels**
- **More advanced prime movers allow more improvement**
  - **Diesels: 80%**
  - **Full hybrids: 3X**
  - **Fuel cells: still higher**
  - **PHEV40s: 4X including electricity**
  - **EVs: 5X**

1 kWh = 3413 Btu

Developed Vehicle Cost Estimates

- **"Literature Review" vehicle costs based on literature review plus industry advice**
- **"Program Goals" costs incorporate goals of DOE programs**
- ***In essence, we are assuming technology success! We do NOT consider the possibility that the technology may fail.***

Insights:

- ***Ideally, cost estimates for different technologies use the same level of underlying optimism…in practice, this is extremely difficult to achieve***
- ***"Normalizing" alternative cost estimates is extremely difficult***

We project substantial cost reductions over time for advanced drivetrain technologies:

	2010		2030
■ Fuel cell systems	$67-$108/kW	→	$30-$52/kW
■ HEV batteries	$40-$55/kW	→	$20-$38/kW
■ EV batteries	$400-$675/kWh	→	$150-$325/kWh

- **2030 glider mass reduction of 30% costs $1300 for leading edge midsize car**
- **Costs for SI and CI engines and automatic transmissions stable (higher sophistication balanced by continued learning)**

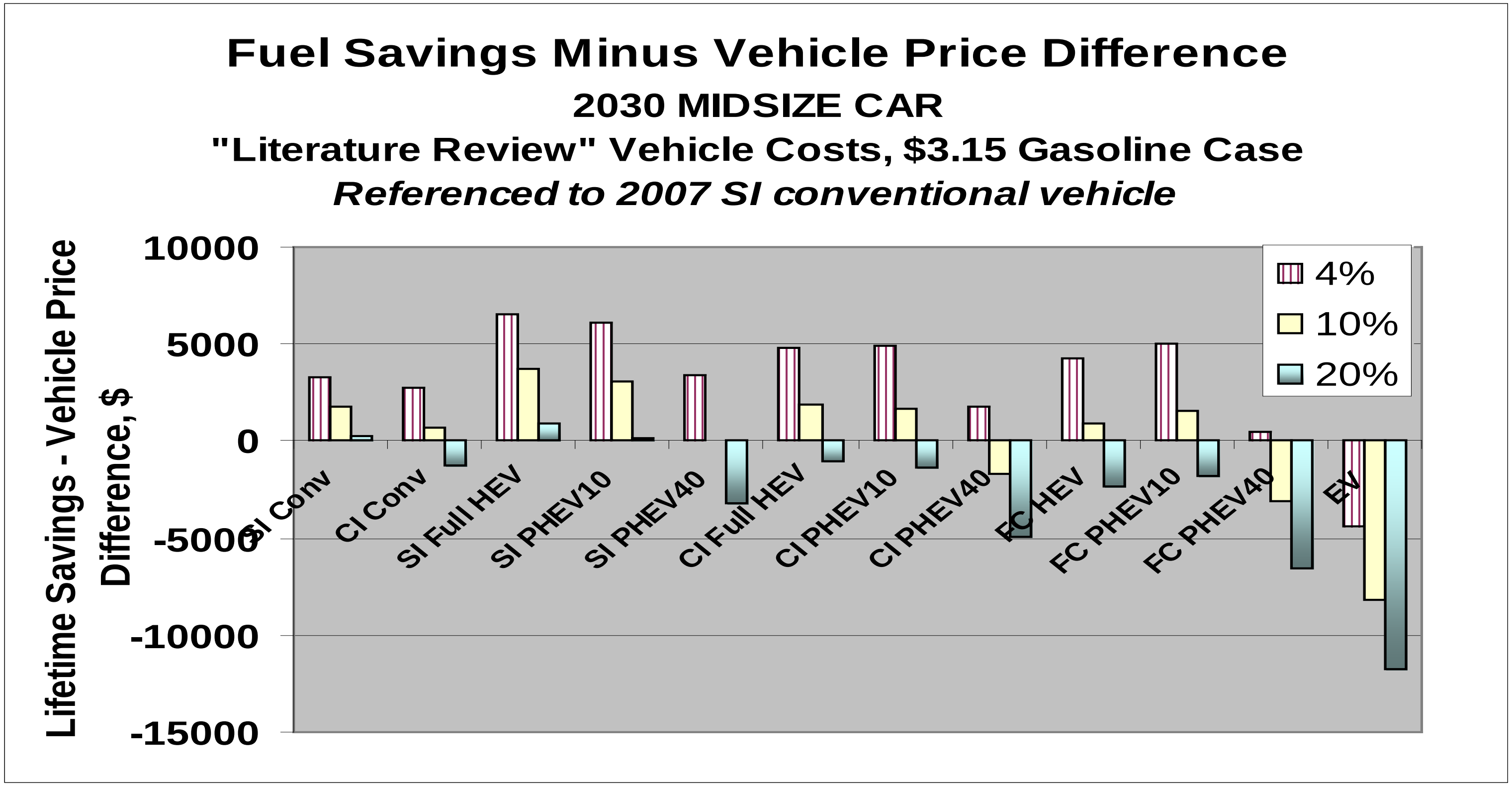
This assumption is crucial….it makes engine improvements "low hanging fruit," lowers apparent attractiveness of more advanced drivetrains.

