Light Duty Vehicle Technology: Opportunities & Challenges

John German

American Honda Motor Co., Inc

August 23, 2007

Asilomar Conference on Transportation and Climate Policy

3 Issues for the Future Automobile:

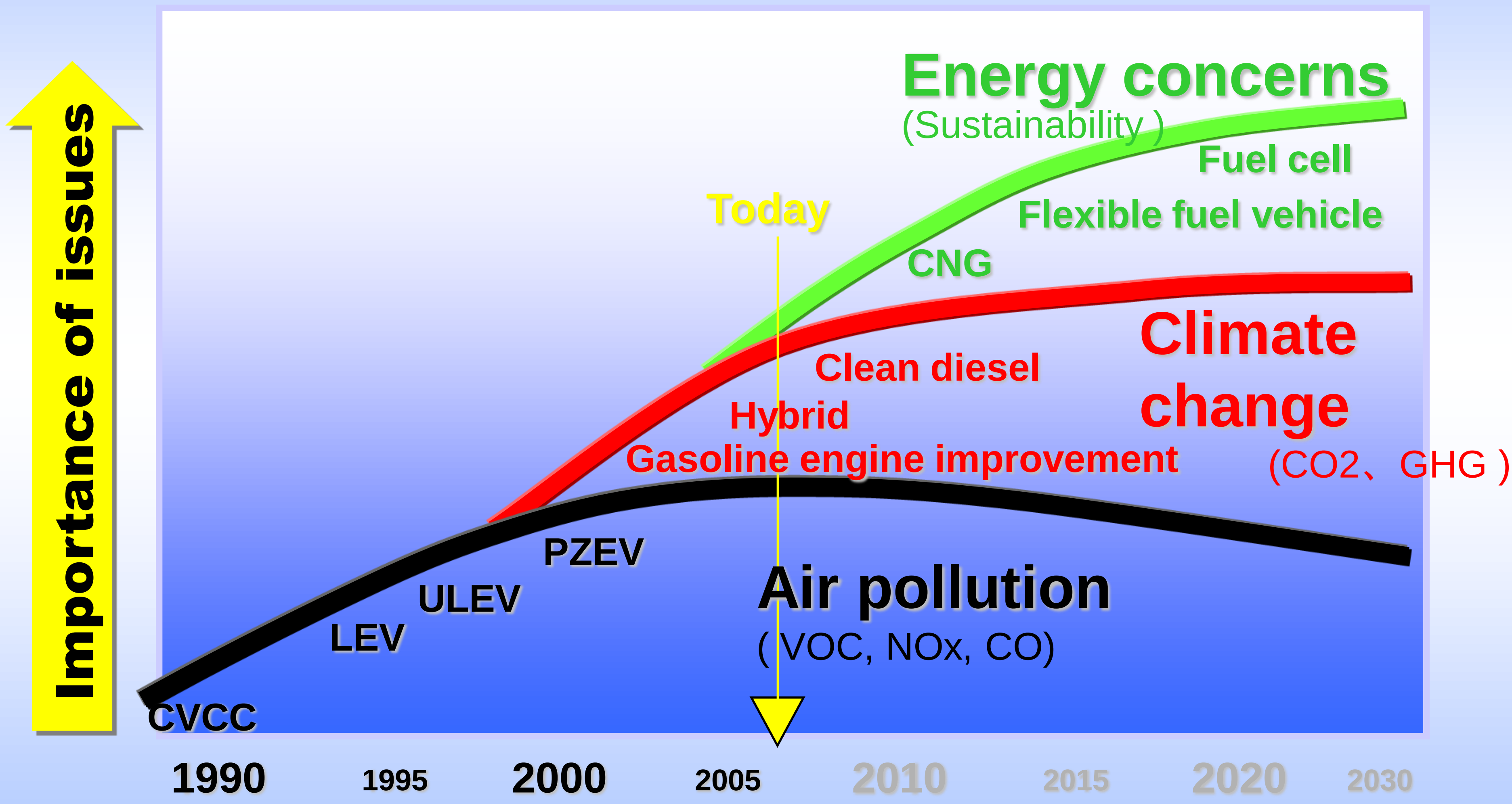
Energy Supply & Demand
Sustainability

Climate Change

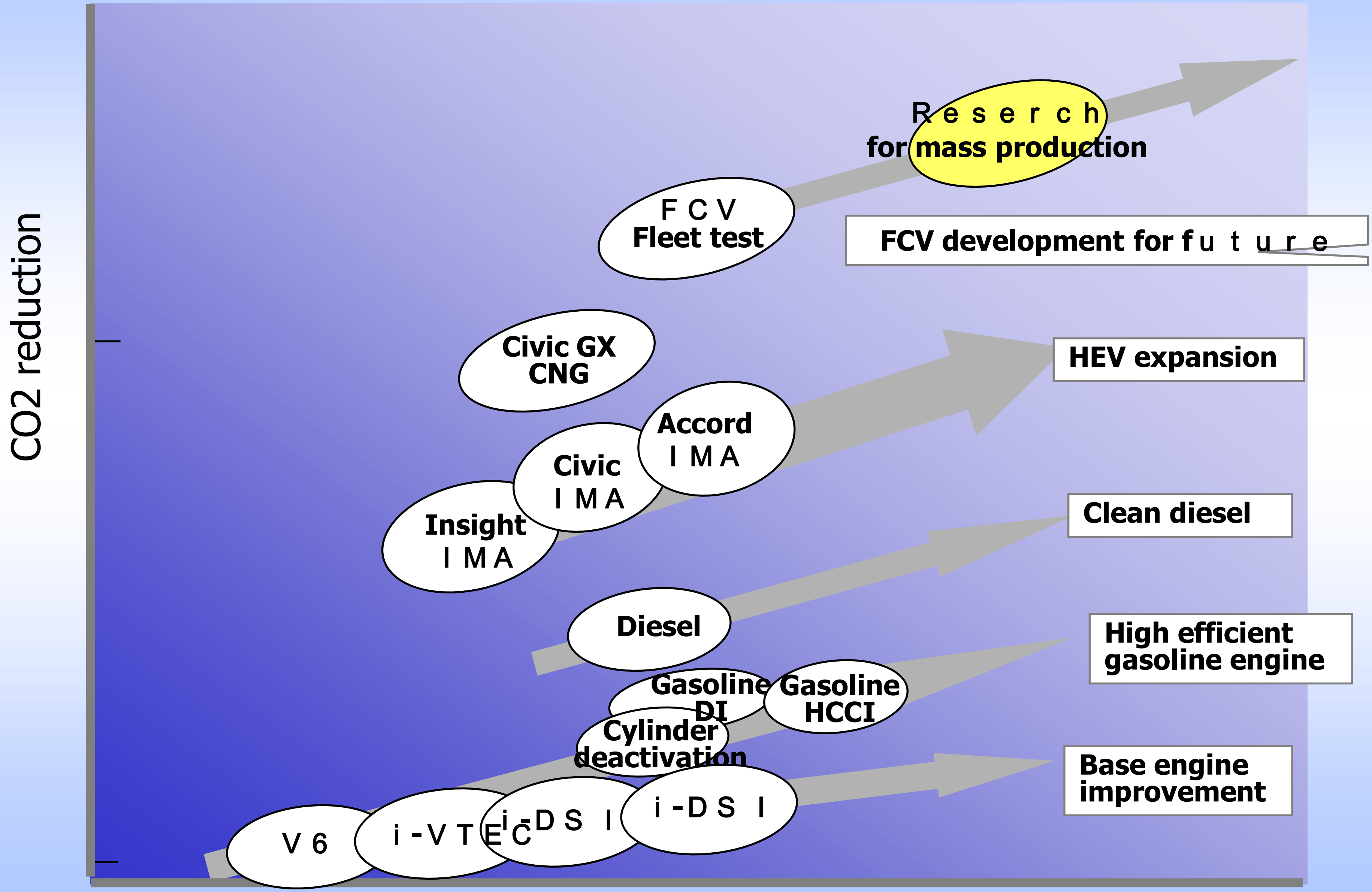
Urban Air Quality

Emissions & Energy Issues

& Technology Directions



Honda’s Powertrain Progress for CO2 reduction

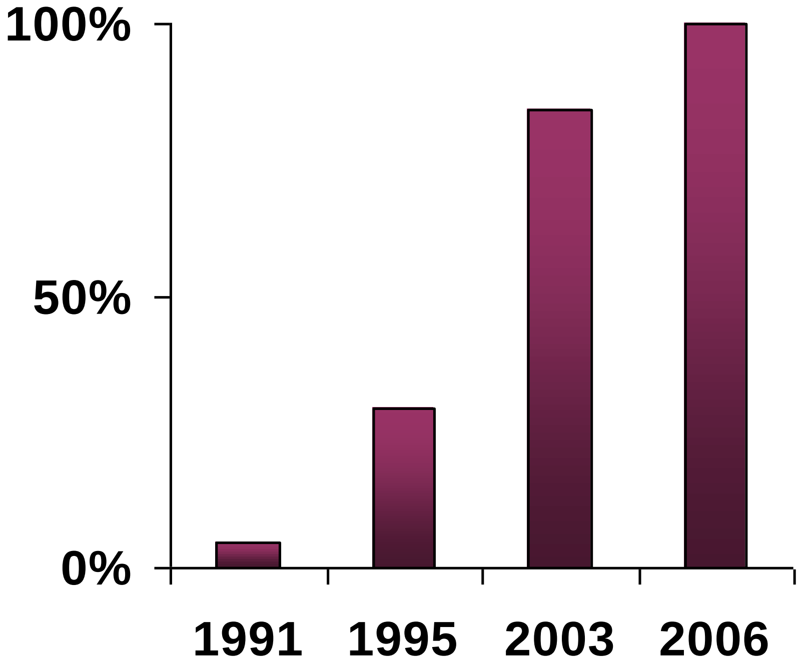


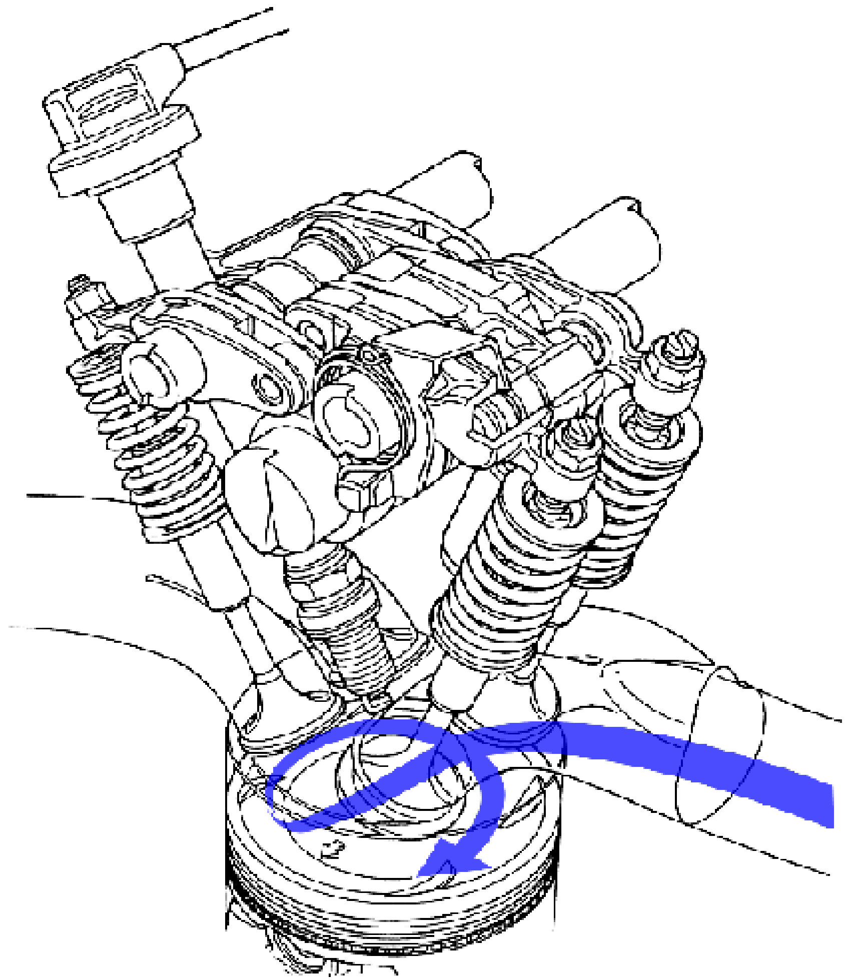
Technology

Honda VTEC Combustion:

(Variable valve Timing and lift, Electronically Controlled)

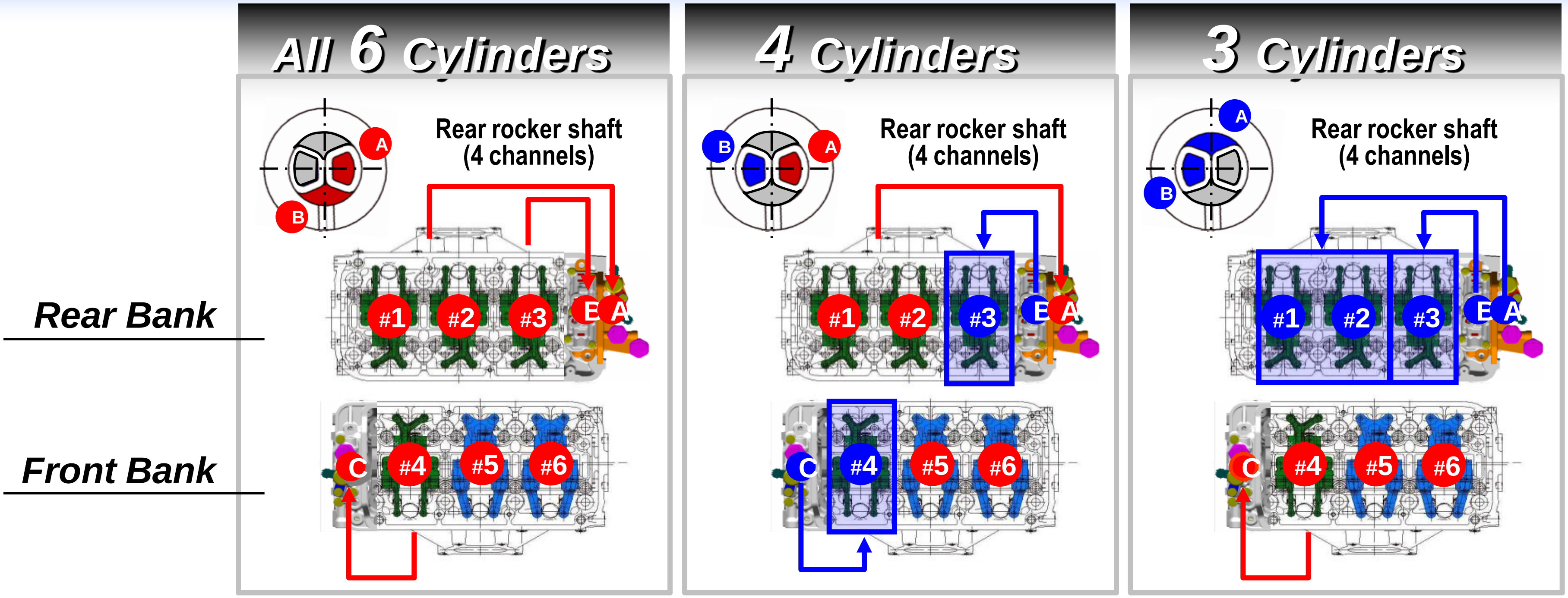
- **HIGHER EFFICIENCY**
- **LOWER EMISSIONS**
- **GREATER PERFORMANCE**



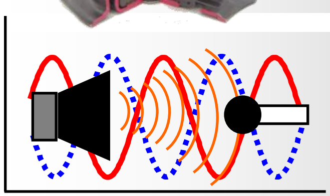


Near-Term Market Introduction - Advanced VTEC with continuously variable intake valve timing and lift

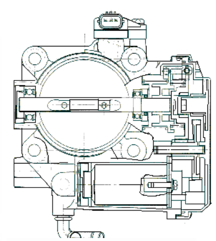
New Variable Cylinder Management



New Active Control Engine Mount



Active Noise Control



Drive by Wire

Torque Converter Lockup Long Torsion Spring

Transmission Advances

Computer controls are enabling a variety of improved transmission designs

- Dual-clutch automated manual
  - Smooth shifting and potentially cheaper
