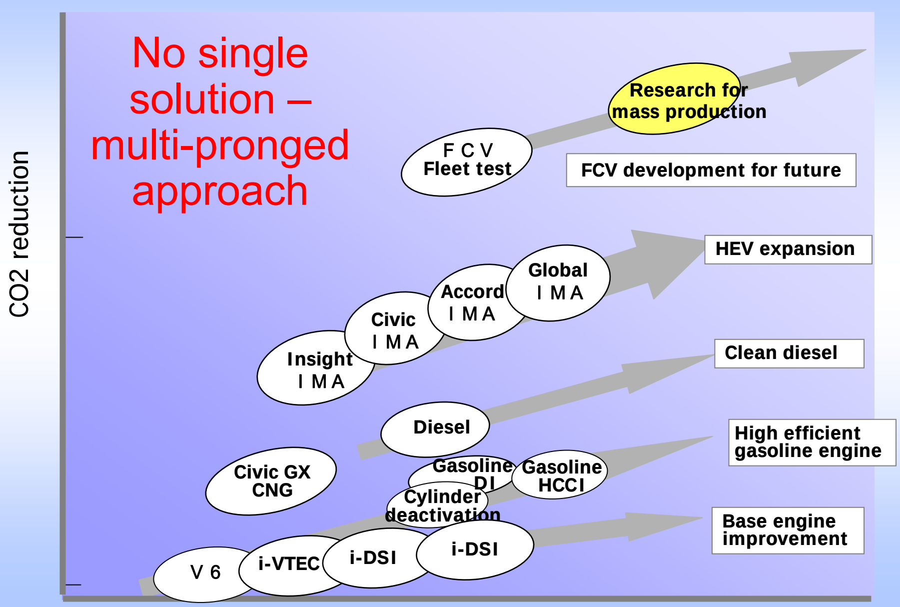
How Far can Technologies and Fuels Currently in Development Take Us?

Transportation / Land Use / Environment Connection
John German
American Honda Motor Co., Inc.
October 20, 2008

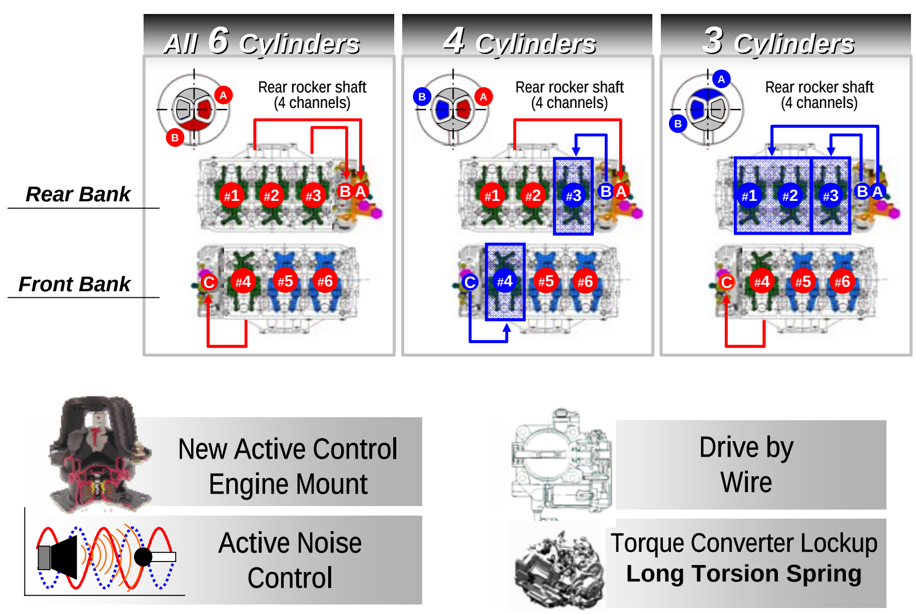
Honda's Powertrain Progress for CO2 reduction



2002 NAS CAFE Report

Technology – Fuel Consumption Improvement Baseline – OHC, 4V, Fixed Timing, Roller Finger Follower Baseline (Large) –2V, Fixed Timing, Roller Finger Follower	Improvement %	Retail Price Equivalent (RPE)		Sub * Avg. 30.14 mpg 3.31 g/100m			Comp * Avg. 26.96 mpg 3.71 g/100m			Mid * Avg. 24.09 mpg 4.15 g/100m			Large * Avg. 20.46 mpg 4.89 g/100m		
Production-Intent Engine Technology		Low	High	1	2	3	1	2	3	1	2	3	1	2	3
Engine Friction Reduction – 1-5%	1% - 5%	$35	$140	x	x	x	x	x	x	x	x	x	x	x	x
Low Friction Lubricants – 1%	1%	$8	$11	x	x	x	x	x	x	x	x	x	x	x	x
Multi-Valve, Overhead Camshaft – 2-5% (2-V vs. 4-V)	2%-5%	$105	$140										x	x	x
Variable Valve Timing – 1-2%	1%-2%	$35	$140	x	x	x	x	x	x	x	x	x	x	x	x
Variable Valve Lift & Timing – 3-8%	3%-8%	$70	$210		x	x		x	x		x	x		x	x
Cylinder Deactivation – 3-6%	3%-6%	$112	$252									x		x	x
Engine Accessory Improvement – 1%-2%	1%-2%	$84	$112	x	x	x	x	x	x	x	x	x	x	x	x
Engine Supercharging & Downsizing – 5-7%	5%-7%	$350	$560									x			x
Production-Intent Transmission Technology															
5-Speed Automatic Transmission - 2-3%	2%-3%	$70	$154	x			x			x	x		x	x	
Continuously Variable Transmission – 4-8%	4%-8%	$140	$350		x	x		x	x			x			x
Automatic Transmission w/ Aggressive Shift Logic – 1-3%	1%-3%	$-	$70	x			x			x			x		
6-Speeds Automatic Transmission – 1-2%	1%-2%	$140	$280								x		x	x	
Production-Intent Vehicle Technology															
Aero Drag Reduction - 1-2%	1%-2%	$-	$140					x	x		x	x		x	x
Improve Rolling Resistance – 1-1½%	1%-1½%	$14	$56	x	x	x	x	x	x	x	x	x	x	x	x
Safety Technology															
5% Safety Weight Increase	-3% to -4%	$0	$0	x	x	x	x	x	x	x	x	x	x	x	x
Emerging Engine Technology															
Intake Valve Throttling – 3-6%	3%-6%	$210	$420		x			x			x			x	
Camless Valve Actuation – 5-10%	5%-10%	$280	$560			x			x			x			x
Variable Compression Ratio – 2-6%	2%-6%	$210	$490			x			x			x			x
Emerging Transmission Technology															
Automatic Shift Manual Transmission (AST/AMT) – 3-5%	3%-5%	$70	$280								x			x	
Advanced CVT's – 0-2% - Allows High Torque	0%-2%	$350	$840									x			x
Emerging Vehicle Technology															
42 Volt Electrical Systems – 1-2%	1%-2%	$70	$280			x			x	x	x	x	x	x	x
Integrated Starter/Generator – 4-7% (Idle Off – Restart)	4%-7%	$210	$350			x			x			x			x
Electric Power Steering – 1.5% -2.5%	1½%-2½%	$105	$150			x			x		x	x		x	x
Vehicle Weight Reduction – 5%= 3-4%		$210	$350												5