Some key conclusions of the cost analysis:

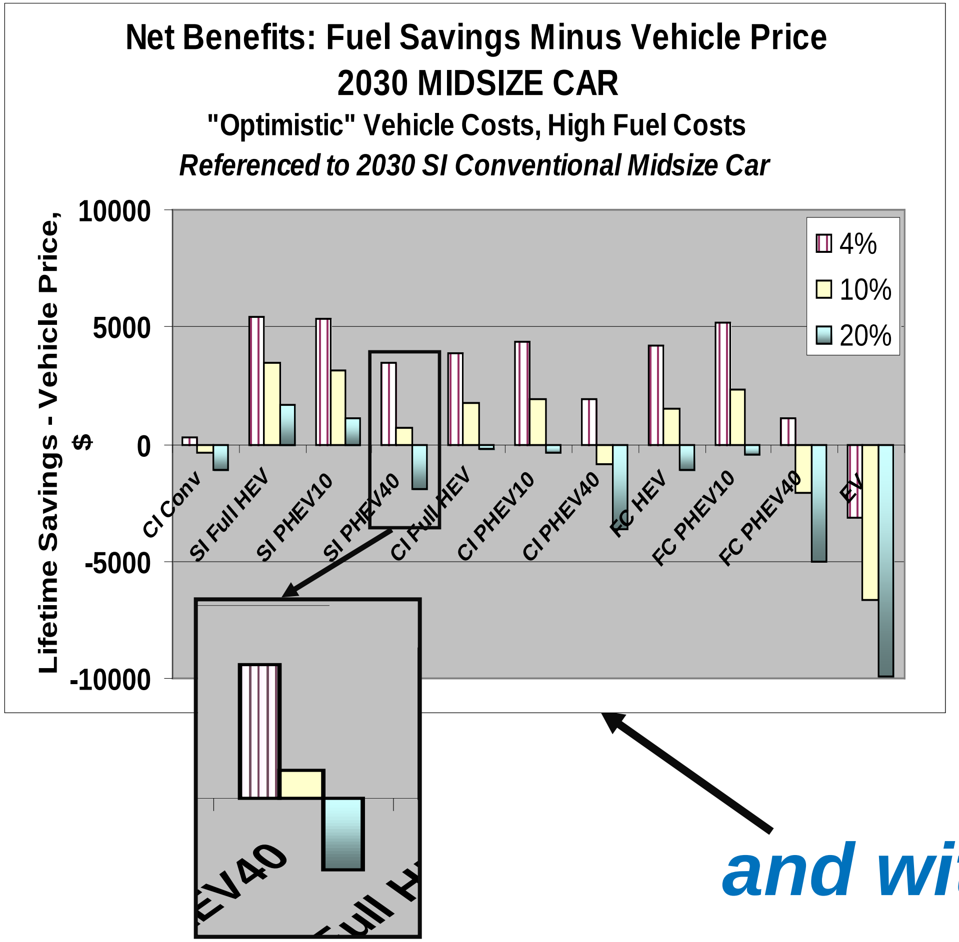
- **Even assuming the most positive outcome in cost reduction, introductory costs for advanced drivetrains are projected to be high enough to make manufacturer or government subsidies necessary for several years.**
- **By 2030, technology costs could be much lower, although electric drivetrain vehicles with relatively long ranges should remain significantly more expensive than conventional SI drivetrains.**
- **Reducing vehicle loads will reduce the cost penalties of the advanced drivetrains vs. their conventional competitors -- and failing to greatly reduce these loads will damage prospects for the most advanced drivetrains.**

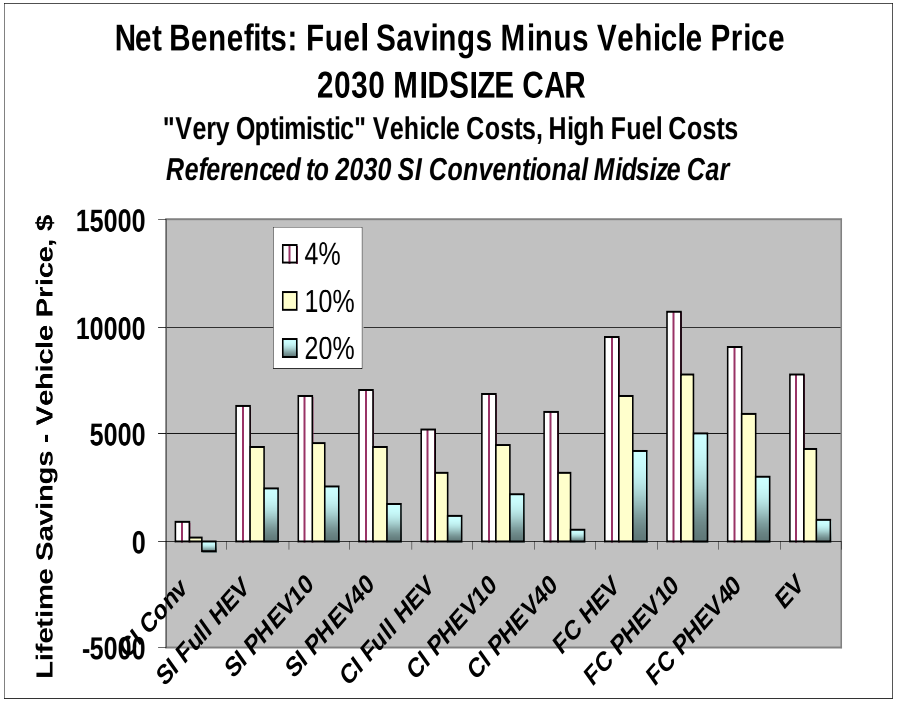
Simple analysis of "cost-effectiveness" is revealing

- Examine **net benefits = (lifetime fuel savings) minus (differential vehicle price)** for the advanced technology vehicles
- with varying assumptions about technology costs, fuel prices, discount rates, and where we are on the cost curve



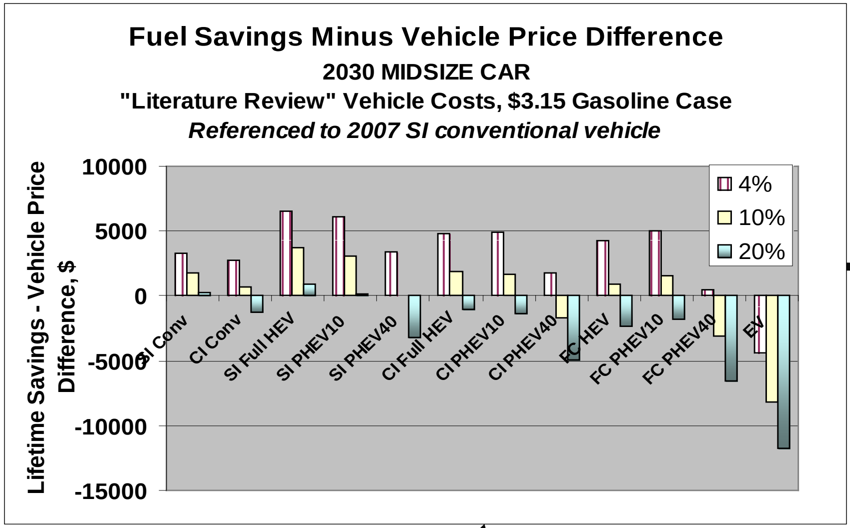
Cost-effectiveness varies dramatically between "optimistic" and "very optimistic" costs……..