  - But launch concerns (no torque converter), huge investment
- Continuously Variable Transmission (CVT)
  - Excellent city efficiency and extremely smooth
  - Can deliver steady-state engine speeds to facilitate HCCI
  - But torque limited, highway efficiency lower (belt friction), huge investment
- Improved shift points and lock-up strategies
  - Low investment
- Lapillier 6- to 8-speed automatics

Not yet clear which is most cost-effective – all may co-exist

Incremental FE Technology

- Engine technology
  - High specific output (including 4 valve/cylinder)
  - Variable valve timing/lift
  - Cylinder deactivation
  - Direct injection
  - Precise air/fuel metering
  - Lower engine friction
  - Turbocharging
- Transmission efficiency
  - 5/6/7/8 speed
  - CVT
  - Dual-clutch automated MT
- Reduced losses
  - Lightweight materials
  - Low drag coefficient
  - Low resistance tires
  - Lower accessory losses

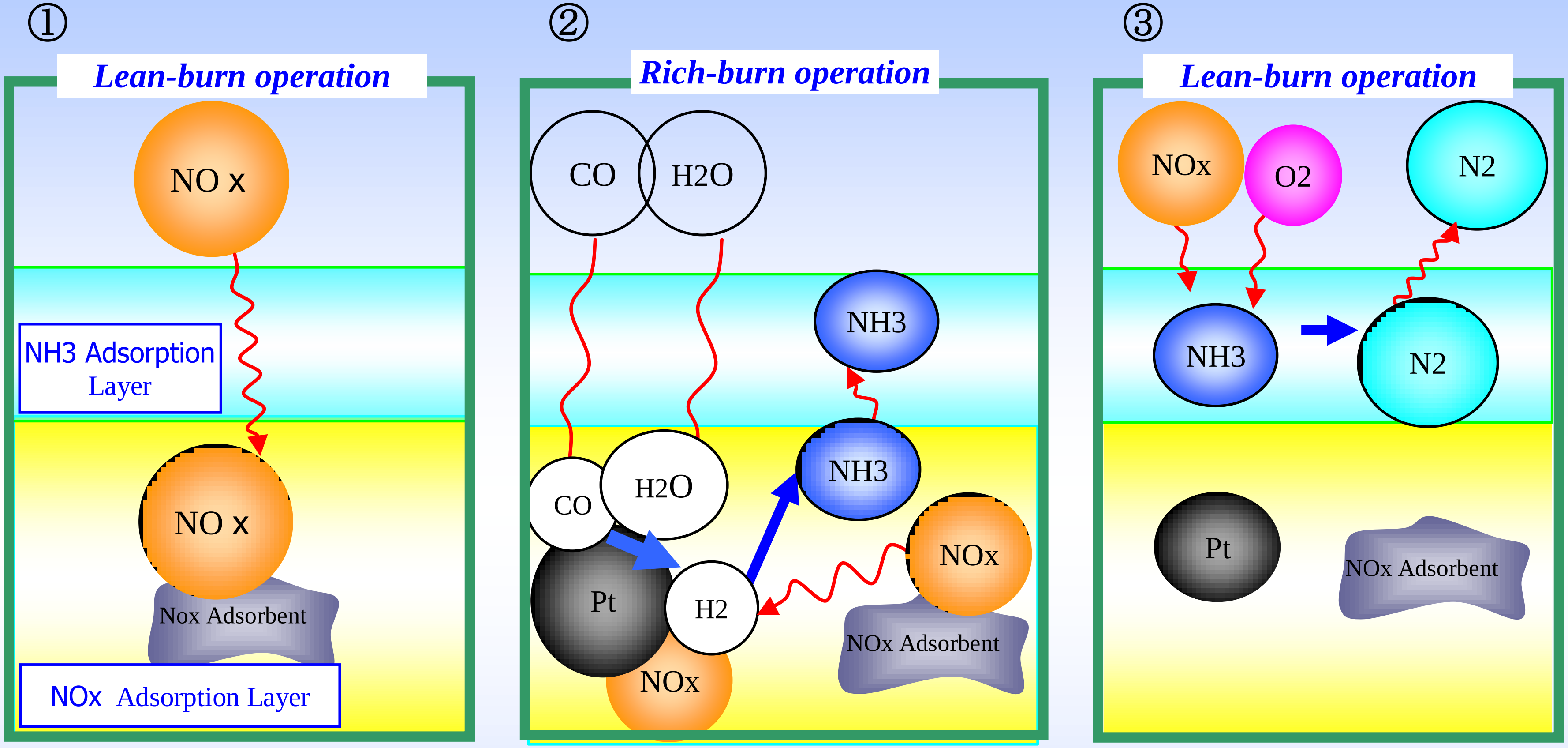
Cost and value issue

- These technologies are continuously being incorporated into vehicles.
- However, consumers value other attributes more highly, such as performance, safety, utility, and luxury.
- Putting in technologies just to improve fuel economy may not be valued by customers.