New Variable Cylinder Management

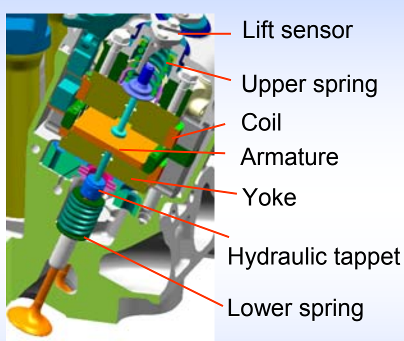


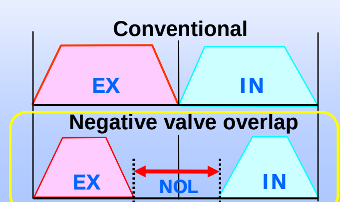
Lightweight Materials

- High strength steel
  - Over 50% of the steel in most Honda vehicles
  - Also improves safety
- Aluminum
  - Requires lots of electricity, price has been going up
- Plastic
  - Cheap, color goes below surface
  - Less rigid and must paint
- Carbon fiber
  - Very strong and light
  - Difficult to work with and expensive
- Safety is extremely important
- Must be able to manufacturer on assembly line
- Must be able to repair and recycle or reuse

Next-generation Gasoline Engines

Camless Valve Actuation

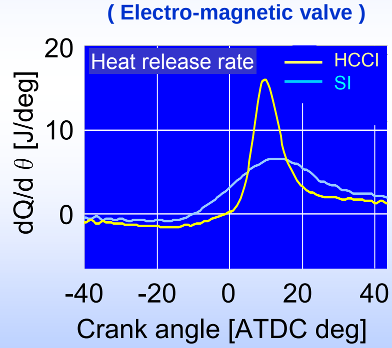




HCCI Engine

Improvement in fuel economy: **30%**

Honda Prototype Engine Base
(Electro-magnetic valve)

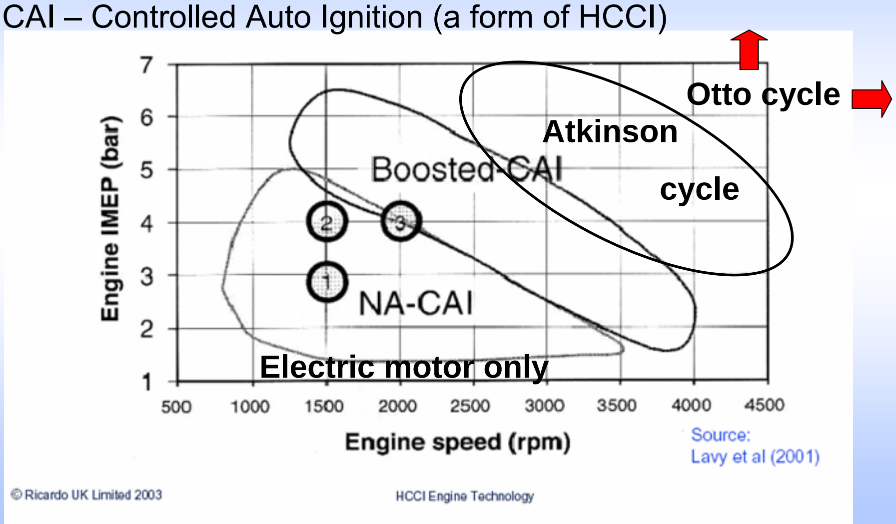


Requires increasing the self-ignition region

Potential Operating Modes

Assumes camless valve actuation and e-turbo

CAI – Controlled Auto Ignition (a form of HCCI)



Are We Looking the Wrong Way?