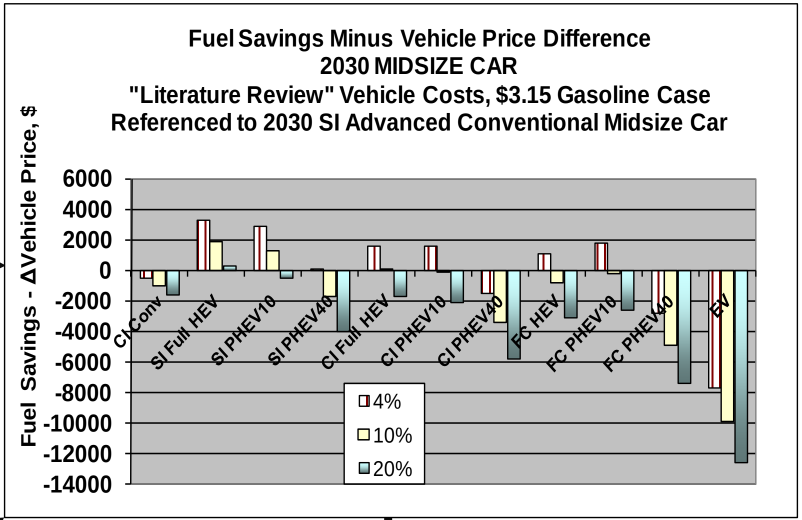


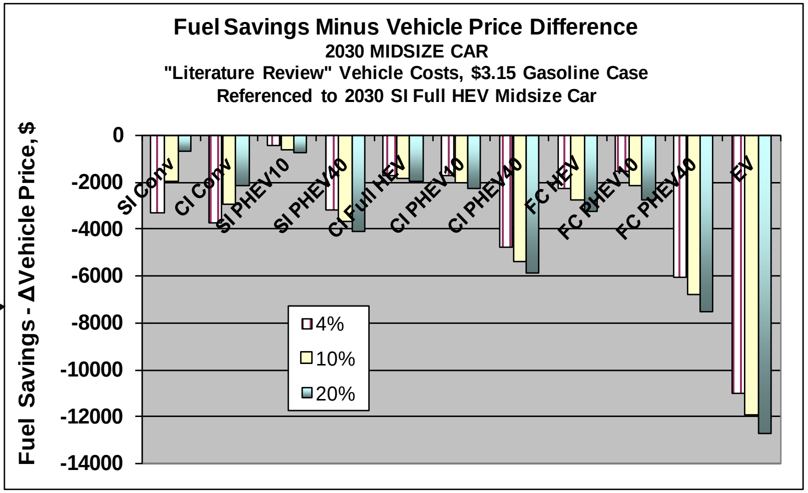


and with discount rates……….

….and with the reference vehicle to which the vehicle is being compared…



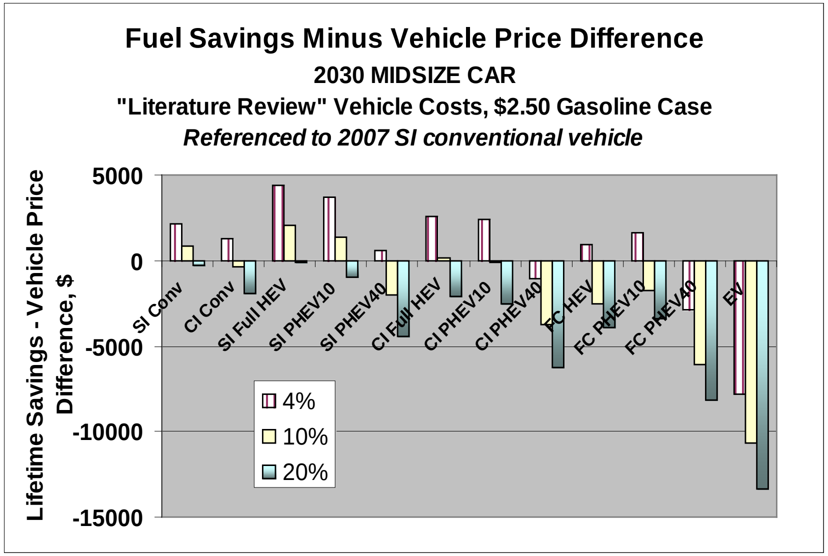


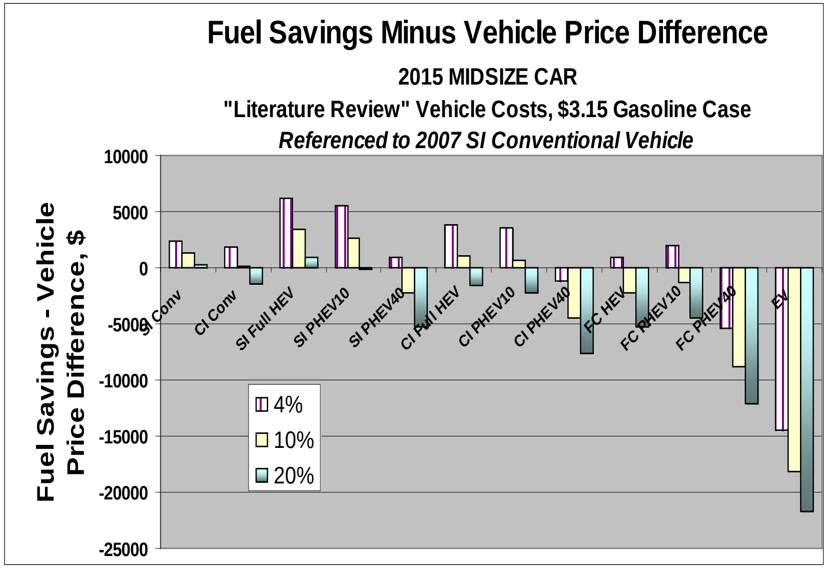


to a 2007 car….. good for most;
to a 2030 car…. poor;
to a 2030 hybrid… terrible!

