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Improving Automobile Fuel Economy in the Real World

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Projecting future fleet fuel economy is a lot more complex than most studies imply

- **Start with technology potential analyses, as in the National Academy report**
- **Take account of technological risk and new opportunities**
- **Take account of incentives to actually do this – regulations, fuel prices, consumer attitudes**
- **Mix in changes in vehicle performance & weight**
- **And differences between test results and real world driving**
- **And stuff like replacement tires, maintenance, etc.**

What changes might we expect if automakers and auto buyers get serious about fuel economy…?

***Engines*: gasoline direct injection and a lot more DI diesel, both with turbocharging, lots more in-cylinder monitoring and control, camless valves, ability to shift away from Otto cycle in gasoline engines, cylinder deactivation with 6 cylinders or more.**

***Transmissions*: 6 and 7 speed automatics, automated manuals, CVTs**

Expectations, continued

- ***Automotive bodies*: extensive weight reduction – high strength steel plus lightweight materials; 20-30% weight reduction may be possible, more with breakthroughs with carbon fiber**
- ***Aerodynamics*: 0.26 is current best for mass-produced car, and progress is slow – but 0.22 should be achievable**
- ***Tires*: tradeoffs with handling, longevity -- .006 C_R should be possible; replacement tires must follow suit!**

Expectations (continued)

- ***Accessories, etc.*: electric power steering, ultra-efficient lighting and air conditioning….and attention to things like window coatings to reduce heat input**
- **Plus attention to the little things….lubricants, friction reduction, etc.**

Put this all together, and a current 28 mpg (EPA test) midsize car would get 40 mpg or more (maybe 32 mpg, vs. 22 mpg today in real-world driving), by 2020 or 2025

Plus another 10-50% with various forms of hybrid drive, which can save energy through multiple means:

- **Engine off during idling, deceleration**
- **Electric motor provides boost, allows use of smaller engine**
- **Motor substitutes for engine in inefficient modes**
- **Regenerative braking captures braking energy otherwise lost to heat**
- **Easier use of electric accessories, e.g. power steering**
- **Efficient engine cycles otherwise not available (Prius's Atkinson cycle engine)**

Or an added 20-30% with DI Diesel drivetrain

- **New turbocharged DI diesels with oxidation catalysts**
  - **Fuel economy improvement: now 35% over gasoline, 25% in fuel cycle CO_2….but probably less compared to *advanced* SI engine**
  - **higher specific power than IDI diesels**
  - **smoke and odor basically gone, reduced noise**
  - **reduced NO_x, particulates (but still needs work)**
  - **Continuing improvement in high pressure fuel injection**