Fuel Economy Improvement - ???

Depends on how much is already incorporated into fleet and synergies (or lack of synergy) between technologies

Honda Catalyst - Tier 2 Bin 5 Diesel



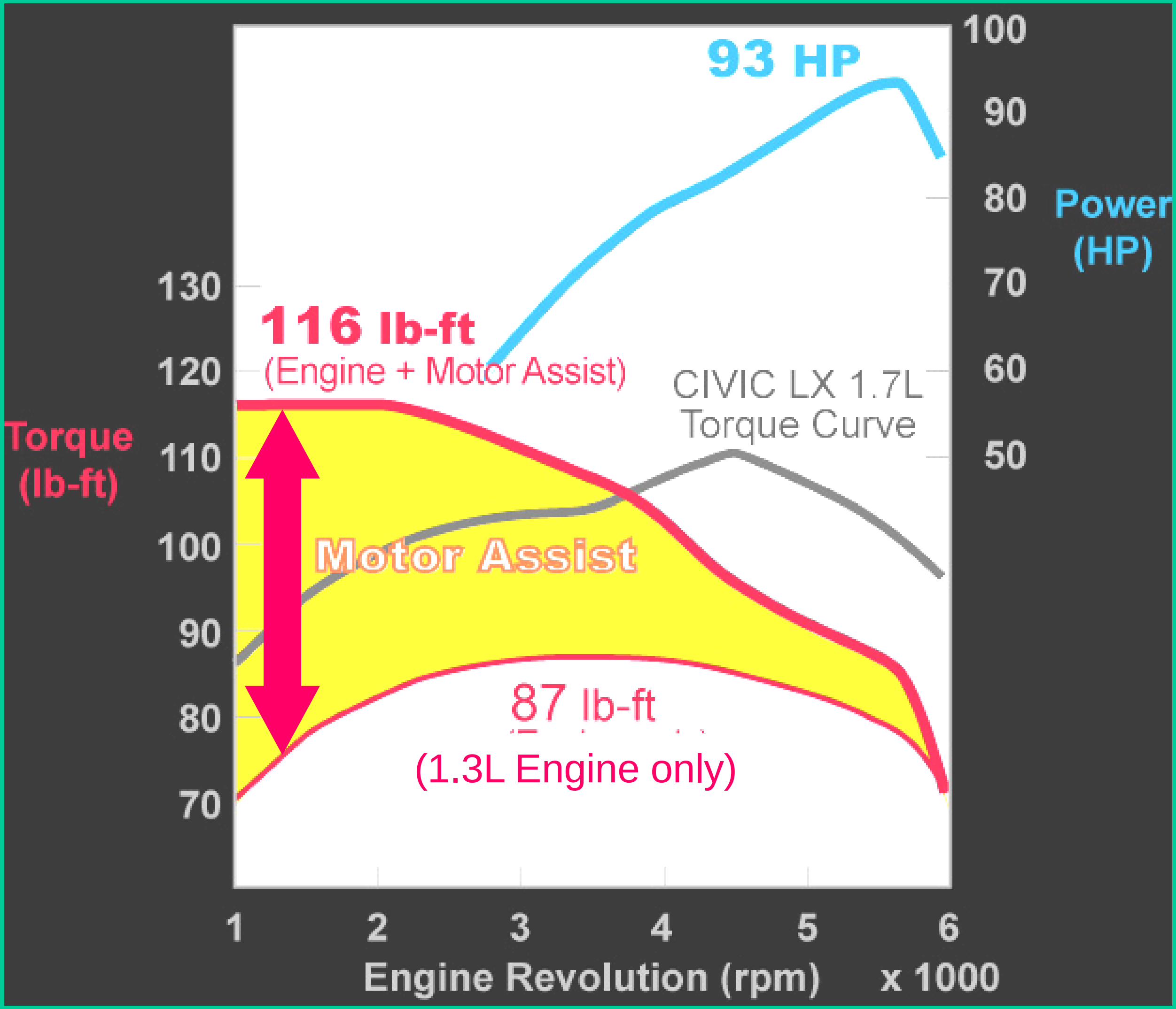
1. During lean burn operation, the NOx adsorbent in the lower layer adsorbs NOx from the exhaust gas.
2. As needed, the engine management system adjusts the engine air-fuel ratio to rich-burn, wherein the NOx in the NOx adsorption layer reacts with hydrogen (H2) obtained from the exhaust gas to produce ammonia (NH3). The adsorbent material in the upper layer temporarily adsorbs the NH3.
3. When the engine returns to lean-burn operation, NH3 adsorbed in the upper layer reacts with NOx in the exhaust gas and reduces it to harmless nitrogen (N2).

Diesel Market Potential in US

- Diesels good for towing, low rpm power, and highway efficiency
  - Hybrids get better fuel economy in city driving
- Diesels are currently cheaper than hybrids, but are not cheap
  - $1500 for 4-cyl., $2000-$3000 for V-8
  - Tier 2 emission standards will add cost
  - Hybrid costs will come down in the future
- Will public recognize improvements in noise, vibration, smell, starting, and emissions?
- Pickup customers want a “tough” diesel, not a wimpy quiet one
- **Must compete with improved gasoline engines and hybrids**
- Europe refineries already shipping unwanted gasoline to US
  - Can refineries adjust output if US also shifts to diesels?
- **Market split?**
  - **Diesels for larger vehicles and rural areas**
  - **Hybrids for smaller vehicles and urban areas**

Hybrid Output Characteristics

CIVIC HYBRID



Attractive Hybrid Features

Integrated Electric Motor

Low Operating Cost: **Fuel Savings!**

Best “Idle” Quality: **Beats any Luxury Car!**

Superior Driving Range: **Fewer Trips to the Station!**

Pride of Ownership: **Social Benefits!**

Dedicated Honda Hybrid

- All-new, more affordable, dedicated hybrid car
- Launched in North America in 2009
- Annual North American sales volume target of 100,000 units
- **Target price significantly lower than the current Civic Hybrid**

Hybrid Synergies

- More efficient electric pumps and compressors
  - Beltless engine
- Part-time 4wd
- Extend operating windows for Atkinson cycle and cylinder deactivation
- Provide quasi-steady-state load conditions for HCCI/CAI operation (especially with CVT)
- E-turbo
  - High electric power – supercharger boost
  - When power is not needed, use exhaust energy to drive e-turbo and recharge battery

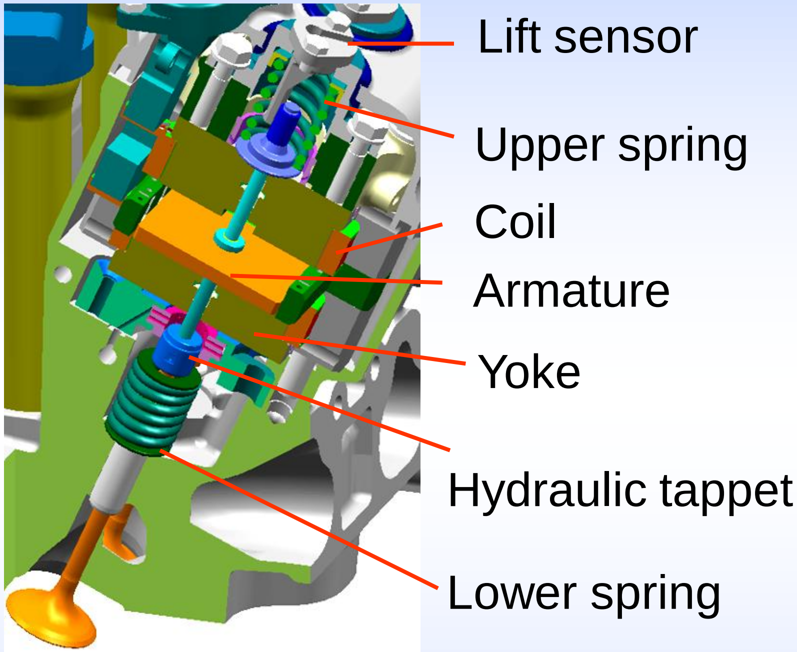
Plug-In Hybrid Payback

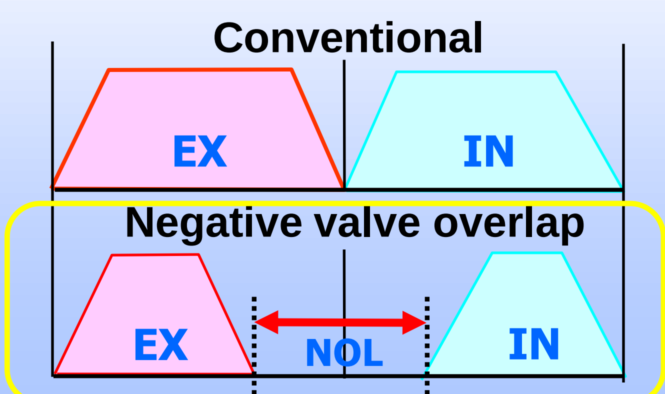
Table 8, Plug-In Hybrids, ACEEE, Sep 2006			Calculated
	Hybrid	**Plug-In, 40-Mile range**	**Plug-In vs. Hybrid**
Near-term Incremental costs			
Battery	\$2,000	\$17,500	\$15,500
Other incremental costs	\$1,500	\$1,500	0
Annual fuel savings	\$480	\$705	\$225
Payback (years)	**7.3**	27.0	**68.9**
Long-term Incremental costs			
Battery	\$600	\$3,500	\$2,900
Other incremental costs	\$1,000	\$1,000	0
Annual fuel savings	\$480	\$705	\$225
Payback (years)	2.9	**6.4**	**12.9**

Assumptions include:
12,000 miles per year, hybrid FE of 50 mpg, conventional vehicle FE of 30 mpg, 50% of plug-in miles on electricity, \$3.00/gal, no discounting of fuel savings, **no FE penalty for additional weight of plug-in batteries, no battery replacement for plug-in**