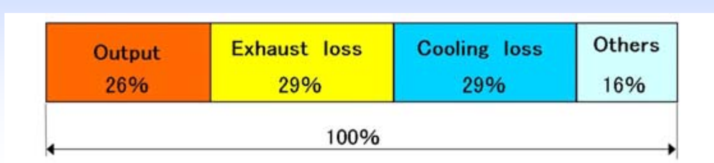
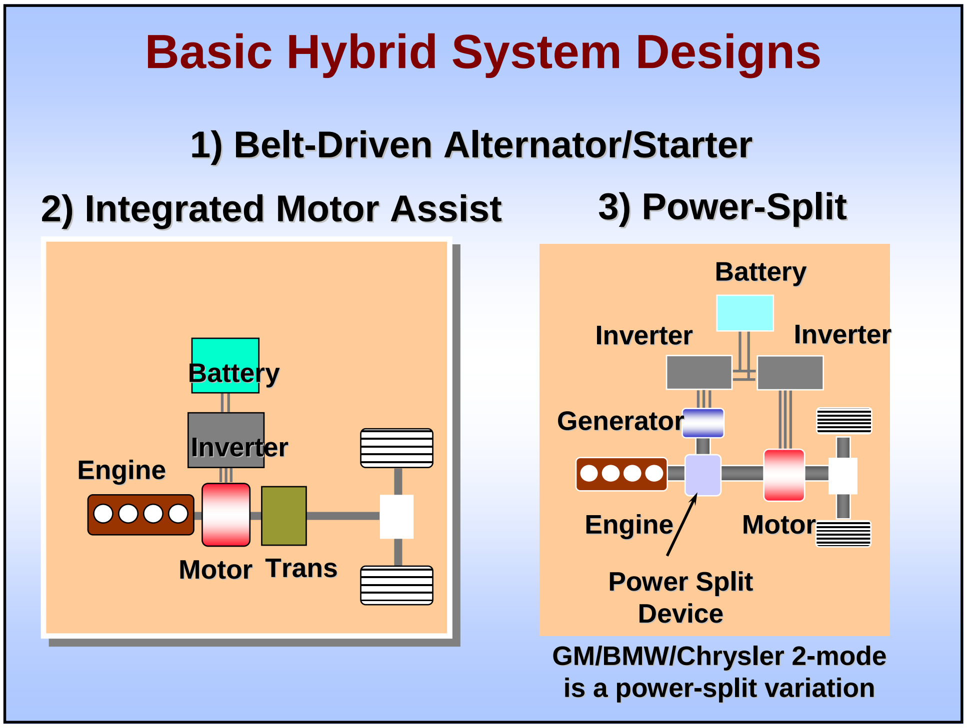
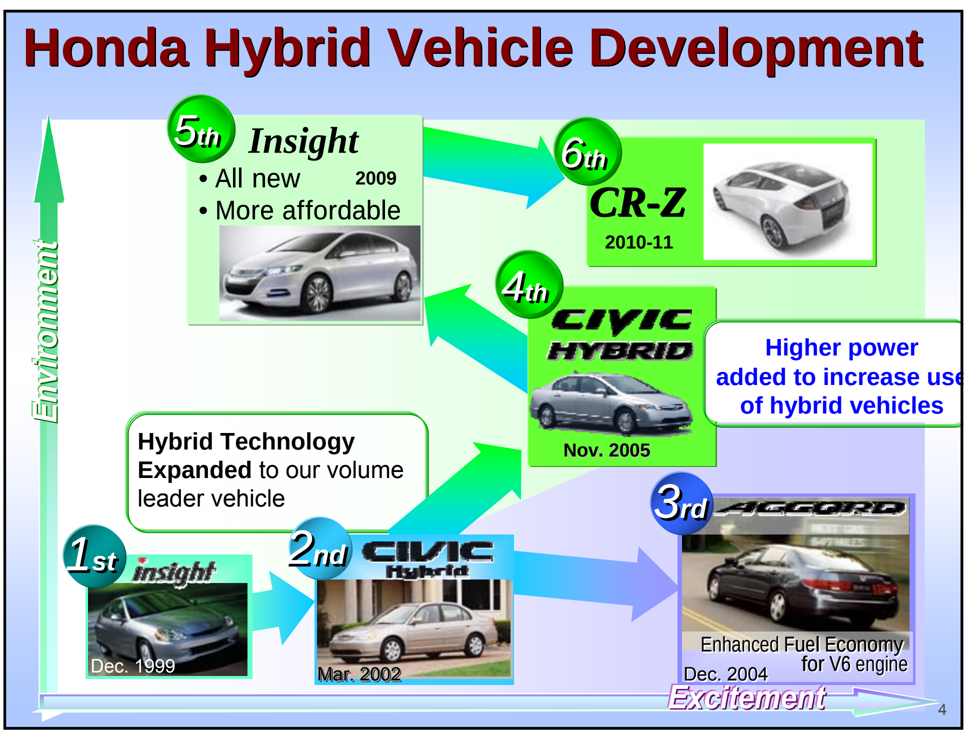


Fig. 2 Example of heat balance in a conventional engine

- Combustion work focuses on raising output efficiency over typical driving cycles
  - From roughly 20% to 35%
- **Heat losses are the 800-pound gorilla in the closet**


Basic Hybrid System Designs
1) Belt-Driven Alternator/Starter
2) Integrated Motor Assist
3) Power-Split
Battery
Inverter
Engine
Motor
Trans
Battery
Inverter
Inverter
Generator
Engine
Motor
Power Split Device
GM/BMW/Chrysler 2-mode is a power-split variation


Honda Hybrid Vehicle Development
5th Insight
• All new 2009
• More affordable
6th CR-Z
2010-11
4th CIVIC HYBRID
Nov. 2005
Higher power added to increase use of hybrid vehicles
Hybrid Technology Expanded to our volume leader vehicle
1st insight
Dec. 1999
2nd CIVIC Hybrid
Mar. 2002
3rd ACCORD
Enhanced Fuel Economy for V6 engine
Dec. 2004
Environment
Excitement
4

i-DTEC - Super Clean Diesel for US

Improved Combustion

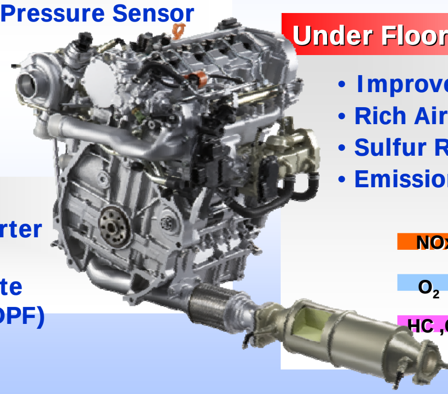
- New Combustion Chamber Design
- High Pressure Piezo Common Rail
- Compression Ratio
- Combustion Pressure Sensor

New Software

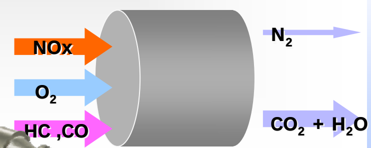
- LNC Control
- Combustion Control
- Cetane Estimation

Under Floor Lean NOx CAT System

- Improved Lean NOx Catalyser
- Rich Air / Fuel Ratio Spike Control
- Sulfur Regeneration
- Emission Stabilizing System

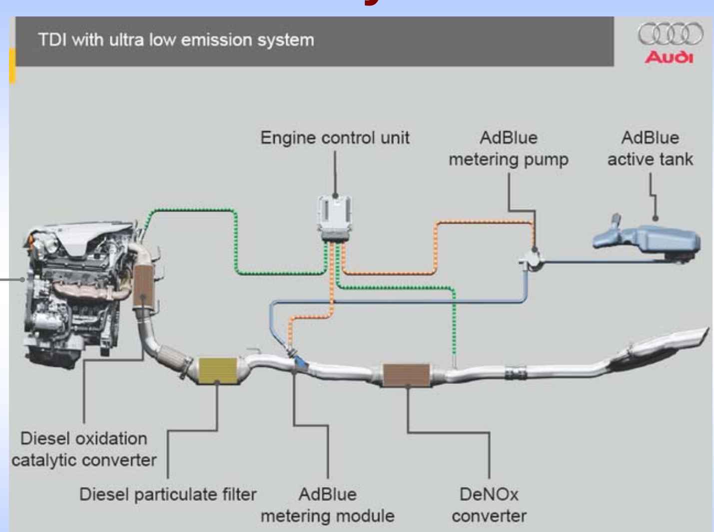


Closed-coupled Catalytic Converter
+
Diesel Particulate Filter (DPF)