And other possibilities……

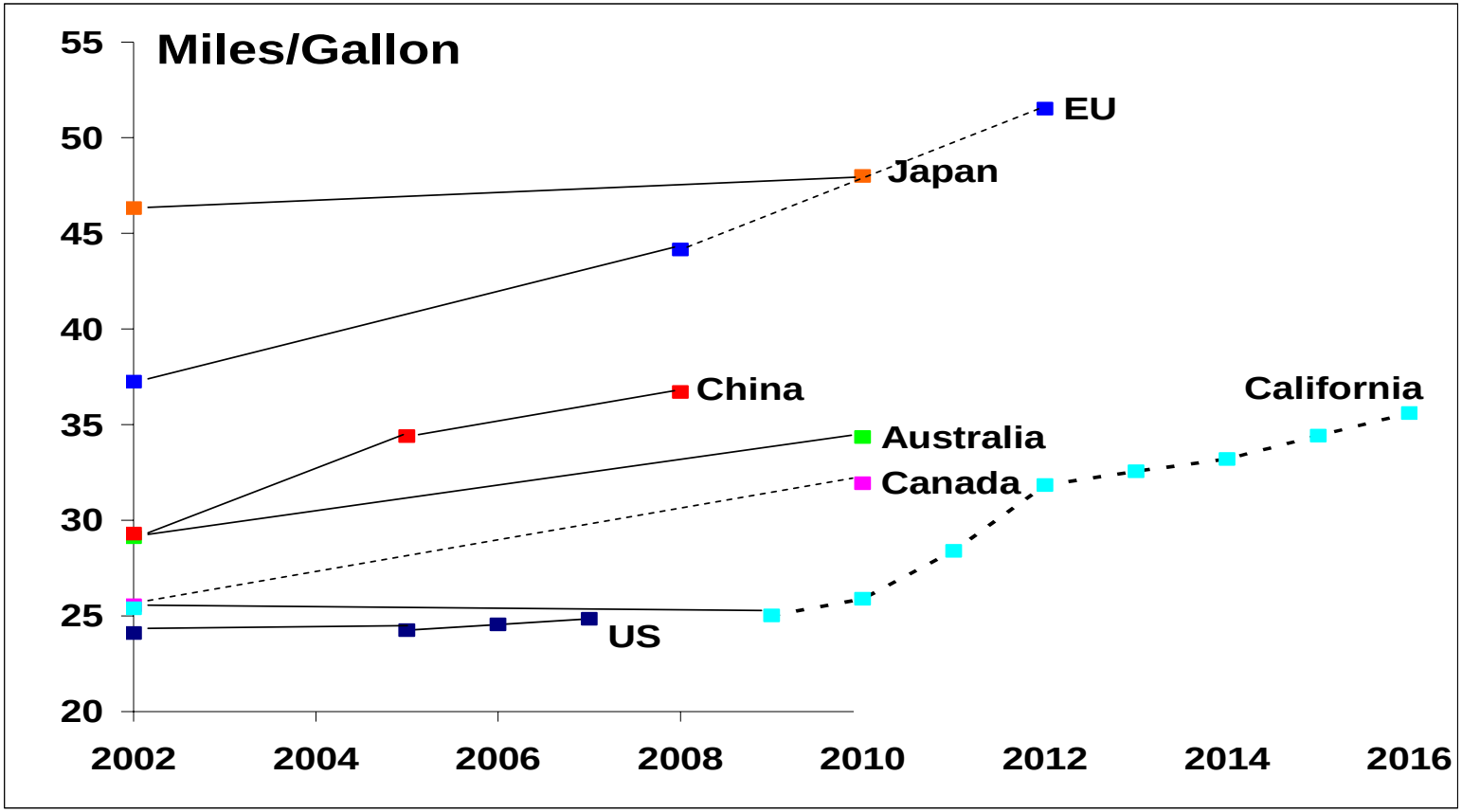
- **Plug-in hybrids**
- **Hydrogen fuel cell vehicles (for the long term)**
- **Ethanol (perhaps with dedicated high compression engines or plug-in hybrids)**

So what's the probability of any of this happening???????

- **Regulatory pressures**
- **Economic incentives/fuel prices**
- **Consumer attitudes**
- **Other issues – changes in emissions standards, technological progress**

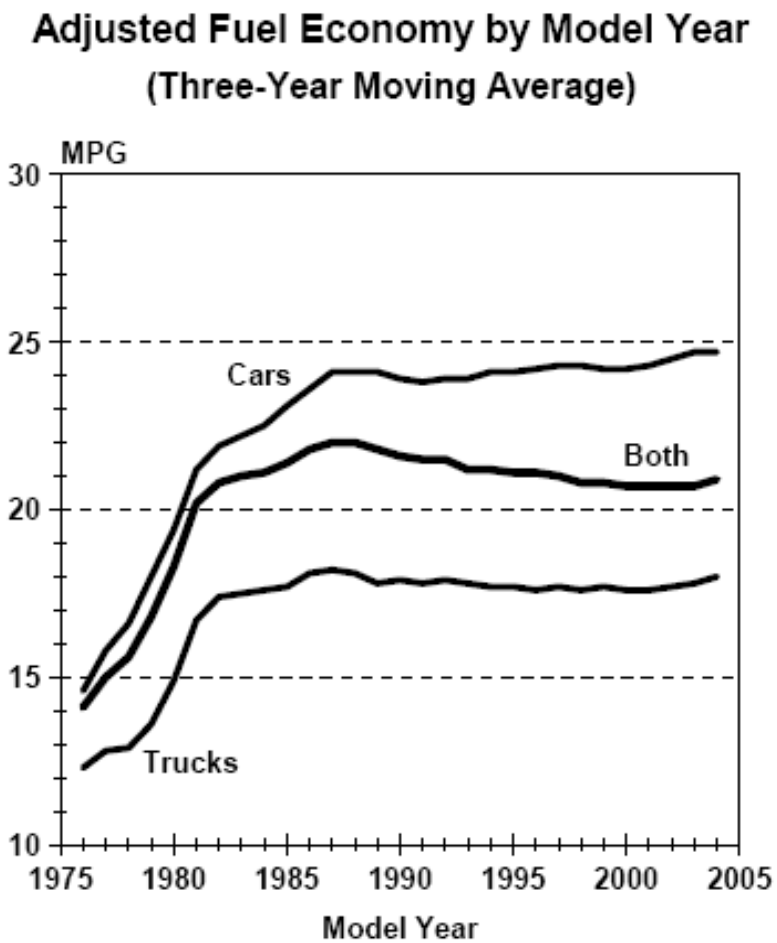
New standards are proliferating….even where gasoline is $6/gallon!