Next-generation Gasoline Engines

Camless Valve Actuation

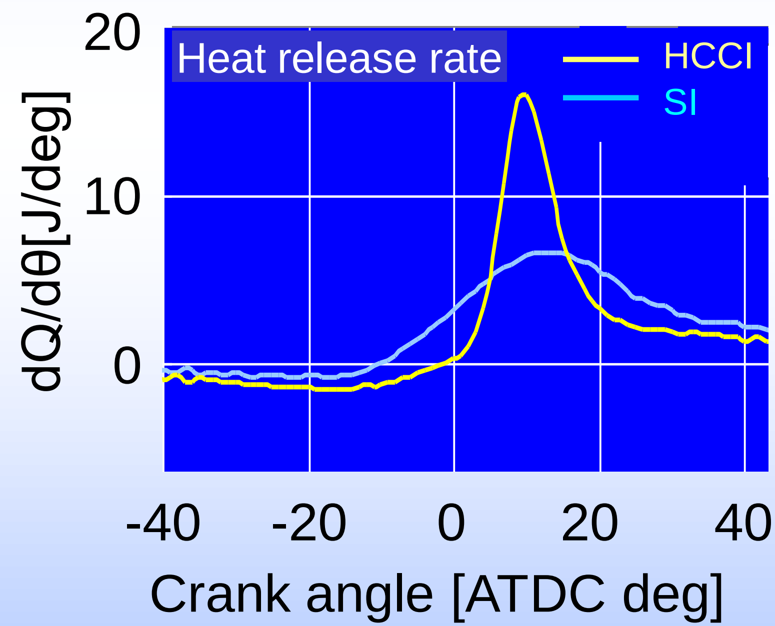




HCCI Engine

Improvement in fuel economy: 30%

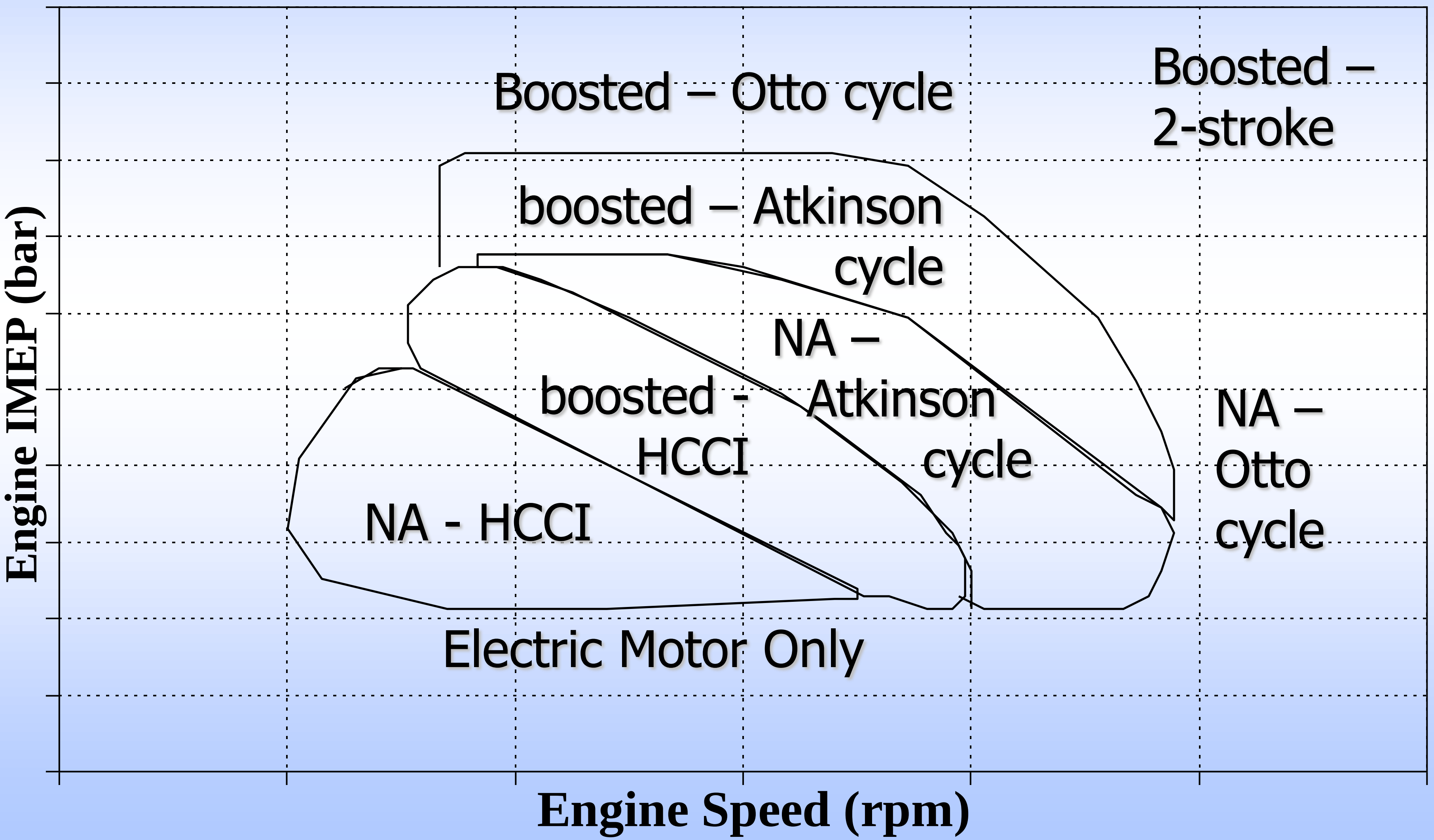
Honda Prototype Engine Base (Electro-magnetic valve)



Requires increasing the self-ignition region

Potential Operating Modes

Assumes camless valve actuation, direct injection, e-turbo



Civic GX Natural Gas Vehicle

Range = 200-240 mi

CO_2 reduction ~20%

Performance = Gasoline

Near Zero Emissions

Demonstrated reliability and durability

Satisfied customers

CARB AT-PZEV, EPA Bin2 ILEV

The Home Refueler / Civic NGV

- ***"Phill" :   Home Refueling***
- ***World debut in California (Honda with Fuelmaker)***
- ***Expands AFV marketability with home refueling device***

- Maintenance free
- Quiet
- Certified for home use
- Easy to use
- 110 volt
- Gas detection

Next FCX Model Direction

FCX CONCEPT

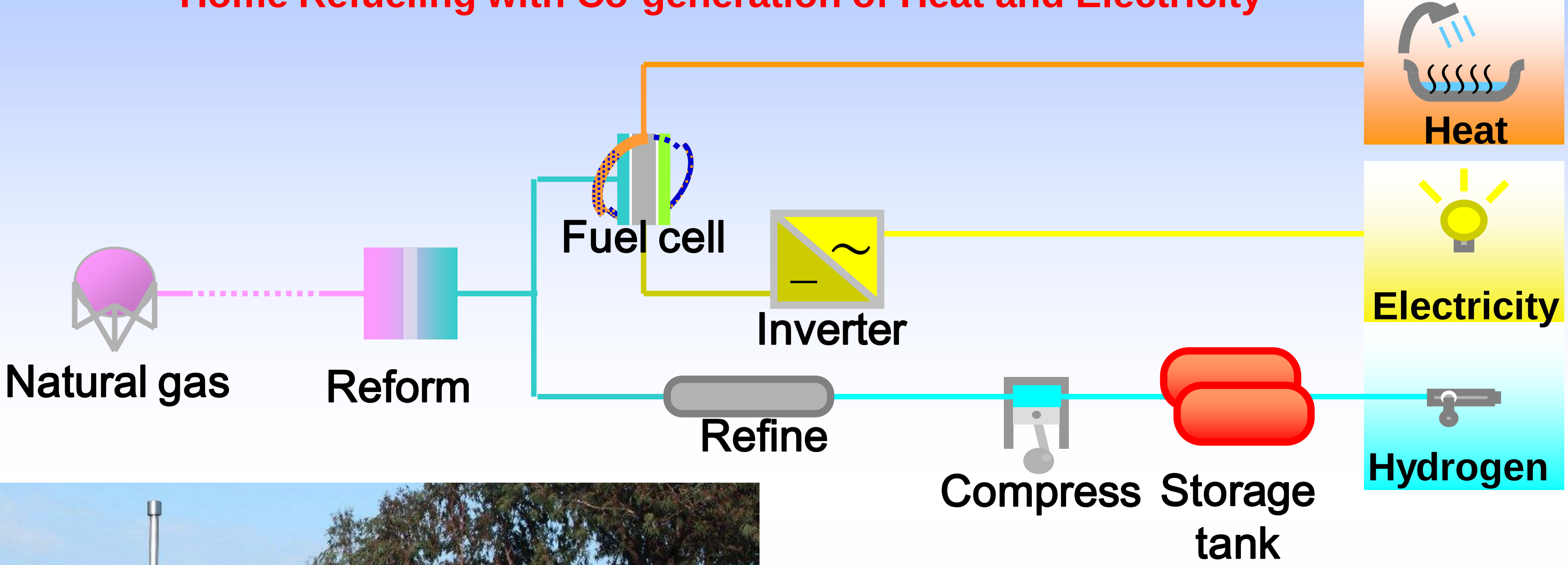
Timing: 2008 model year

Vertical gas flow
Vertebral layout
Volume-efficient
V Flow

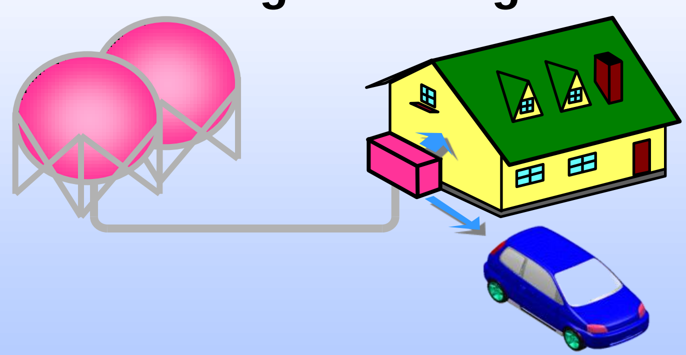
- Low Floor
- Compact Fuel Cell Components
- V-flow stack technology
- 270 mile range (concept car)