Audi TechDay 2007

29,000 psi (2,000 bar) piezo injectors and combustion chamber sensors



- Heated lines and tanks (in blue)
- Passive AdBlue 15.5L tank (not shown – also heated)
- Green lines are to NOx sensors

Crystal Ball is Very Cloudy

- **Improved gasoline engines keep raising the bar**
  - Especially a problem for diesels
- Diesels: Towing, low rpm torque, highway efficiency
  - But will public recognize improvements in noise, vibration, smell, starting, and emissions?
- Hybrids: City efficiency and electrical synergies
  - But reduces space and concerns about battery life
- **Market split?**
  - **Diesels for larger vehicles and rural areas**
  - **Hybrids for smaller vehicles and urban areas**
- **Both must slash costs for mass market**
  - Diesels currently cheaper, but Tier 2 will add major costs
  - Hybrid costs will likely decrease faster in the future

laboratory
for energy
and the
environment

2007 MIT Study of Greenhouse Gas Emissions from Plug-in Hybrids, Battery EVs, and Fuel Cell EVs.

Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet

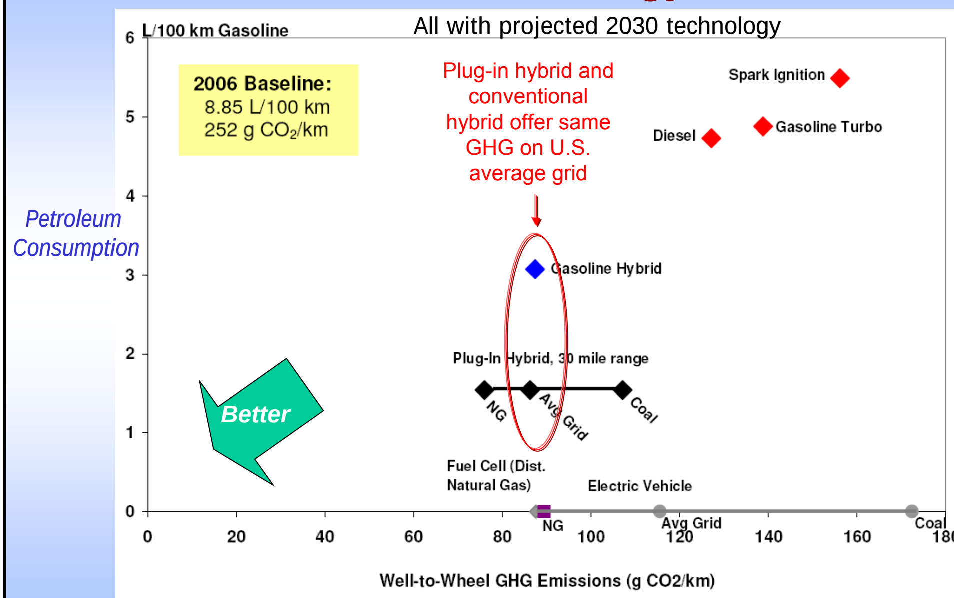
Matthew A. Kromer and John B. Heywood

May 2007
LFEE 2007-02 RP

Sloan Automotive Laboratory
Laboratory for Energy and the Environment
Massachusetts Institute of Technology
77 Massachusetts Avenue,
Cambridge, MA 02139

Publication No. LFEE 2007-02 RP

MIT's Estimate of Technology Potential



GHG

Source: 2007 MIT Study

Cost-Effectiveness Comparison

All compared to 2030 NA-SI baseline

Base Case: Estimated OEM battery cost from Tables 16 and 26

	Units	HEV	PHEV-10	PHEV-30	PHEV-60
Battery Size	kWh	1.0	3.2	8.2	16.5
Specific Cost	$/kWh	$900	$420	$320	$270
Battery Cost	$	$900	$1,450	$2,700	$4,500

Optimistic Case based on a $200/kWh battery

Table 28: Comparative cost-effectiveness of different PHEV configurations, as compared to the HEV and NA-SI. Results are based on a vehicle lifetime of 150,000 miles. Parentheses indicate the incremental cost for the optimistic cost projection. A comprehensive list of assumptions is detailed in Table 51.

	Incremental Cost	Fuel Used (L)	$/L Saved, Compared to NA-SI		$/L Saved, Compared to HEV	
			Base Case	Optimistic	Base Case	Optimistic
NA-SI	-	13,200	--	--	--	--
HEV	$1,900 *($1,700)*	7,500	$0.33	$0.30	--	--
PHEV-10	$3,000 *($2,700)*	5,800	$0.39	$0.35	$0.57	$0.52
PHEV-30	$4,300 *($3,800)*	3,900	$0.45	$0.40	$0.64	$0.56
PHEV-60	$6,100 *($5,200)*	2,600	$0.58	$0.49	$0.87	$0.73

Source: 2007 MIT Study

The Liquid Fuel Advantage

ENERGY FUTURE: Think Efficiency
American Physical Society, Sept. 2008, Chapter 2, Table 1

	Energy density per volume		Energy density per weight	
	kWh/liter	vs gasoline	KWh/kg	vs gasoline
Gasoline	9.7		13.2	
Diesel fuel	10.7	110%	12.7	96%
Ethanol	6.4	66%	7.9	60%
Hydrogen at 10,000 psi	1.3	13%	39	295%
Liquid hydrogen	2.6	27%	39	295%
NiMH battery	0.1-0.3	2.1%	0.1	0.8%
Lithium-ion battery (present time)	0.2	2.1%	0.14	1.1%
Lithium-ion battery (future)			0.28 ?	2.1%

Future Hybrid Potential

- Must compare to ***future*** gasoline engines
  - Gasoline engines will improve dramatically
- Watch direction of battery development
  - HEVs need higher power batteries
    - Current batteries have 2 to 3 times excess energy storage, to ensure adequate power and durability
  - PHEVs need higher energy batteries
- **High power Li-ion batteries currently in development will decrease HEV costs – increasing PHEV cost premium**