Some other conclusions

- If fuel prices are lower than expected, vehicle cost-effectiveness suffers considerably
- In the early years of technology introduction, there are higher technology costs but generally higher fuel savings for advanced vehicles (because conventional vehicles are less efficient):
  - For "lower level" advanced vehicles, net benefits in 2015 are little changed from 2030
  - But beyond PHEV10s, cost-effectiveness suffers in 2015





In summary, major conclusions are:

- **The perceived cost-effectiveness of new vehicle technologies depends critically on how one values future fuel savings (expressed as discount rate).**
- **Even using only optimistic cost projections, there's a wide range of cost-effectiveness outcomes, from very positive to very negative for the range of technologies examined.**
- **Even when the cost-effectiveness of a total package of improvements is highly positive, *marginal* cost-effectiveness may be quite negative. <u>Moving much beyond full hybrid technology may be unattractive without major breakthroughs in cost reduction.</u>**
- **However, even at our moderate "literature review" cost levels, most advanced vehicles will exceed the cost-effectiveness of today's vehicles.**

Major conclusions (continued):

- **Vehicle cost-effectiveness may suffer considerably at lower fuel prices**
- **Obtaining positive cost-effectiveness is especially difficult at technology introduction…particularly for the more advanced technologies**

NOTE THAT THE “PROGRAM GOALS” COST CASE IS BASED ON ACHIEVING DOE GOALS THAT ARE “NORMATIVE” RATHER THAN BASED ON ENGINEERING ANALYSIS….THAT IS, THEY WERE SET AT LEVELS TO GUARANTEE COMMERCIALIZATION POTENTIAL, WITH AN UNCERTAIN LEVEL OF REALISM (and some are now being reconsidered).

SCENARIO ANALYSIS

Scenario analysis couples vehicle characteristics with general assumptions about the future

- We use a version of EIA's National Energy Modeling System – "NEMS-MP" -- with key modifications
  - Extended to 2050…but this disallowed use of input/output model – we lost crucial information about economic impacts
  - H2 module added
  - Made Vehicle Choice Model more favorable for advanced technology vehicles (eliminated "consumer wariness" differences)
  - Eliminated fleets (NEMS wasn't adding advanced technology vehicles to fleets…an interesting discovery)*
  - Changed PHEV electricity price to residential sector electricity price (from "metrorail price") *
  - PHEV representation in the model limited to one range – a major problem, as it turned out

* UNDERSTAND YOUR MODEL!!!!!

Scenarios include a Base Case and multiple versions of technology-focused cases

- **Base Case**
  - **Based on AEO 2007 extended to 2050, uses its High Oil Case oil prices ($93/bbl in 2030, $116/bbl in 2050)**
  - **Incorporates new CAFE standards passed in Dec 2007**
  - **No Renewable Fuels Standard**
    - ***Tried, but could not reach 36 billion gals renewable fuels by 2022 without significantly overshooting the standard in later years***
- **Three technology-focused cases – and 4 sub-cases for each**
  - **Mixed**
  - **H2 Success**
  - **(P)HEV & Ethanol**

•Optimistic ("Literature Review" Costs;
•Very Optimistic ("Program Goal" Costs;
•Optimistic Costs + Subsidies
•Very Optimistic Costs + Subsidies

The three basic scenarios are friendlier to new LDV technologies than is the Base Case

- Vehicle technologies: higher fuel economy, mostly lower costs
- Lower prices for ethanol and hydrogen
- Lower VCM barriers to advanced technology ("consumer distrust" constants are set to zero)
- (P)HEV & Ethanol scenario
  - Lowest ethanol price
  - Highest % of households with recharging capability
- H2 Success scenario
  - Lowest H2 prices
  - H2 stations are "jump started"

Subsidies were added to push market shares upwards towards scenario goals

Subsidies for "Very Optimistic Plus Subsidies" Cases

VEHICLE	YEAR	MIXED	(P)HEV & ETHANOL	H2 SUCCESS
SI PHEV40	2030	$4,000	$5,000	-
	2050	$3,000	$4,000	-
FCV	2030	$700	-	$500
	2050	$700	-	$4,000
FC Plug-in	2030	$2,000	-	-
	2050	$2,000	-	-
SI HEV	2030	-	$1,000	-
	2050	-	$1,000	-