Home Energy Station

Home Refueling with Co-generation of Heat and Electricity



Reformated Gas
Home Refueling with Co-generation



Cooperative development with Plug Power

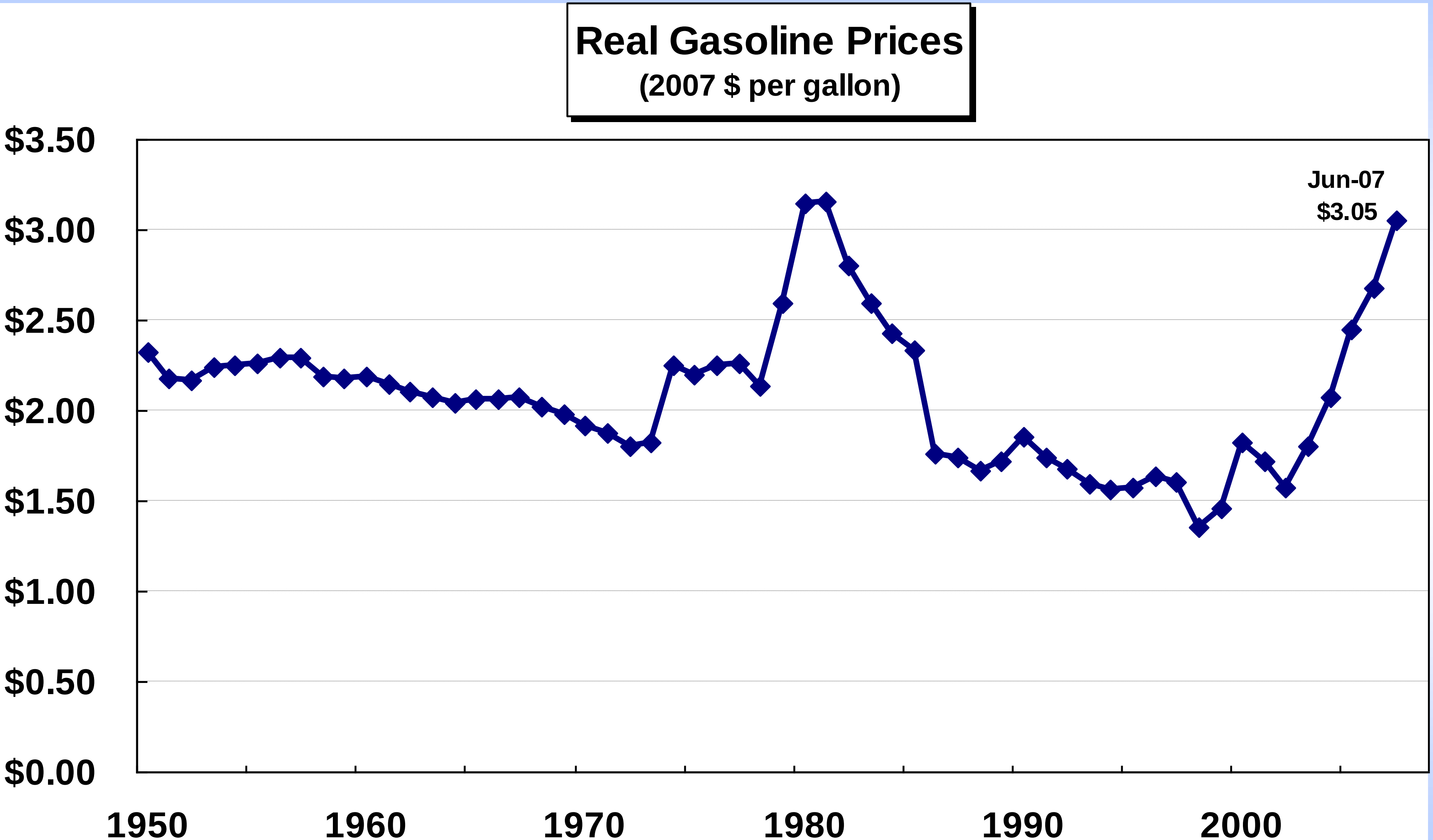
Crystal Ball is Unclear

- **Improved conventional engines keep raising the bar**
  - Lower fuel consumption reduces the benefit from alternative technology
- Ultimate goal is fuel cells, but timing unclear (not near term)
  - Plug-in hybrids might prolong fossil fuel era
- Hybrid technology is progressing rapidly
  - Costs coming down
  - Synergies with other technologies developing
  - Consumer features will develop
- Diesels for rural areas and larger vehicles, hybrids for urban areas and smaller vehicles?
- CNG may appeal to a segment who dislikes refueling
- Multiple transmission designs likely

Challenge is customer’s low value of fuel economy

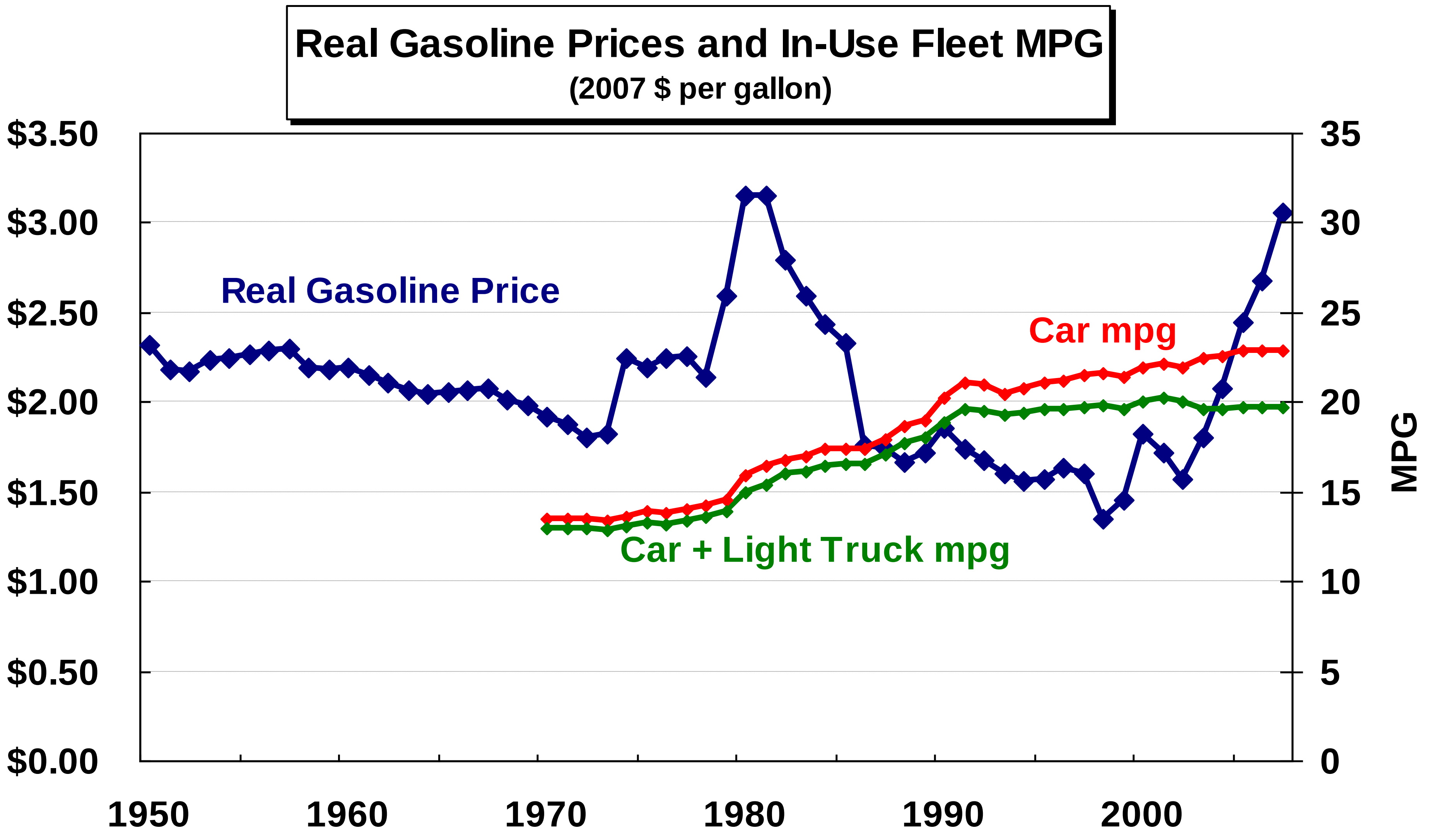
- Real cost of driving very low
- Performance, utility, comfort, safety valued more highly
- Most only consider fuel savings during ownership period

Real Gasoline Price



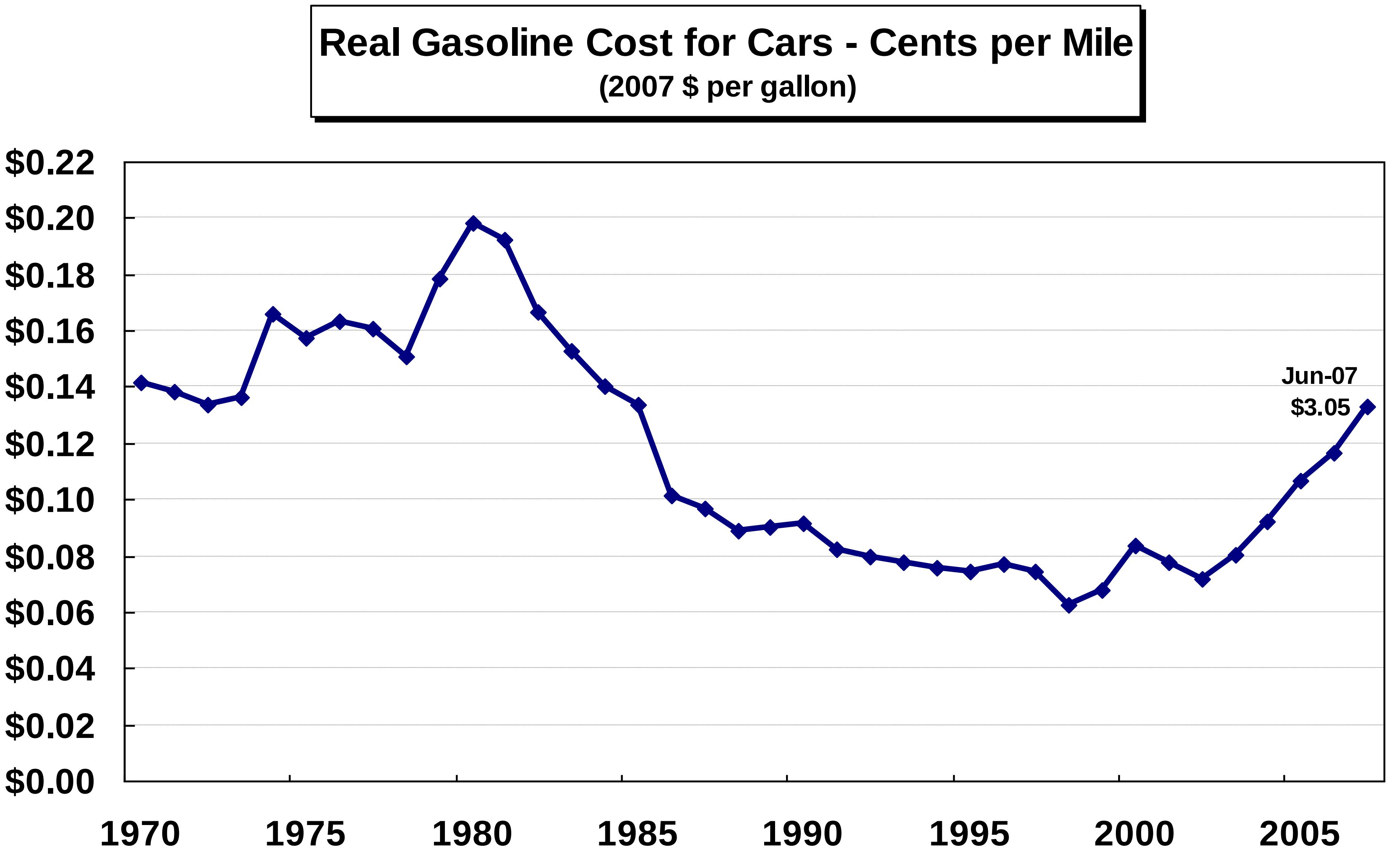
Motor Gasoline Retail Prices, U.S. City Average, adjusted using CPI-U