Plug-In Hybrid Future

Challenges

- Battery durability will be shorter
  - Deep discharge cycles
  - Higher loads at lower SOC
- Battery pack uses ~ 4 cu. ft.
  - Reduced vehicle utility
- Battery pack adds 200-250 lbs
  - Lower FE and performance
- Requires safe off-board charging system operation
  - Limits market
  - May affect resale value
- **Cost**
  - Larger motor and power electronics
  - **Battery**

Market Acceptance

- **Niche market is coming**
- **Energy storage breakthrough or oil shortages needed for mass market acceptance**

The Real Barrier - Leadtime

- Ironically, there are too many technologies coming
  - Each with unknown future cost, potential, and synergies
- Must allow time to ensure quality and reliability
  - Rigorous product development process – 2-3 years after feasibility has been demonstrated
  - Prove in production with a small pilot program – 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
- Longer leadtime is needed for new technologies
- Costs increase dramatically if normal development cycles are not followed
  - Greatly increases development costs, tooling costs, and the risk of mistakes

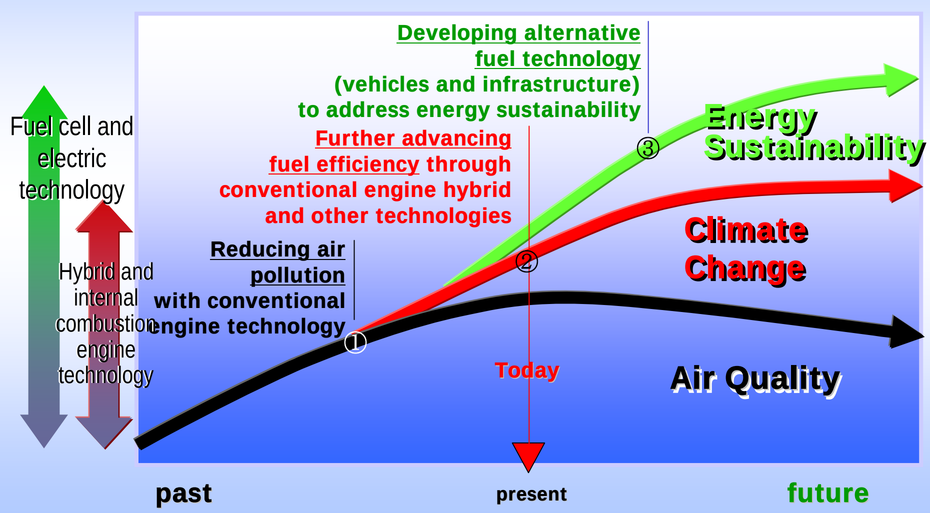
Technology du jour

- 25 years ago – Methanol
- 15 years ago – Electric vehicles
- 10 years ago – Hybrid/electric vehicles
- 5 years ago – Fuel cell vehicles
- 2 years ago – Ethanol
- Today – Plug-in hybrid vehicles
- 2011 – What's next?

Extremely disruptive and wasteful

Significance of Fuel Cell and Electric Vehicles

Fuel cell and electric vehicle technology have the potential to concurrently help solve the problems of air pollution, global warming, and limited energy resources

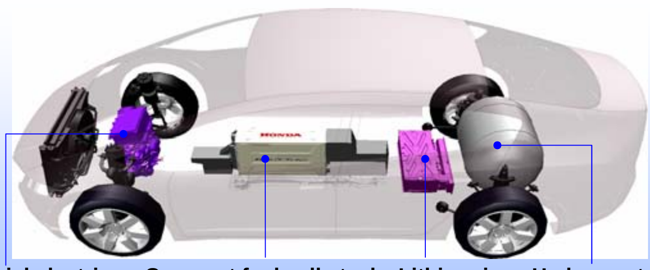


New Achievement for Fuel Cell Vehicles

FCX CLARITY

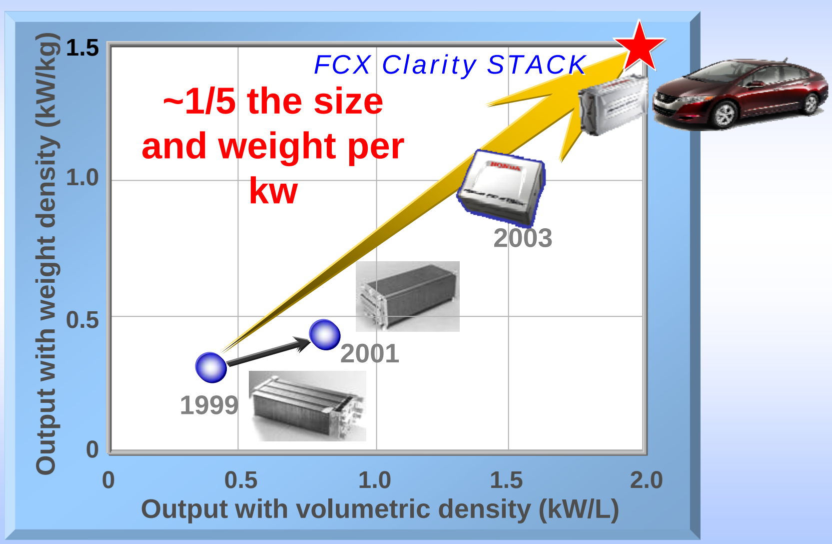
Maximum speed	100 mph	Motor Output	100 kW
Driving Range	280 miles	Motor Torque	256 Nm
Fuel Cell Stack Output	100 kW	Hydrogen Storage & Pressure	≈ 4kg 5000psi
Energy Storage	Lithium-ion battery	Refueling Time	3 – 5 minutes

Limited marketing: Summer 2008 U.S. (CA) and Japan



Fuel Cell Performance

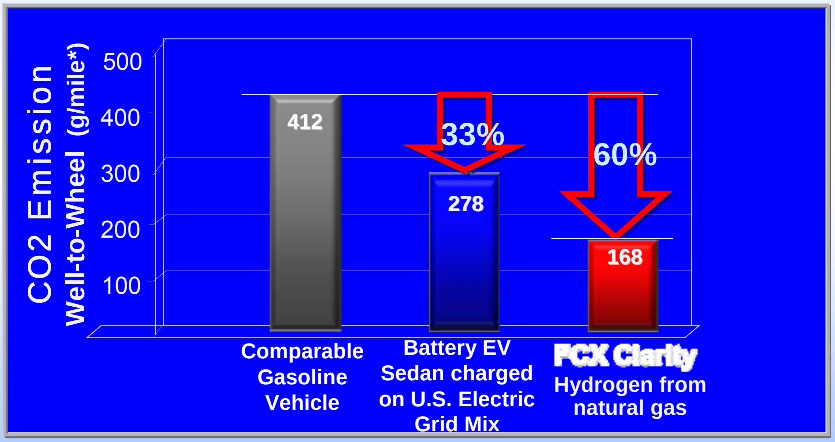
Rapid advances in size & weight reduction