Subsidies for the "Optimistic Plus Subsidies" cases

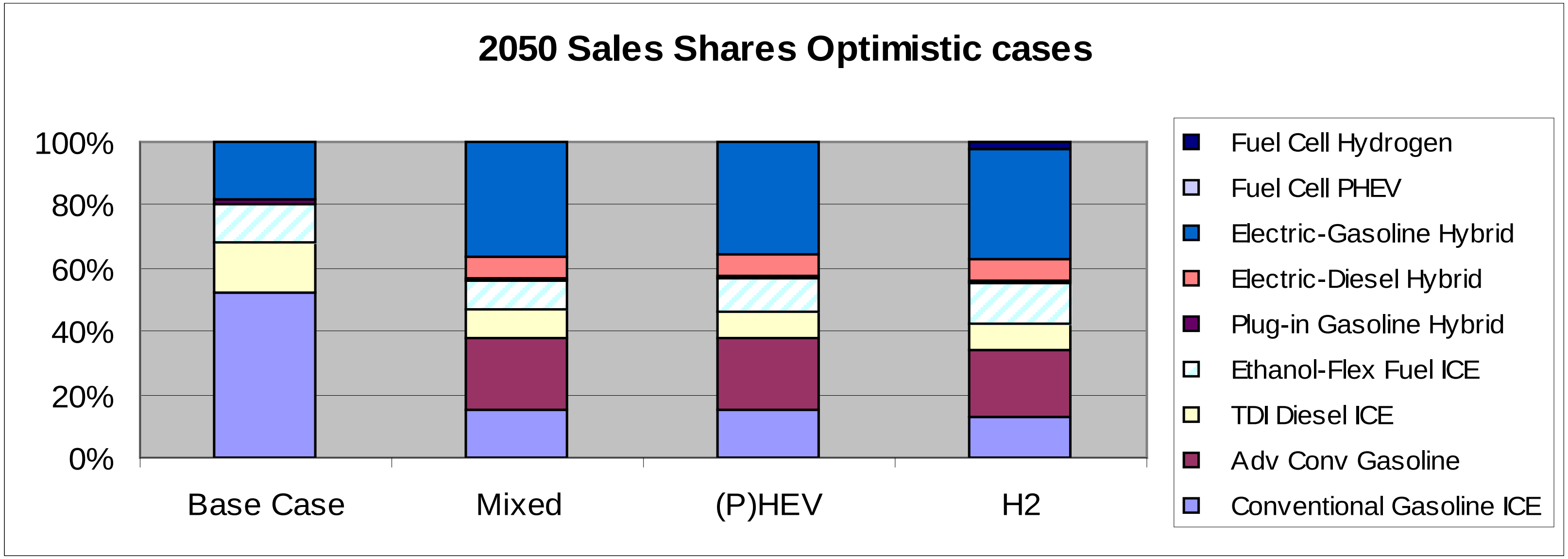
- **$7500/vehicle through 2050**
- **for the following vehicles:**
  - **PHEVs, FCVs and plug-in FCVs in the Mixed scenario;**
  - **PHEVs only in the (P)HEV & Ethanol scenario**
  - **FCVs only in the H2 Success scenario.**

Before showing NEMS-MP results….some cautions

- **Analysis extension to 2050 negates use of the macro-economic model in NEMS….so many feedback effects (on total vehicle sales, GDP, etc.) don't happen in NEMS-MP**
- **Vehicle payback period embedded in VCM is short -- not compatible with underlying MP assumption about consumer attitudes**
- **Vehicle costs are crucial to VCM….but are simple extrapolations from detailed estimates for only *2* classes of *leading edge* vehicles (vs. the *12* classes of *average* vehicles actually used in the model)**
- **Rebound effect should be applied to each technology….but gets applied to the fleet as a whole…distorts fuel use estimates**
- **NEMS-MP allows only one PHEV slot. We chose PHEV40s…..but likely market will have variable ranges…may suppress PHEV share**
- **NEMS-MP estimates only CO2, no non-CO2 GHGs**
- **Plus usual uncertainties about fuel prices, technology costs, etc.**

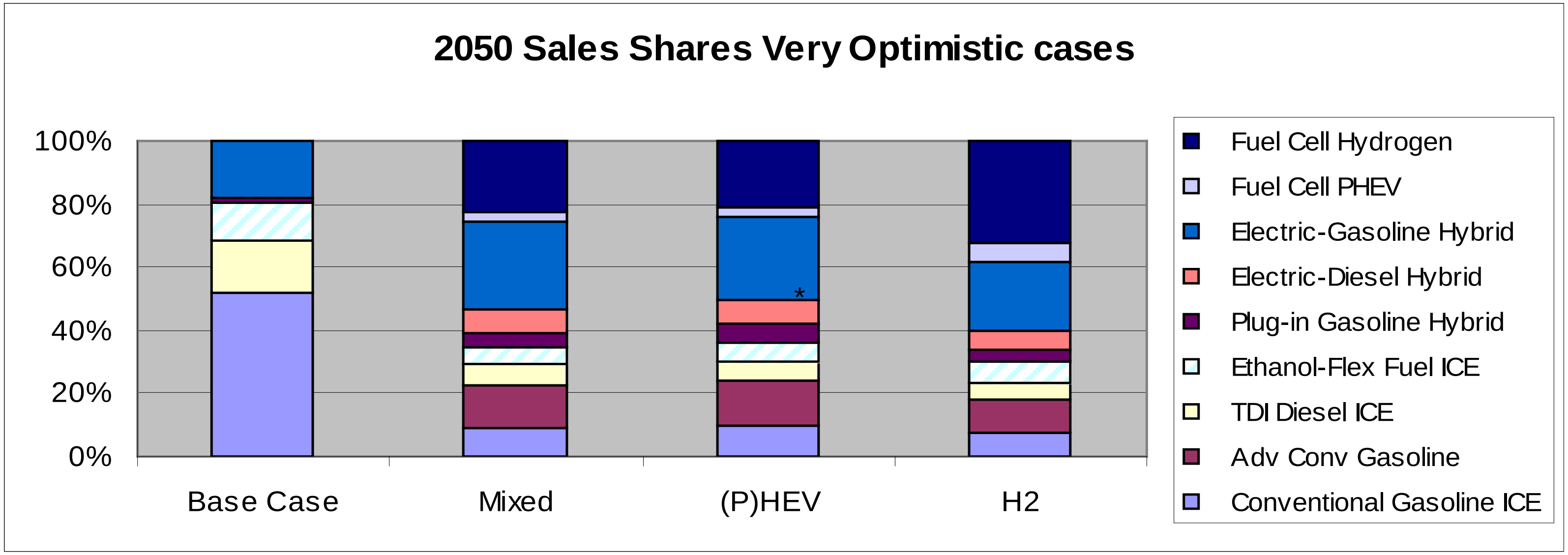
NEMS-MP Results

Advanced technologies will significantly penetrate the vehicle market in all scenarios