Fleet Fuel Economy

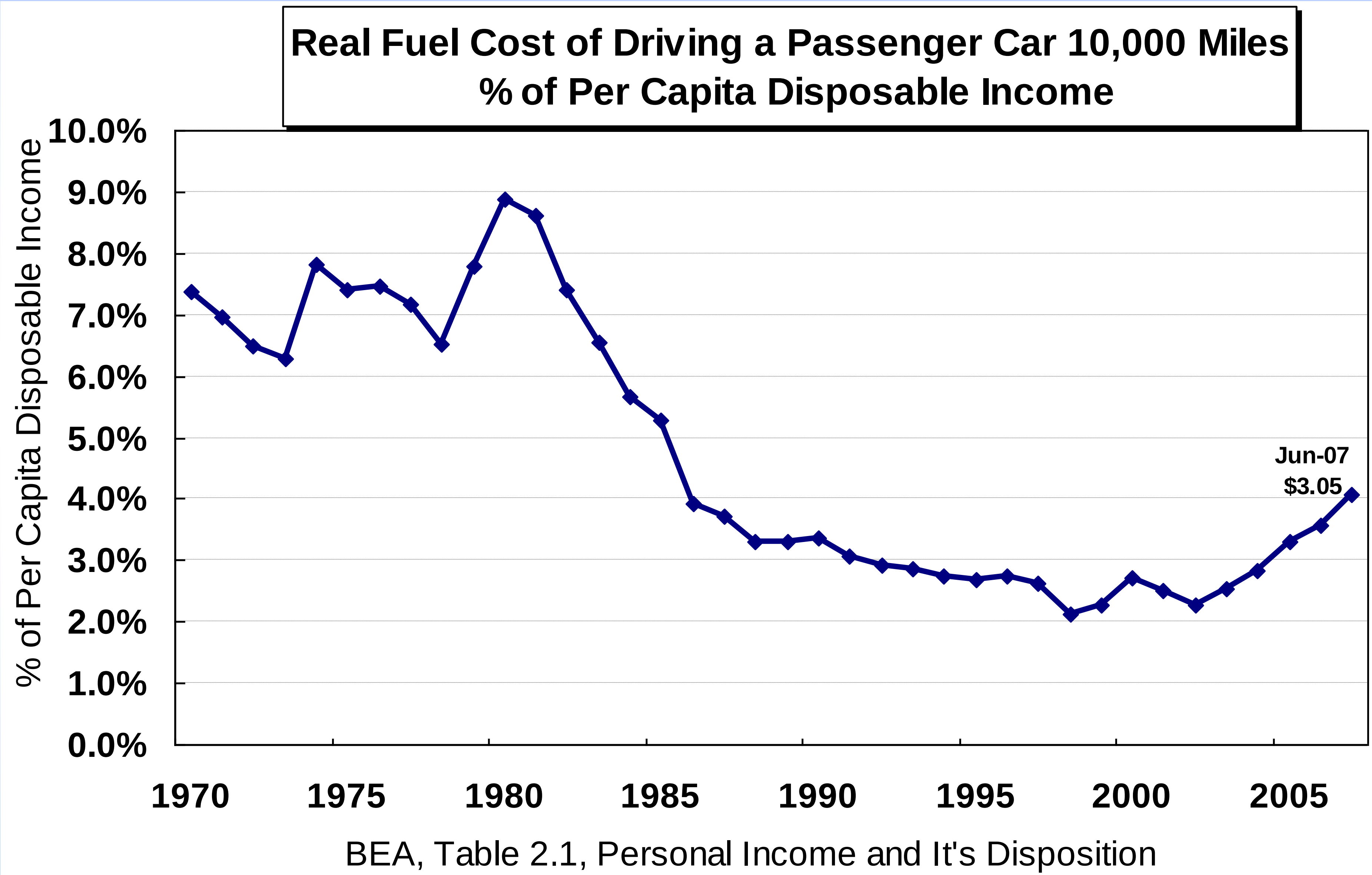


In-Use MPG from Transportation Energy Data Book: 2007

Gasoline Cost per Mile



Real Fuel Cost - % of Disposable Income

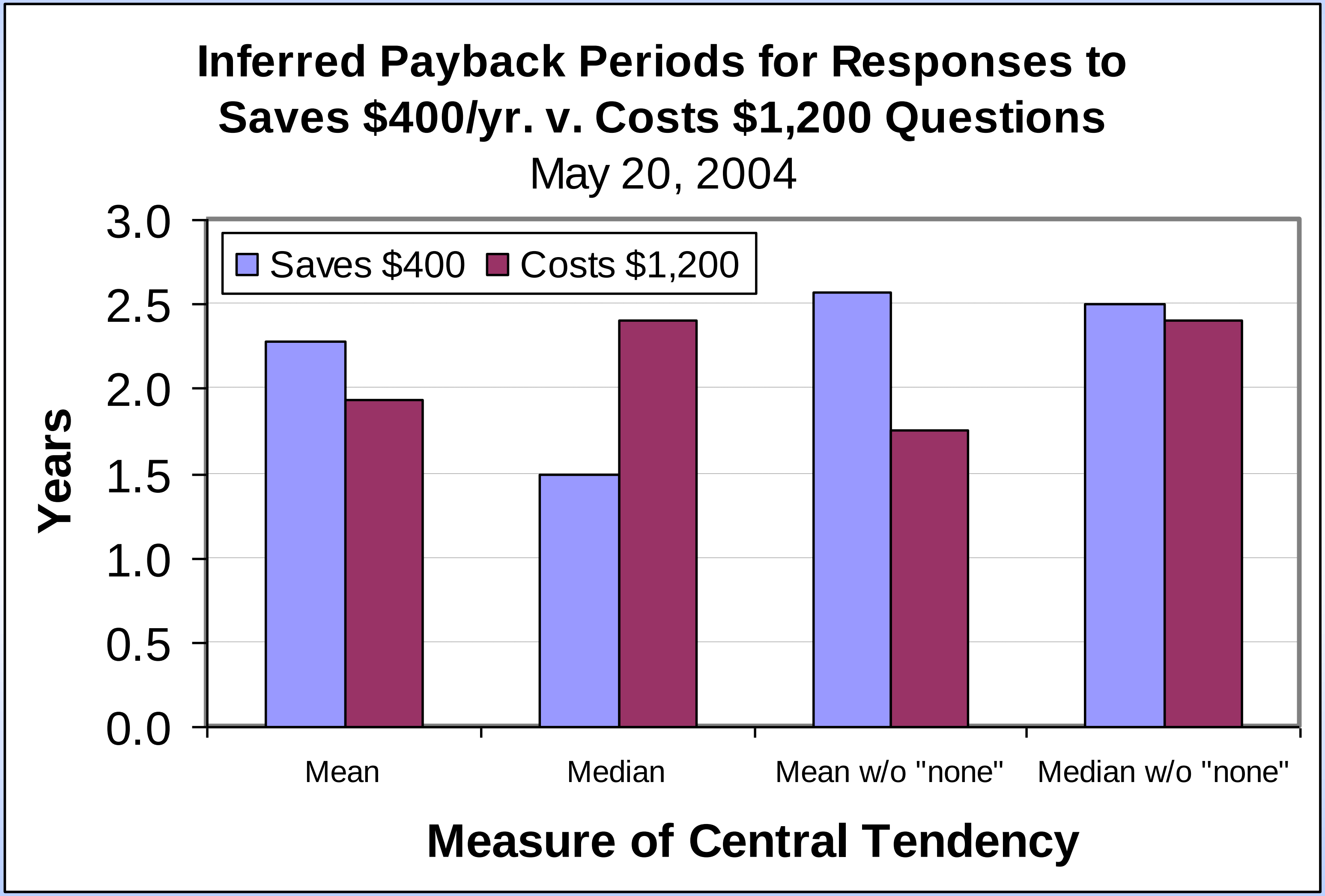


In-depth interviews of 60 California households' vehicle acquisition histories found *no evidence* of economically rational decision-making about fuel economy. (Turrentine & Kurani, 2004)

- Out of 60 households (125 vehicle transactions) 9 stated that they compared the fuel economy of vehicles in making their choice.
- 4 households knew their annual fuel costs.
- None had made any kind of quantitative assessment of the value of fuel savings.