Greenhouse Gas Reductions

- ***Well-to-wheel CO2 emissions -***

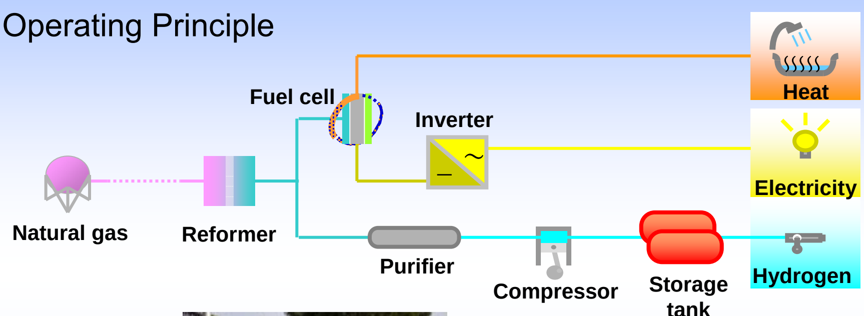
Battery EV & Fuel Cell EV show GHG reductions based on <u>today's</u> U.S. energy sourcing



Source: DOE's GREET model (Argonne/U Chicago), EPA unadjusted f.e. values
(Clarity f.e. estimated by Honda R&D, BEV using 3.5 EER)

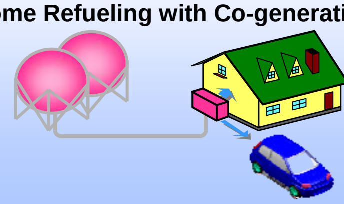
New Value from Fuel Cell Infrastructure

Operating Principle



- Home Energy Station, 4th-generation
- Cooperative Development with Plug Power

Reformed Gas
Home Refueling with Co-generation



Electricity versus Hydrogen

- Both are energy carriers – can be dirty or clean, depending on how created
- Neither will replace gasoline internal combustion for a long time

	Advantages	Needed improvements
Electricity	• Existing infrastructure ??? • Battery charge/discharge losses lower than fuel cell losses	• Driving range – energy storage breakthrough • Lower carbon grid • Safe place to plug in • Charge time 15 min = 440v x 1,000 amp
Hydrogen	• 90% of energy from air • Remote generation (wind, geothermal, waves, solar) • Cogeneration – heat and electricity for home, fuel for car	• Breakthrough in hydrogen storage and delivery • Better ways to create hydrogen • New infrastructure

Future Directions

- Future gasoline engine improvements will raise the bar for other technologies and will extend the fossil fuel era
- Government needs to set *performance* objectives and requirements
- Need advanced batteries and H storage
  - New high-power Li-ion chemistries will increase cost gap between HEVs and PHEVs

No silver bullet

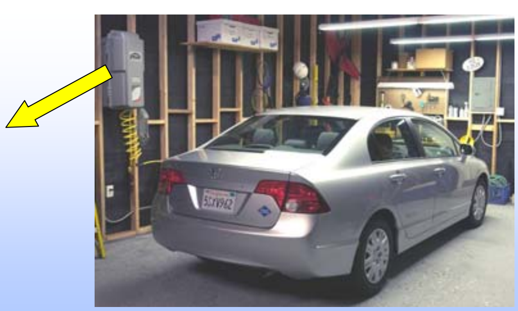
- Energy and GHG so immense we must do everything – avoid trap of single solutions

Future Fuels

Home Refueling of a CNG Vehicle

- Critical bridge to fuel cells and hydrogen (refueling infrastructure and transitional fuel)
- Near zero emissions; AT-PZEV
- GHG reductions
- Fuel cost just 60% the cost of gasoline using Phill, the home refueling appliance

Phill™



Honda Civic GX

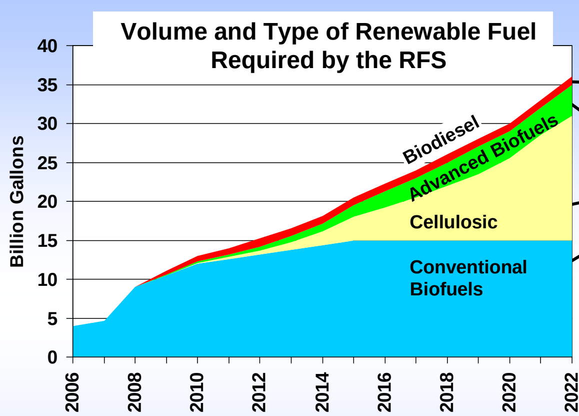
Honda's View on Biofuels

Honda is very supportive of biomass fuel development, and is actively involved in R&D efforts regarding the production and use of biofuels and other bio-products.

Honda believes an "ideal" biofuel…

1. **Has a true positive impact upon GHG reduction and energy security, as determined by complete and objective life cycle analyses.**
2. **Does not harm the environment through secondary effects, such as biodiversity loss.**
3. **Does not impact the price and availability of food supplies, directly or indirectly.**
4. **Has a pathway for sustained growth in the market.**
5. **Is compatible with all current and legacy vehicles, small engines, etc.**
6. **Is transparent to the consumer in terms of performance, price, and availability.**
7. **Can be transported using the existing pipeline infrastructure.**

New RFS Requirements



Examples	GHG Target
• FAME	- 50%
• All other non-corn ethanol • Renewable diesel • Butanol	- 50%
• Cellulosic ethanol	- 60%
• Corn ethanol	- 20%*

* future facilities only

- Big wager on ethanol.
- Waivers are possible, i.e.:
  - Target volume for cellulosic ethanol can be reduced if required volume is not available. In that case…
  - Target volume for renewable fuel and advanced biofuels can be reduced concurrently

What Can We Do with all of that Ethanol?

Assuming ≈ 30B gallons….