Comparison of Fuel Economy and GHG Emissions Standards Normalized by CAFE –Converted MPG



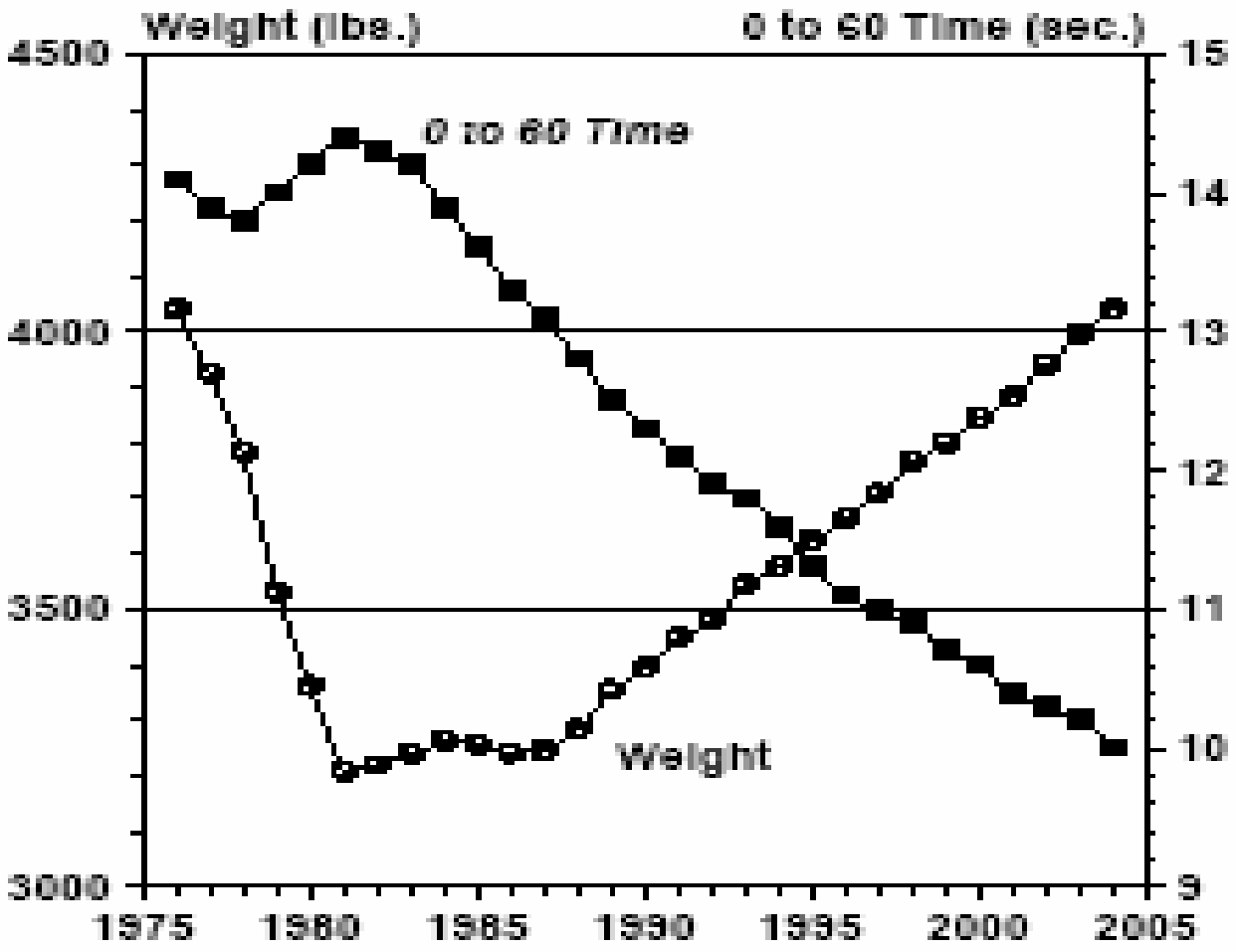
Source: An and Sauer, 2004

U.S. history isn't encouraging: despite continued technology progress, fuel economy has been stagnant for nearly 20 years.