Consumer Payback Period – Fuel Savings

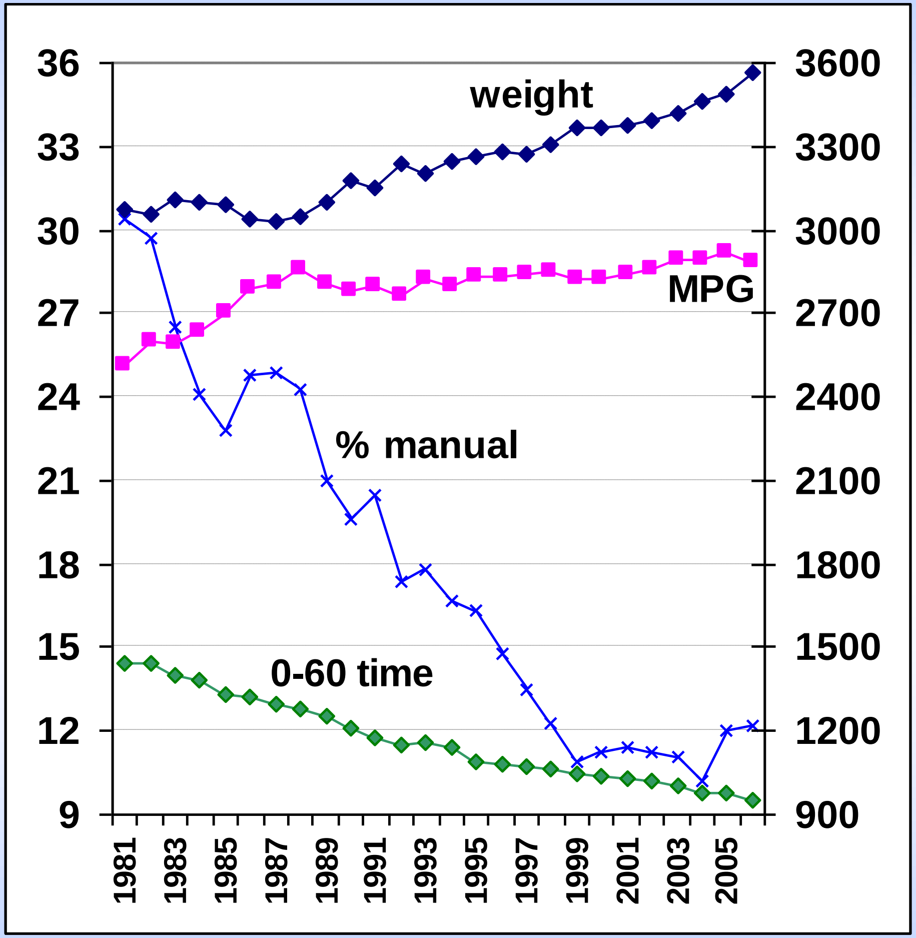
A random sample of consumers gave generally consistent answers to the same question asked from two directions.

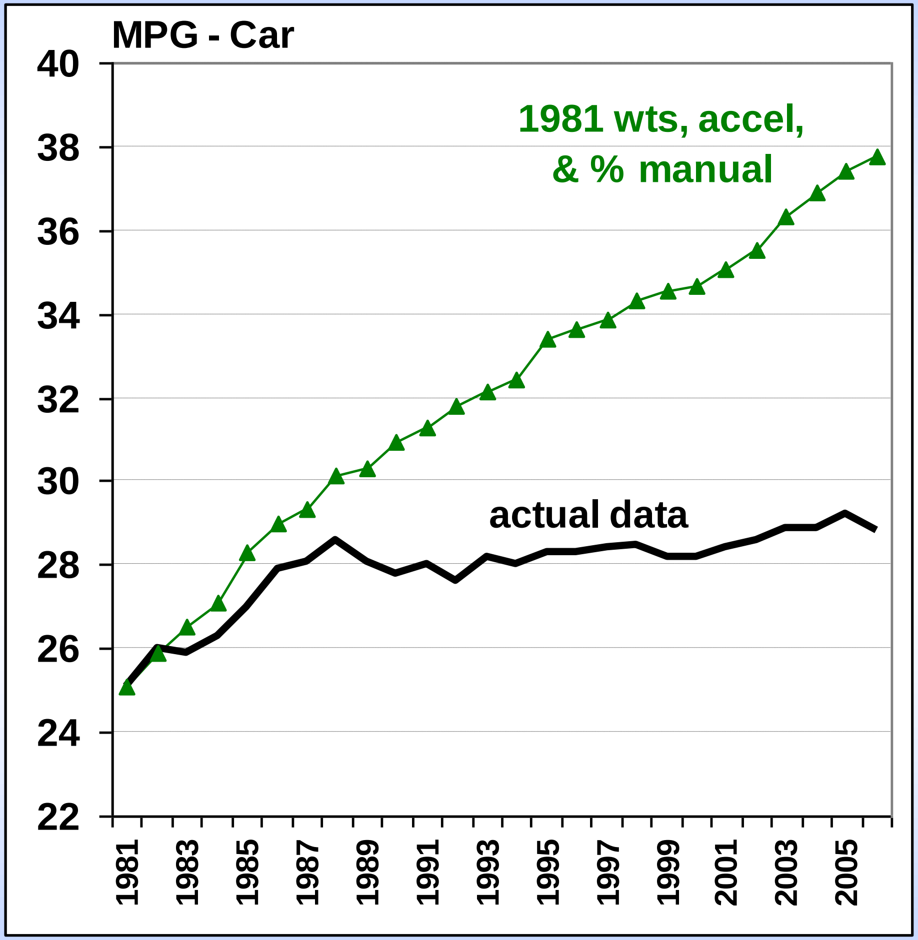


David L. Greene, IAEE/USAEE Meetings, Washington, DC, July 10, 2004 – "Why don't we just tax gasoline? Why we don't just tax gasoline"

Effect of Attribute Tradeoffs - Cars

Car Data from EPA's 2006 FE Trends Report



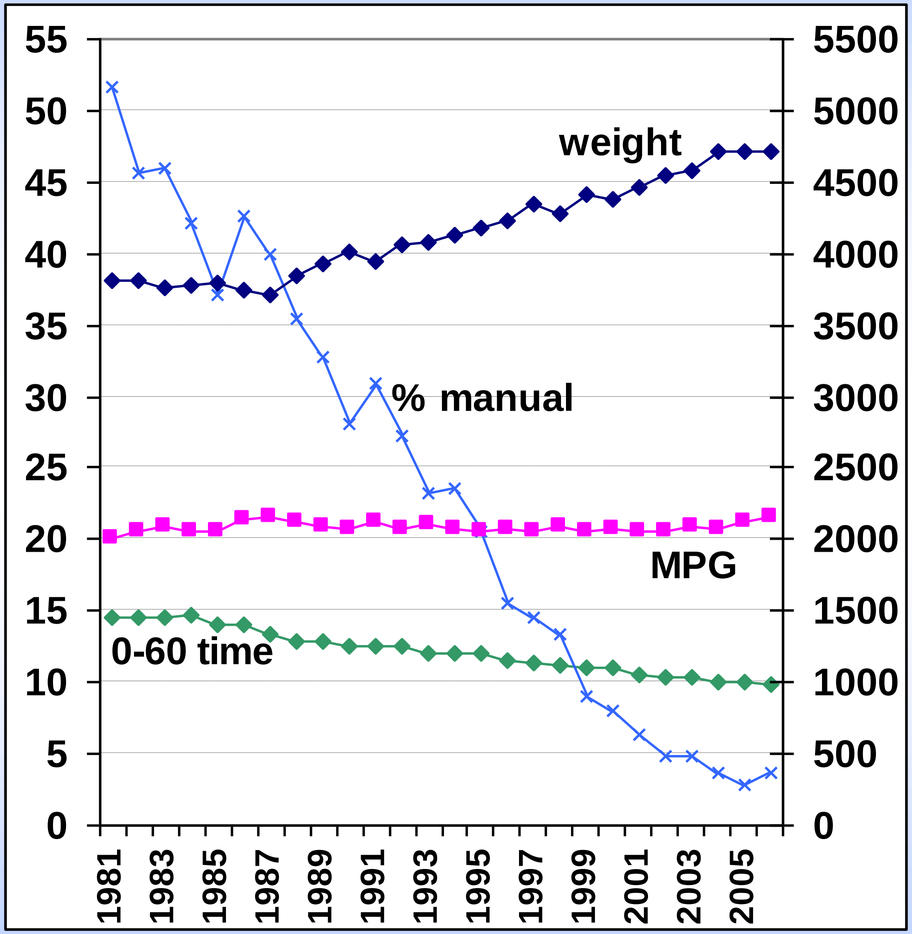


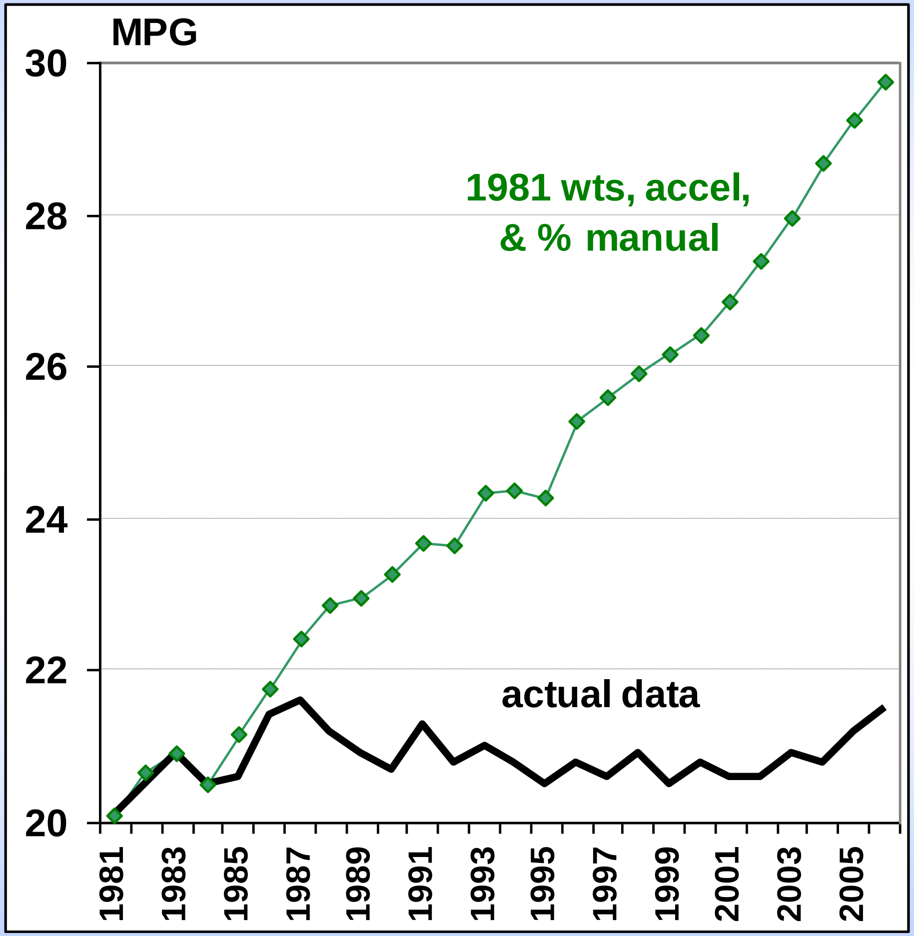
Fuel efficiency has increased by about 1.3% per year since 1987

However, this has all been used to increase other attributes more highly valued by the customer, such as performance, comfort, utility, and safety