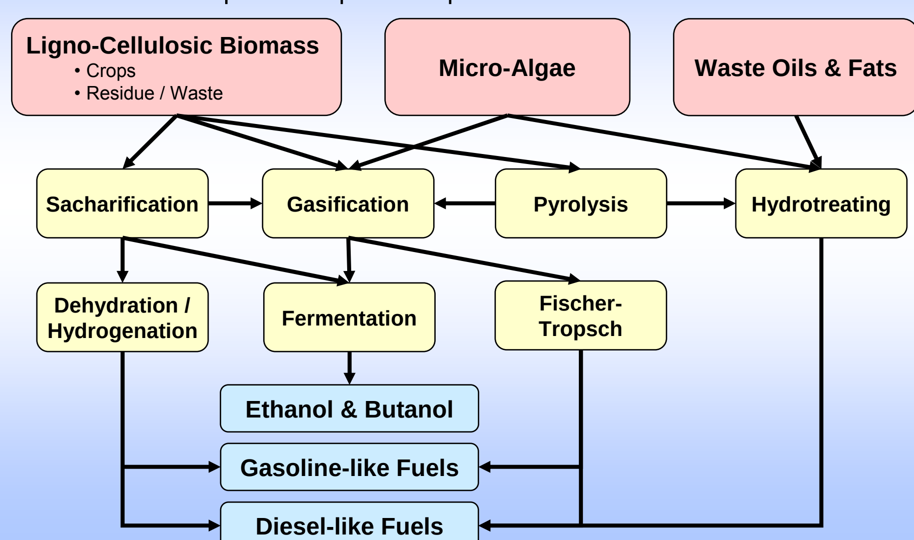
Ethanol Blend		Challenges
E10 nationwide	30B gal	• Acceptance by all states
E11 → E20 intermediate blends	30B gal E20	• Need to confirm compatibility with current and legacy autos, motorcycles, small engines, etc. • Depending on compatibility findings, E10 might need to coexist with an intermediate blend for some period of time.
E85 (FFVs)	30B gal	• Consumer acceptance of a 26% to 36% drop in fuel economy* and range, in the absence of significantly lower E85 prices. • Very limited availability outside of the corn belt states; < 5 public stations in California. • Cellulosic ethanol and new infrastructure needed before significant market penetration is feasible.

* EPA 2008 Fuel Economy Guide

Honda Civic FFV for Brazil market (E20 → E100)
- High consumer demand driven by substantial ethanol cost advantage.
- E100 is widely available.
- Brazil ethanol has small GHG footprint, compared to US corn ethanol.

Next-Generation Biofuel Pathways

- Multiple pathways possible from non-food biomass.
- Many pathways result in fuels that are fungible with today's fuels.
- Some examples for liquid transportation fuels are shown here.



Honda – RITE Cellulosic Ethanol R&D

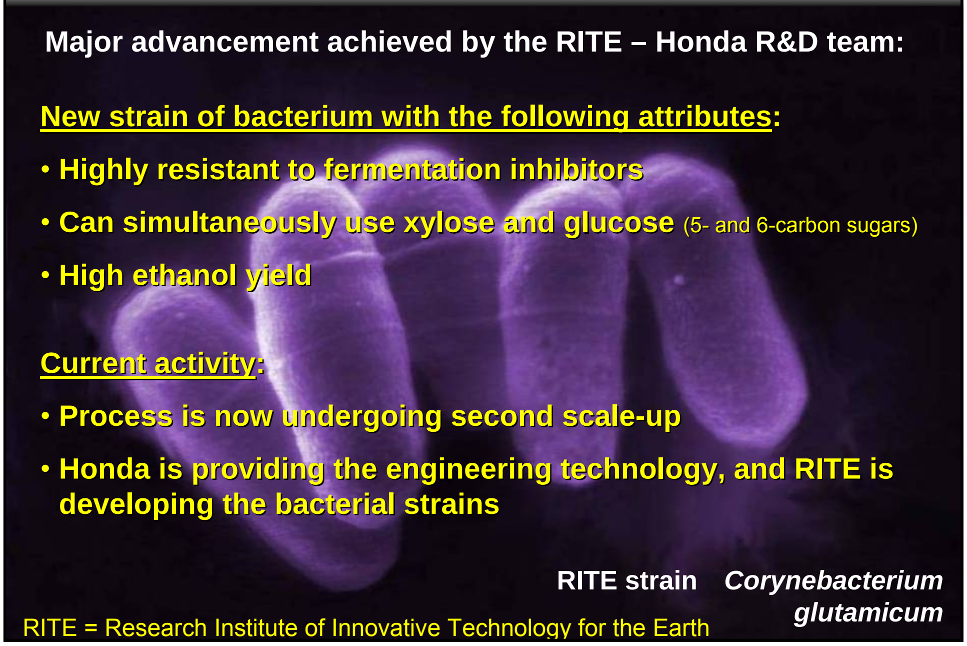
Major advancement achieved by the RITE – Honda R&D team:

New strain of bacterium with the following attributes:

- **Highly resistant to fermentation inhibitors**
- **Can simultaneously use xylose and glucose** (5- and 6-carbon sugars)
- **High ethanol yield**

Current activity:

- **Process is now undergoing second scale-up**
- **Honda is providing the engineering technology, and RITE is developing the bacterial strains**