- **Both cars and light trucks responded dramatically to new fuel economy standards and drastic increases in oil prices**
- **Once standards were attained, progress stopped**
- **What happened?**

Fuel economy was traded for increased weight and performance.

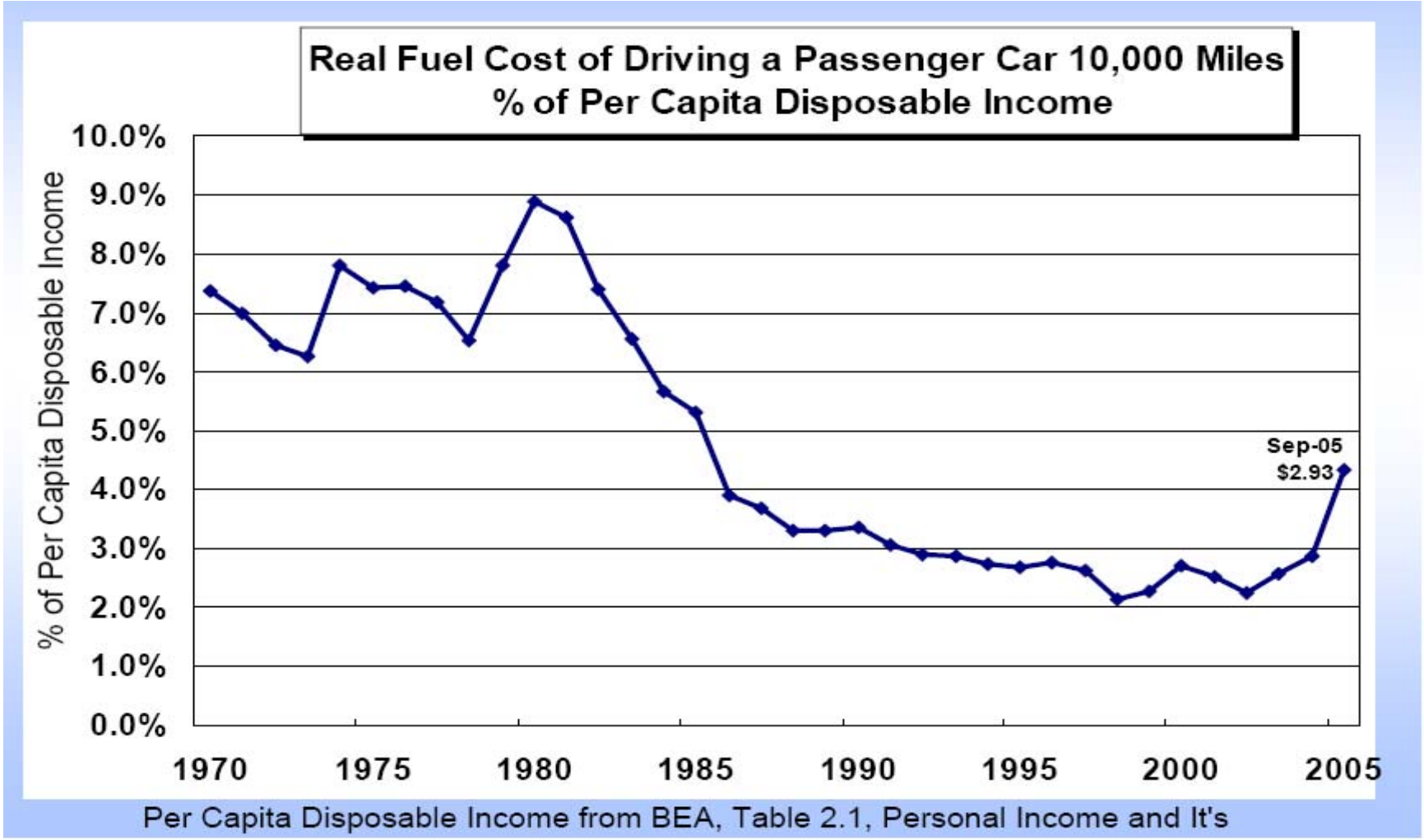


Can we expect these trends to continue, or will fuel economy suddenly get sexy?