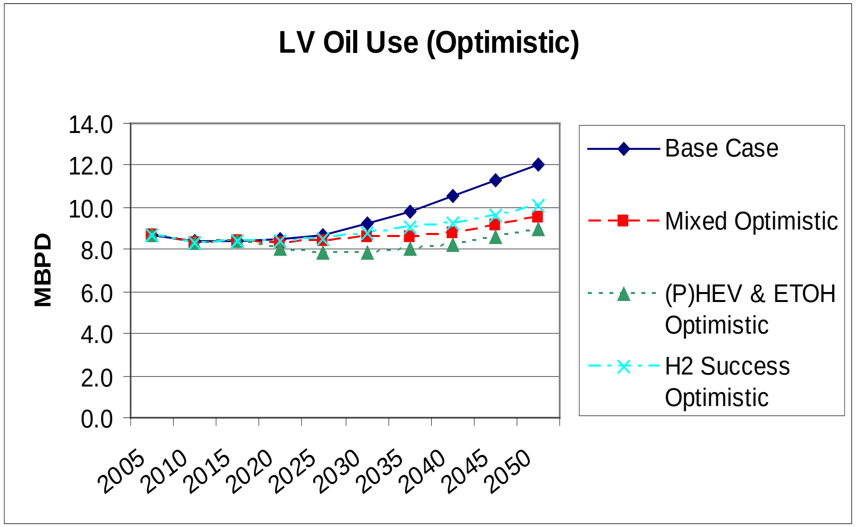
- **Even the Base Case (higher costs, lower fuel economy) has 36% ATVs in 2050**
- **With optimistic costs, Mixed Scenario has 76% penetration in 2050; other scenarios are similar**

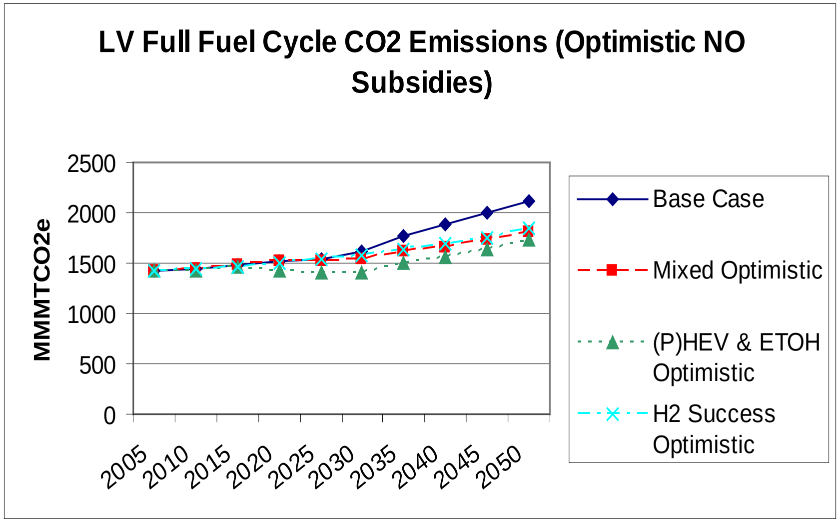
Penetration of the more advanced vehicles is much higher in the "very optimistic" cost scenarios



- **Compared to the optimistic cost cases, penetration of the more advanced vehicles is much higher in the very optimistic cost cases**
- **And penetration of each technology type is quite similar across the scenarios, for each cost case**
- ***The exception is interesting – jump-starting H2 station development greatly increases FCV share (H2 Success scenario)***

The optimistic cost scenarios yield moderate improvements from the Base Case

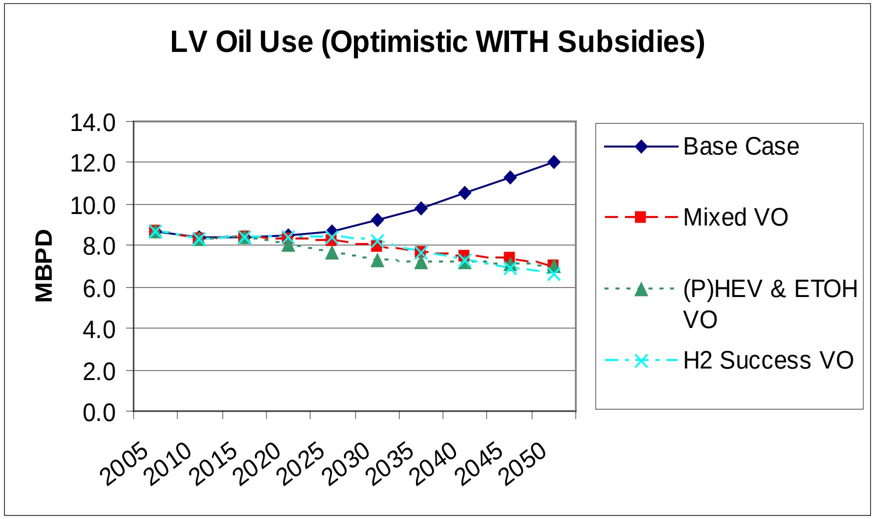


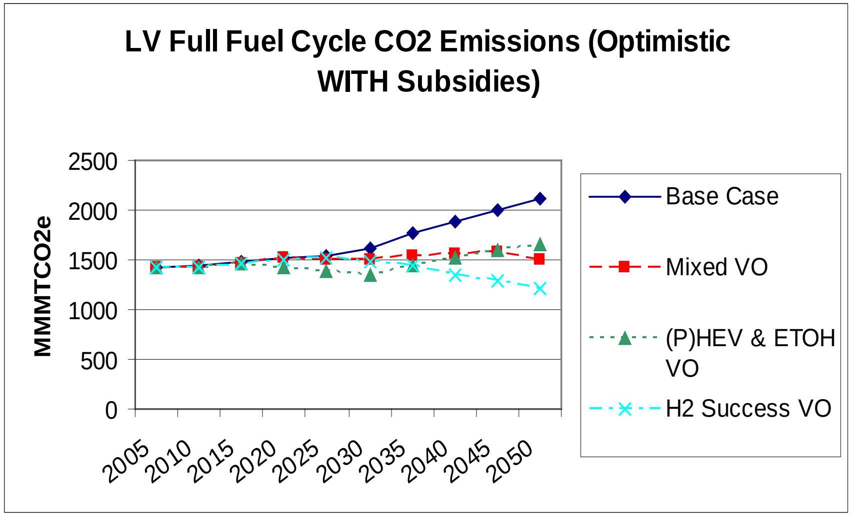


- **LV oil use reduced 2-3 mbpd by 2050**
- **LV fuel cycle CO2 emissions reduced by 13-19%**
- **Gasoline prices down 10%**
- **And LV energy use is down only modestly (9-10%)**

Even with substantial reductions in technology prices, added penetration of ATVs is moderate.