Effect of Attribute Tradeoffs - LDT

Light Truck Data from EPA's 2006 FE Trends Report



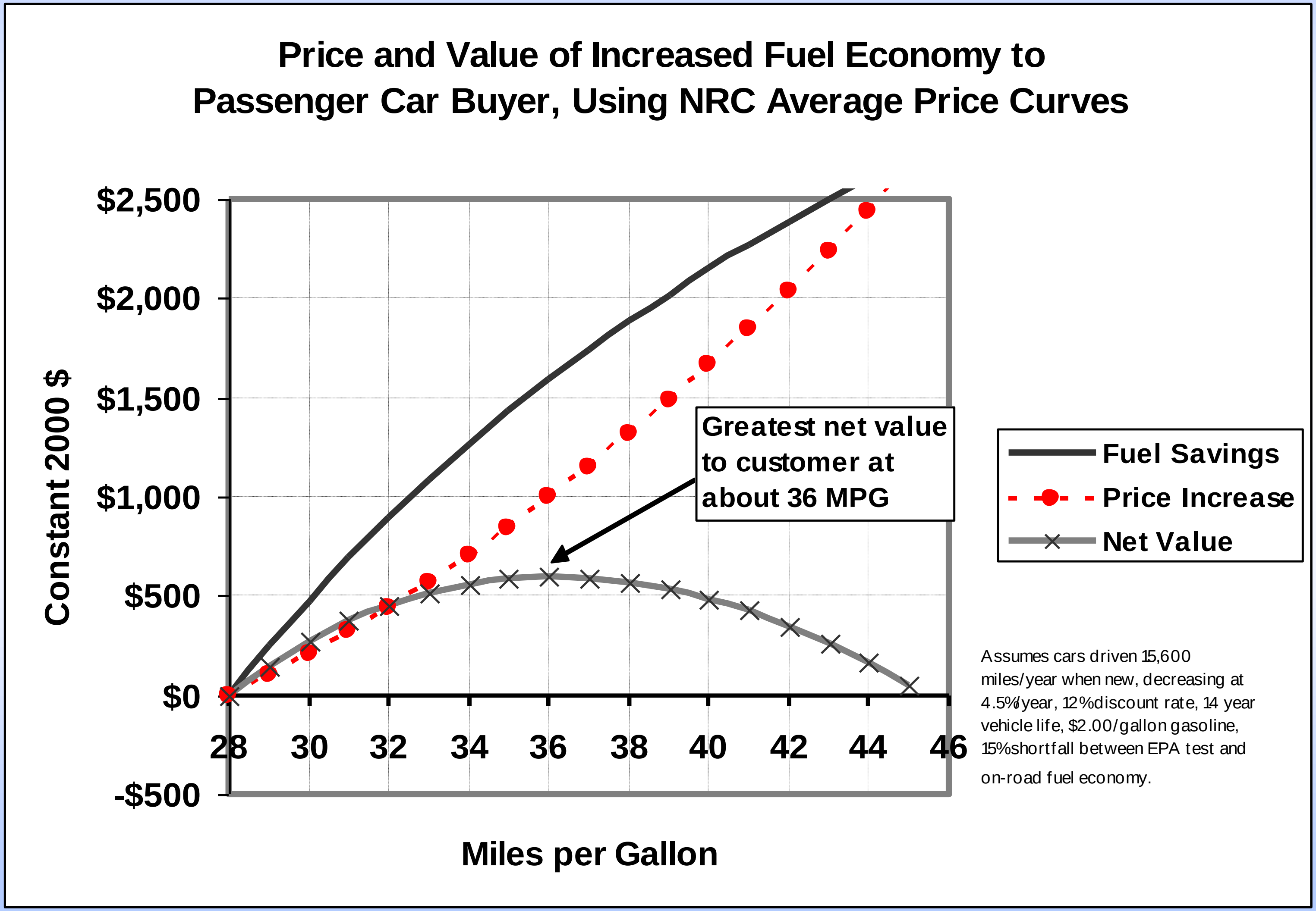


Fuel efficiency has increased by about 1.5% per year since 1987

However, this has all been used to increase other attributes more highly valued by the customer, such as performance, comfort, utility, and safety

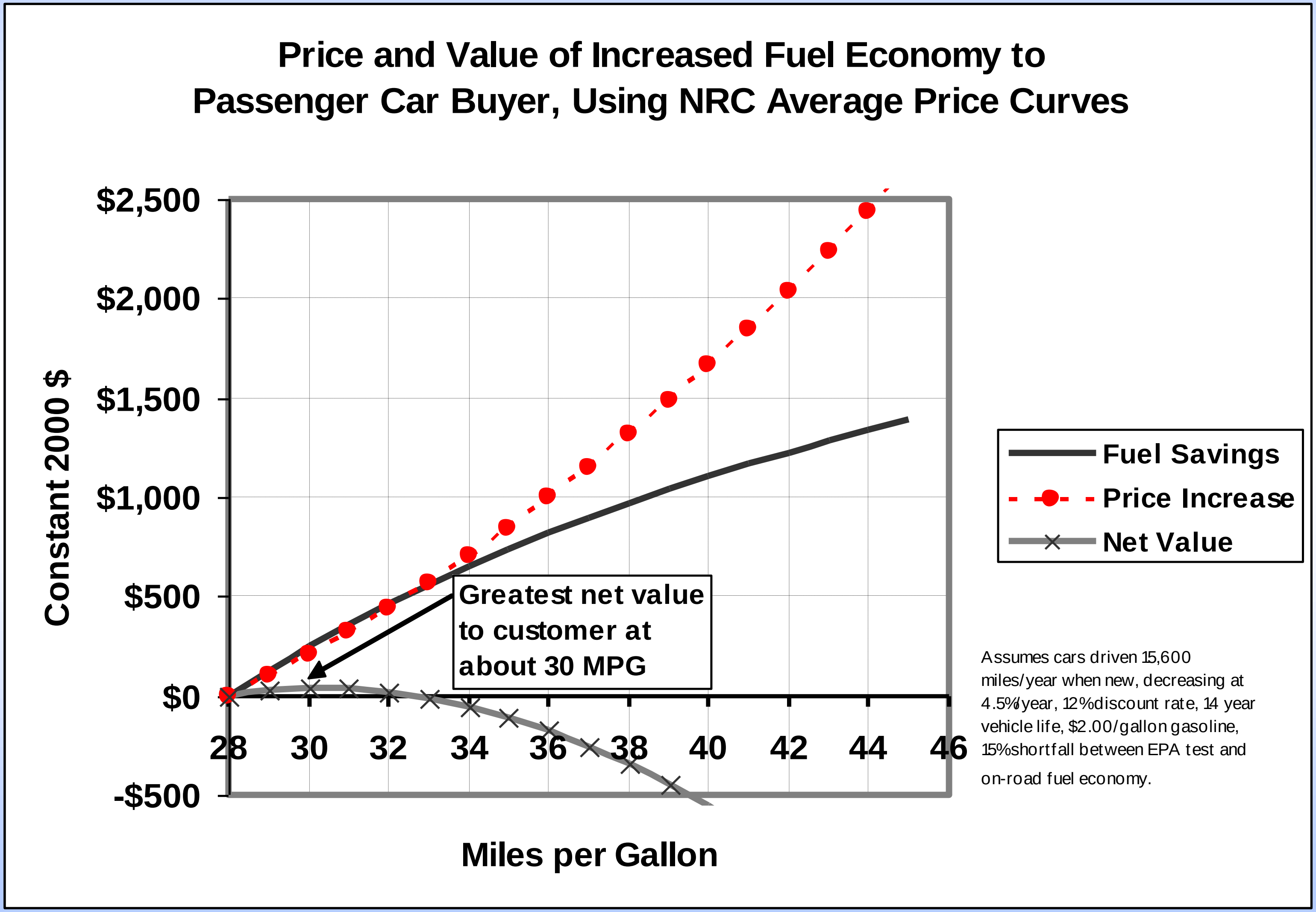
What matters to the consumer is *NET VALUE*

"Economically rational" consumer (14 year payback) – net value is $500 or less for up to a 60% increase in MPG



Most consumers value only 3 years of fuel savings – broad range of indifference to FE improvements

Consider manufacturer’s risk in redesigning all product to increase MPG



David L. Greene, Climate Change Policy Initiative, Washington, DC, Oct. 5, 2006

Incentives/Mandates are Needed

- Fuel price is a good lever for vehicle choice and VMT
  - Gas taxes “should” be raised
- Fuel price is NOT a good lever for technology
  - Technology cost and fuel savings balance
  - Little influence on highly complex and emotional purchase decisions
- Role of Federal government is to reflect full fuel savings and externalities in performance-based requirements or incentives

The Real Barrier - Leadtime

- Market is very competitive: new technologies = huge risks
  - Manufacturer at a competitive disadvantage if the selected technology ultimately proves to be more expensive
  - Even worse is widespread adoption of a technology that does not meet the customer expectations for performance and reliability.
    - Hurts manufacturer's reputation
    - Sets back acceptance of the technology for everyone (GM diesel)
- Must allow time to ensure quality and reliability
  - Rigorous product development process – 2-3 years
  - Prove in production on a limited number of vehicles – 2-3 years
  - Assess impact of higher volume and further development on costs before committing to a single technology
  - Spread across fleet – 5-year minimum product cycles
- Costs increase dramatically if normal development cycles are not followed
  - Greatly increases development costs, tooling costs, and the risk of mistakes

The Ignored NAS Finding

2002 NAS Study - EFFECTIVENESS AND IMPACT OF CAFE STANDARDS

Finding 15. Technology changes require very long lead times to be introduced into the manufacturers’ product lines. Any policy that is implemented too aggressively (that is, in too short a period of time) has the potential to adversely affect manufacturers, their suppliers, their employees, and consumers. Little can be done to improve the fuel economy of the new vehicle fleet for several years because production plans already are in place. The widespread penetration of even existing technologies will likely require 4 to 8 years. For emerging technologies that require additional research and development, this time lag can be considerably longer.

FE Mandates in Japan and Europe

- Europe 1995-2008:
  - CO2 reduced from 185 gCO2/km in 1995 to 140 in 2008
  - Annual FE improvement rate: **2.2% per year**
- Europe 2008-2012 goal:
  - Further reduce CO2 emissions to 130 grams/km by 2012
  - Annual FE improvement rate: **1.9% per year**
- Japan 2005-2016:
  - Increase economy from 13.6 km/l in 2005 to 16.8 in 2016
  - Annual FE improvement rate: **1.9% per year**

Summary

- Benefit and cost of individual technologies is not the real issue
  - Technology clearly can dramatically improve ***efficiency***
- Real concerns are:
  - How to get technology applied to fuel ***economy*** when customers value other features more highly
  - How to get customers to care about fuel ***economy*** when fuel costs are so low
  - Rate at which technology can be introduced without increasing costs and adverse consequences
- **You can push beyond 2% per year improvements, but the potential for adverse consequences, increased cost, and consumer backlash rises exponentially –**

Do you want to live with the consequences?

HONDA

The power of dreams.™