- **Key question: Are we near the size and performance saturation point? Will trucks continue to dominate?**
- **10 years ago, who would have thought we'd have such a powerful fleet?**
- **Have you looked at new luxury cars recently?**

A crucial point: virtually all estimates of fleet fuel economy potential assume constant performance and weight.

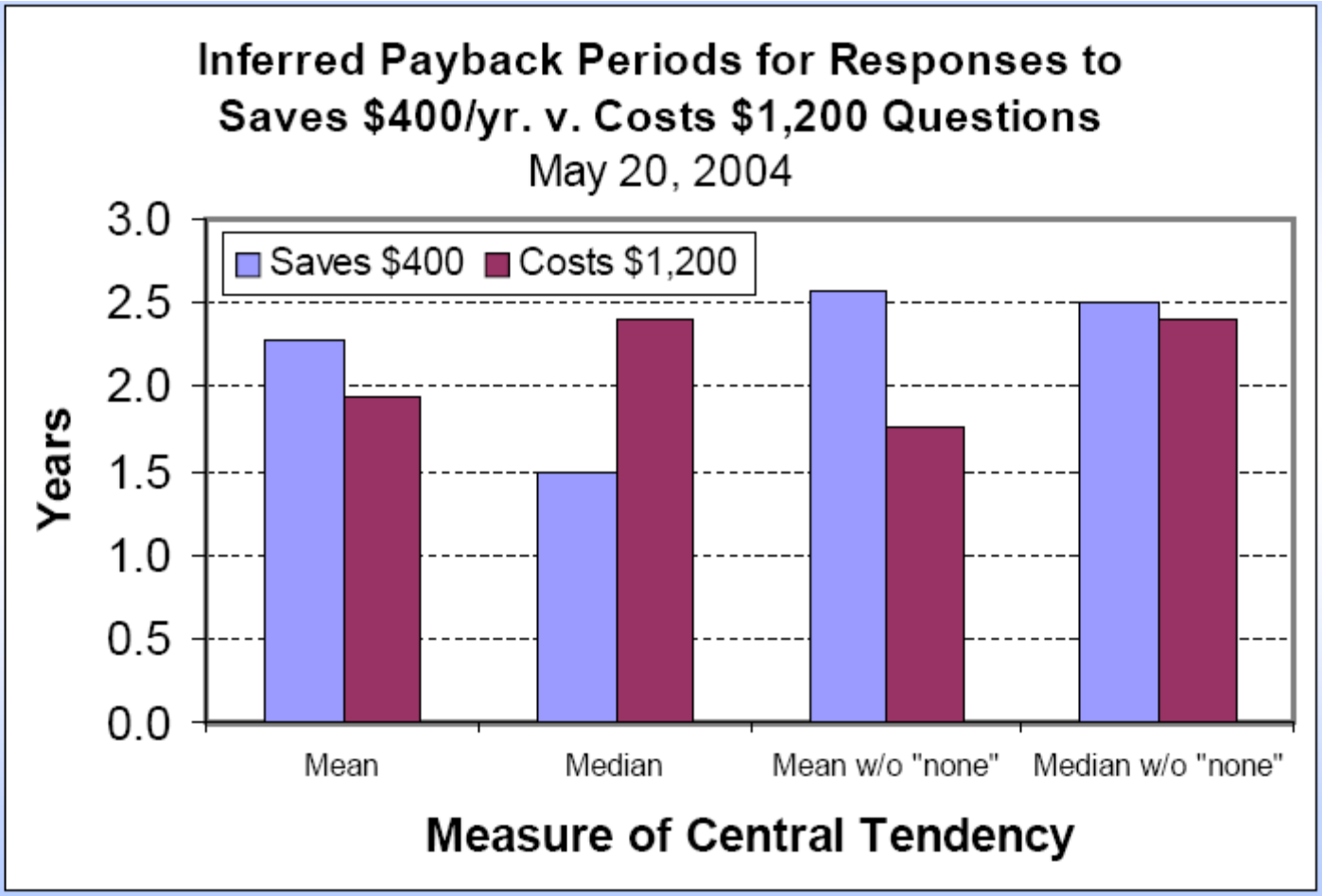
Just how important to future vehicle purchasers is fuel economy going to be?