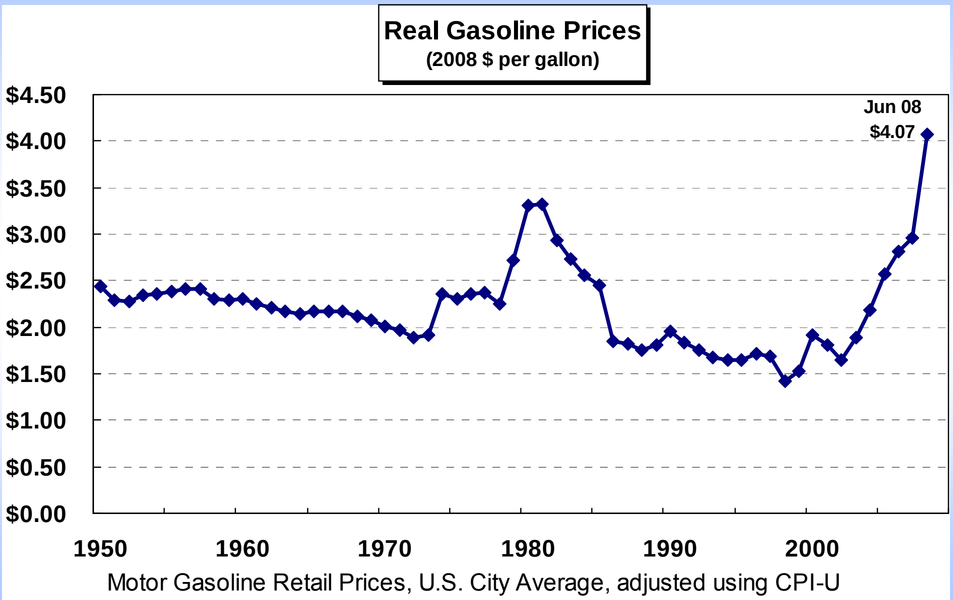


RITE strain ***Corynebacterium glutamicum***

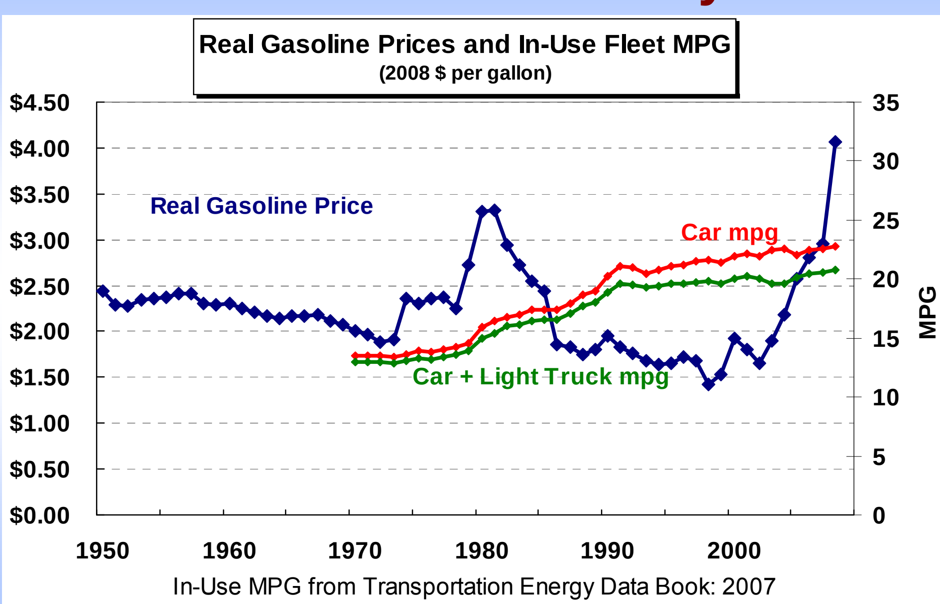
RITE = Research Institute of Innovative Technology for the Earth

Impact on travel and land development

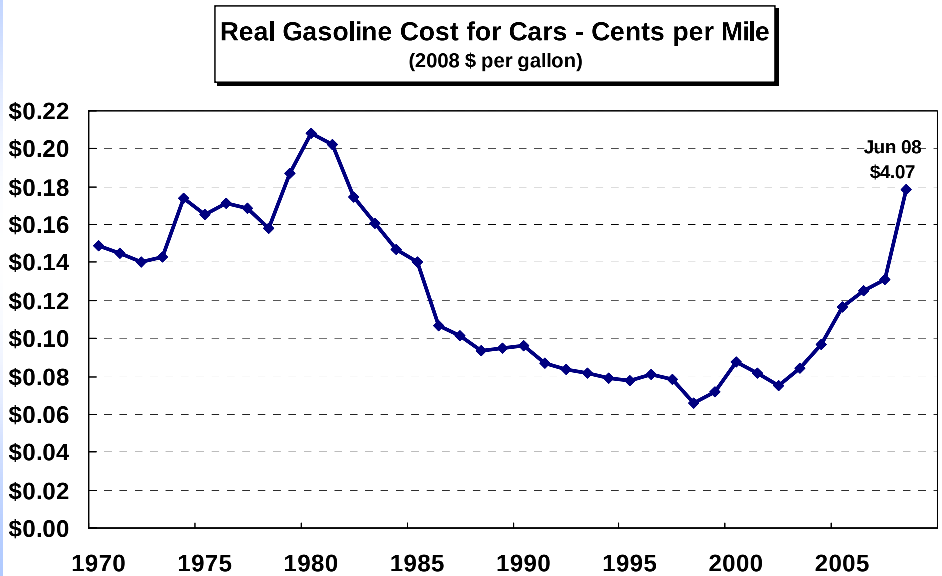
Real Gasoline Price



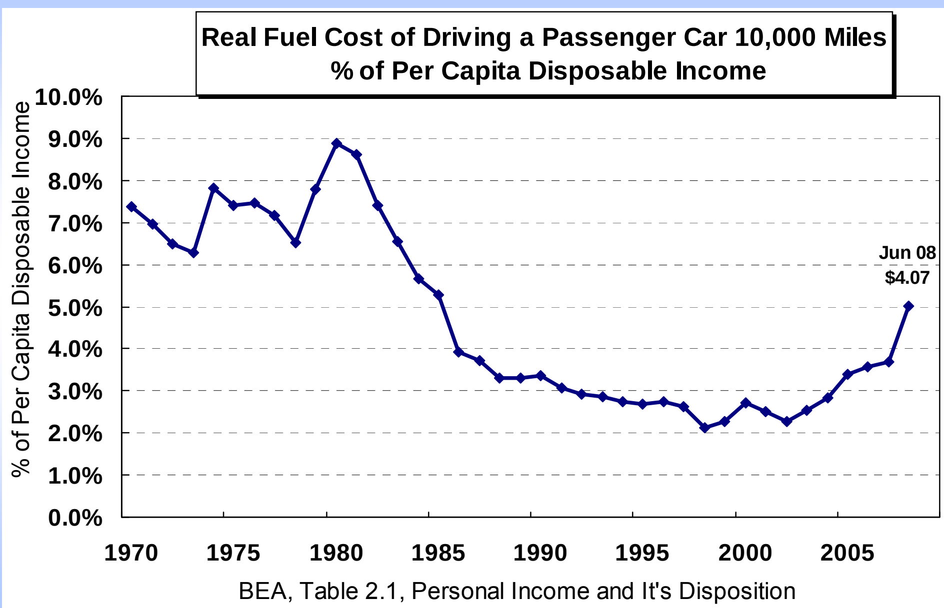
Fleet Fuel Economy



Gasoline Cost per Mile



Real Fuel Cost - % of Disposable Income



$6 per gallon in 2030 – Cost per Mile