The optimistic + subsidy cases allow higher penetration of key technologies (vs. no subsidy case), and significant added benefit





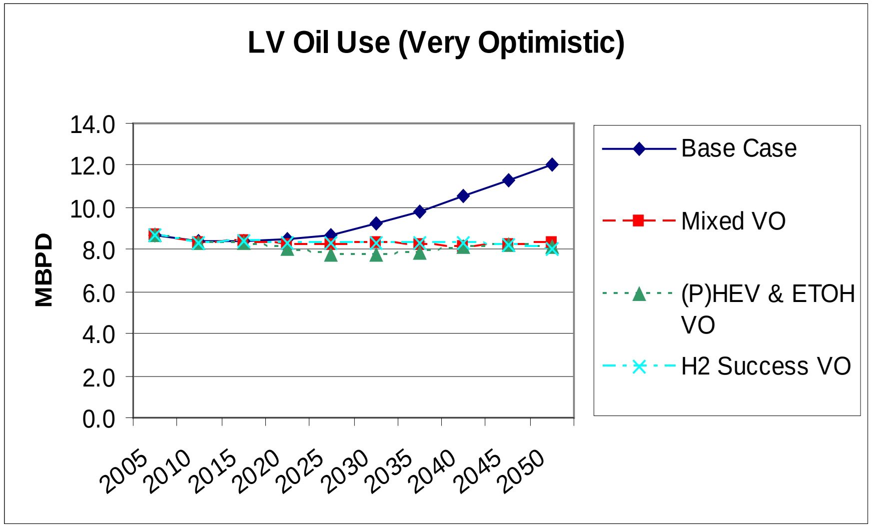
- LV oil use reduced ~5 mbpd by 2050 (vs. 2-3 mbpd w/0 subsidies)
- LV fuel cycle CO_2 emissions reduced by 22-43% (vs. 13-19%)
- Gasoline prices down 20-24% (vs. 10%)
- And LV energy use is reduced by 20-23% (vs. 9-10%)

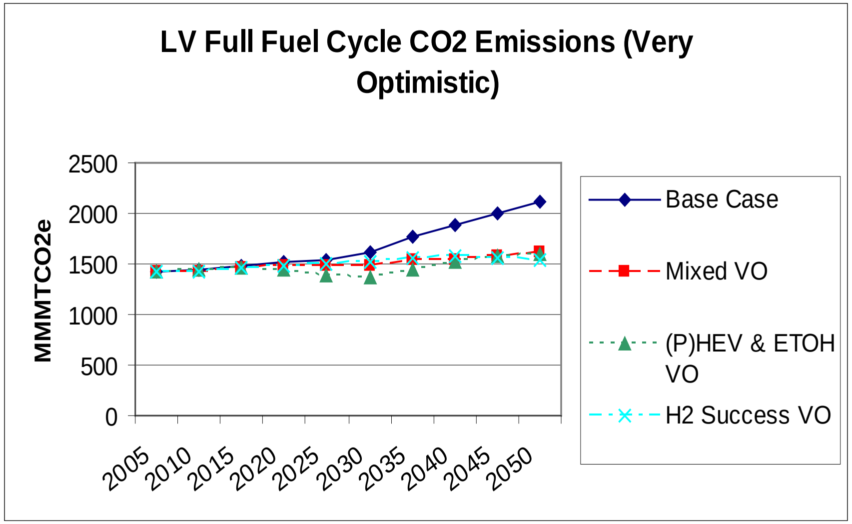
but the cost is high

- Cumulative subsidy through 2050 is $1.7-$2.0 trillion!
- 2015-2075 subsidy cost of oil savings*:
  - Mixed $87/bbl;
  - (P)HEV & Ethanol $120/bbl;
  - H2 Success $74/bbl, and
- 2015-2075 subsidy cost of CO2 reductions*:
  - Mixed $327/tonCO2;
  - (P)HEV & Ethanol $1,116/ton CO2;
  - H2 Success $155/ton CO2

**note: subsidy costs of oil savings and CO2 reductions are not additive, they just divide subsidy cost by each, in turn; and the oil savings costs ignore the monetary value captured by consumers*

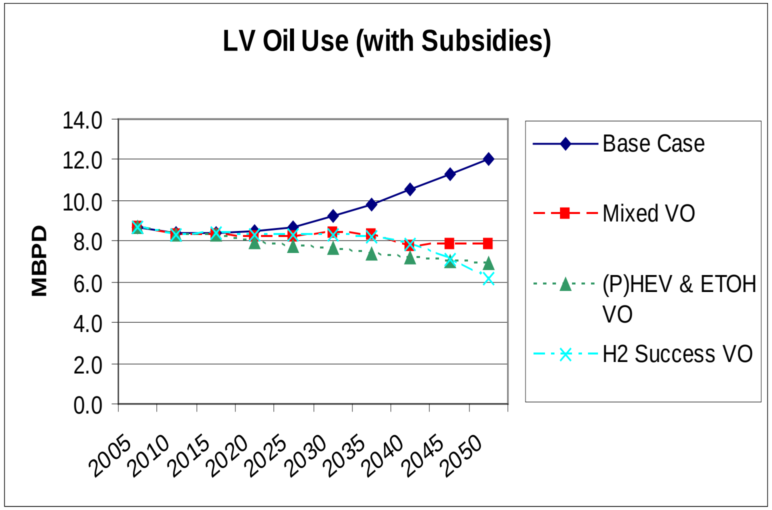
The very optimistic cost scenarios provide a bit lower benefits than the optimistic plus subsidy scenarios.