From John German, Honda

Auto purchasers don't want to pay much for fuel economy improvements

A random sample of consumers gave generally consistent answers to the same question asked from two directions.



David L. Greene, IAEE/USAEE Meetings, Washington, DC, July 10, 2004 –

And if that's not enough…..

- **Europeans are complaining about "off cycle" diesel emissions**
- **Major cost issues with fuel cells, cellulosic ethanol**
- **Plug-in hybrids await a lower cost, longer life battery**
- **Fuel cell GHG emissions depend on how the hydrogen is produced, and fuel cell development creates a huge "chicken or egg" problem**

Another issue: performance "robustness" – How much engine downsizing is feasible?

- **Most analyses of fuel economy potential use simple performance requirements:**
  - **0-60 mph acceleration performance**
  - **Grade-climbing: 6% grade at 60 mph**
- **U.S. consumers want vehicles they can use for multiple purposes/trips**
- **Performance of heavy, powerful vehicles doesn't degrade much at high loads**
- **Performance of lightweight, aerodynamic vehicle may degrade *a lot* on a family vacation trip!**

There's a big difference between fuel economy test results and real world MPG

- **EPA sticker values reduce city test by 10%, highway by 22%, about 15% overall…but most drivers still can't match sticker MPG**
- **Various causes: more aggressive driving than previously understood, plus factors outside test affect real-world MPG (air conditioning, other accessories, cold weather, etc.)**
- **New EPA measurements based on 5 driving cycles may create incentives for automakers to improve real world efficiency – though their accuracy must be tested**

What must manufacturers consider in adding new technologies?

- **Tradeoff between fuel efficiency and performance – including performance "robustness"**
- **Does it affect driving "feel"?**
- **Vehicle purchasers do NOT evaluate fuel economy in terms of fuel savings tradeoffs!**
- **Technology cost**
- **Added complexity – reliability issues?**
- **Repairability (e.g. aluminum)**
- **Image – Is it cool? Is it green? Does it imply technological sophistication?**

It's important to be a skeptical observer when evaluating strategies for technology change

- **Most scenario analyses are driven by initial assumptions**
- **History of trying to move alternative fuels into the marketplace is one of exaggerated claims followed by failure**
- **What do we really know about future costs?**
- **And our understanding of (and modeling ability for) consumer and industry behavior is inadequate.**

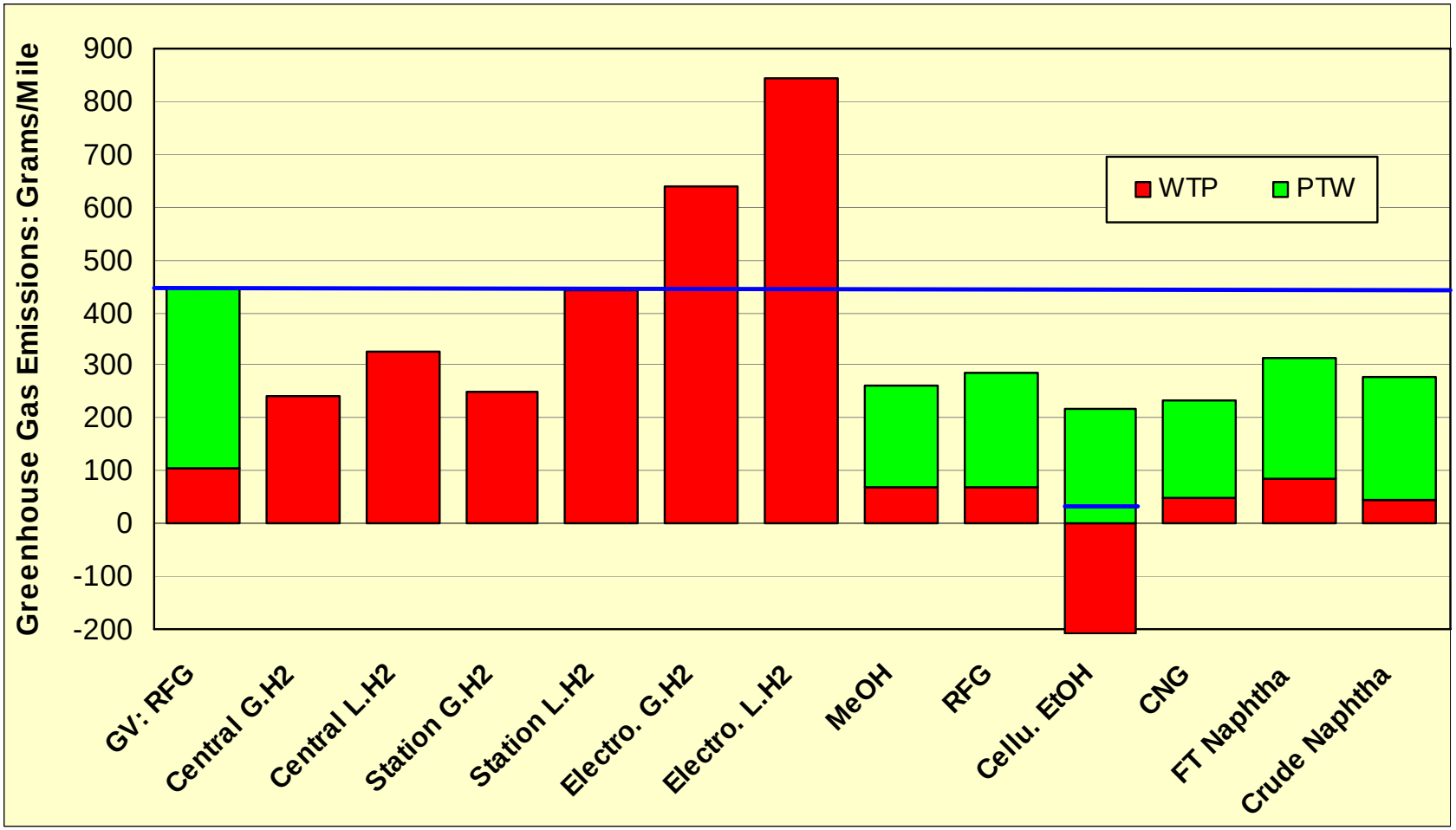
My personal view: a large increase in MPG is quite possible, but not with business as usual

- **Left to itself, fleet MPG may not change much…….but**
- **Energy security and global warming concerns could shift consumer attitudes, willingness to pay for fuel economy technology**
- **An industry-wide shift to efficiency technologies would generate large cost reductions through scale and learning effects**
- **New fuel economy standards can reduce business risk to automakers of changing design tradeoffs towards fuel efficiency**

Extra Slides

Fuel cell greenhouse gas emissions depend strongly on fuels and supply chain:

(from GM/ANL Well-to-Wheel study; available at ANL website)



Plug-in hybrids have multiple benefits:

Full hybrid with larger battery and motor, capable of all-electric range (or charge depletion mode) with recharging from the grid.

- **Oil use reduction**
- **Improved electricity system cost structure (charging evens out the demand curve)**
- ***Potential* reduction of greenhouse gases**
- **Transportation "emergency reserve"**
- **Reduction in most criteria emissions in urban areas**
- **Vehicle-to-grid services**

And, in their use of renewable electricity, PHEVs are much more efficient than FCVs

- **FCV "Plug to Motor"**
  - Electrolyzer **75%**
  - Compression **90%**
    (to 10,000 psi)
  - Fuel cell system **50%**

  (over the EPA cycle)

0.75*0.9*0.5 = 0.34

34% efficiency

- **PHEV "Plug to Motor"**
  - Charger/ battery in 9**0%**
  - Battery out **90%**

0.9*0.9 = 0. 81

81% efficiency

Fuel economy standards have been adopted worldwide…..even with $6/gallon gasoline.

- **Japan weight class standard – aims at 35.5 mpg in 2010, but stringency similar to U.S. (at average 2006 U.S. car weight of 3260 lb., Japan standard = 30.6 mpg, U.S. test mpg = 28.8 mpg)**
- **EU – aims at 41 mpg in 2008 (140 g/km CO_2 on NEDC driving cycle)**
- **Others: China (weight class), Australia, California, Canada, Taiwan, South Korea**