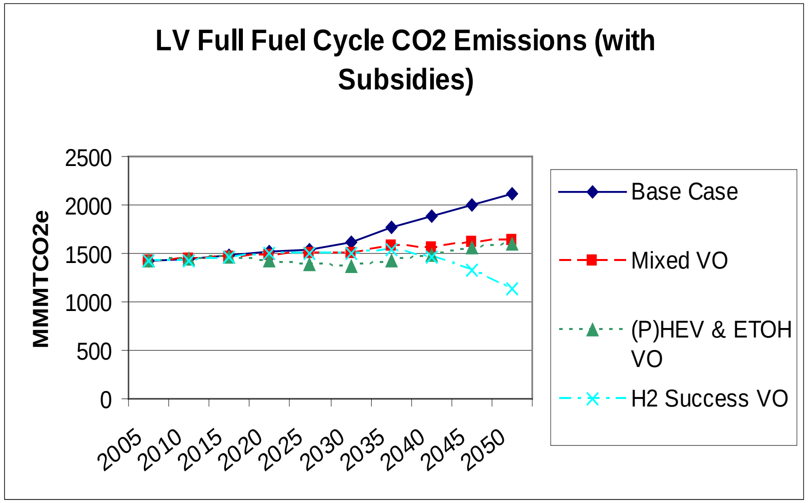




- **LV oil use reduced 4 mbpd by 2050**
- **LV fuel cycle CO2 emissions reduced by ~25%**
- **Gasoline prices down 18%**
- **And LV energy use is down by 14-19%**

The optimistic + subsidy cases allow higher penetration of key technologies than the very optimistic cases, but the added benefit is modest

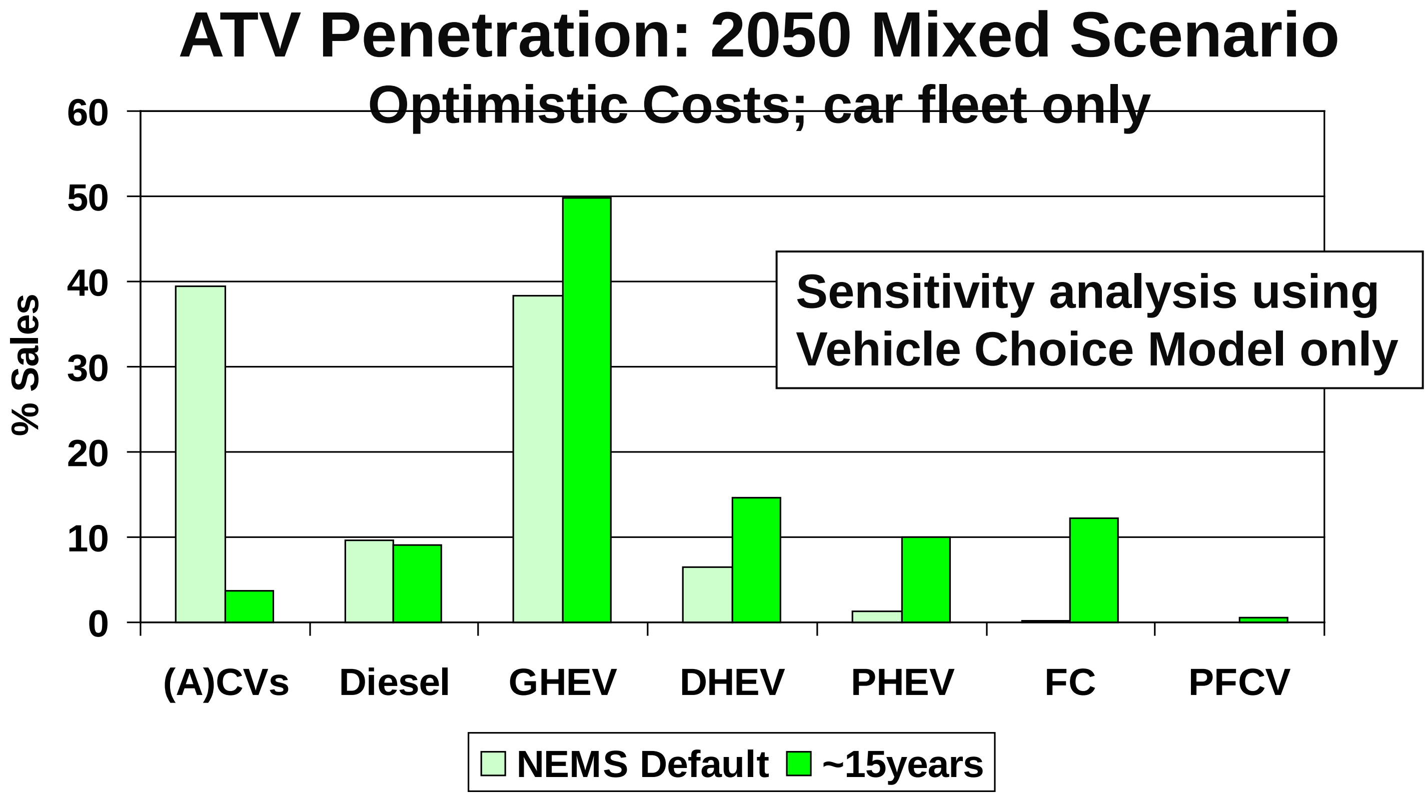




and, again, at high cost

- **2015-2075 cost of oil savings: Mixed \$136/bbl; (P)HEV & Ethanol \$100/bbl; H2 Success \$56/bbl, and**
- **CO2 reductions: Mixed *no savings*; (P)HEV & Ethanol \$5016/ton CO2; H2 Success \$96/ton CO2**

Raising the vehicle payback time in the NEMS VCM dramatically increases penetration of advanced electric drivetrain vehicles



Another example of a relatively arbitrary assumption *drastically* affecting the outcome!

Interesting analytic issues raised by Multi-Path

- Comparing alternative vehicle/fuel pathways
  - As identical as possible, or
  - Optimized for that pathway
- Developing believable scenarios
  - Can we reproduce initial visions using an integrated model?
  - Just what "tweaks" are reasonable?
- Selecting credible assumptions about component costs, performance
  - Can we maintain the same underlying level of optimism across technologies????
- Evaluating vehicle fuel economy performance
  - Limitations of available engine maps
  - Design of complex drivetrains, with many possibilities
- Dealing with the value of future fuel savings in the VCM
  - Embedded assumption in NEMS is 3-4 year valuation
  - *We need a better understanding of consumer choice!*