Advanced Technology Vehicles: Overview and Constraints

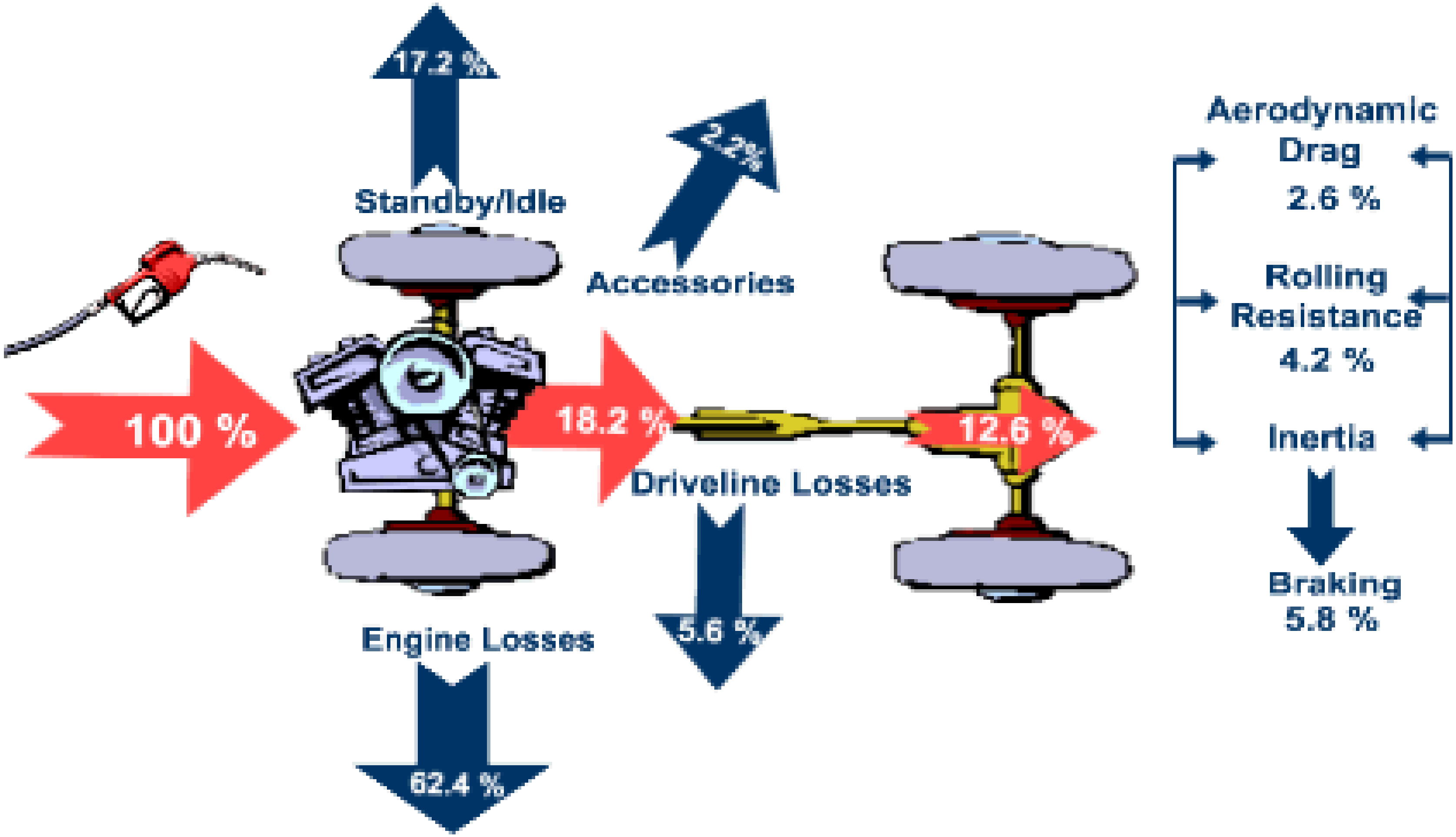
John German, ICCT

EIA Energy Conference

April 26, 2011

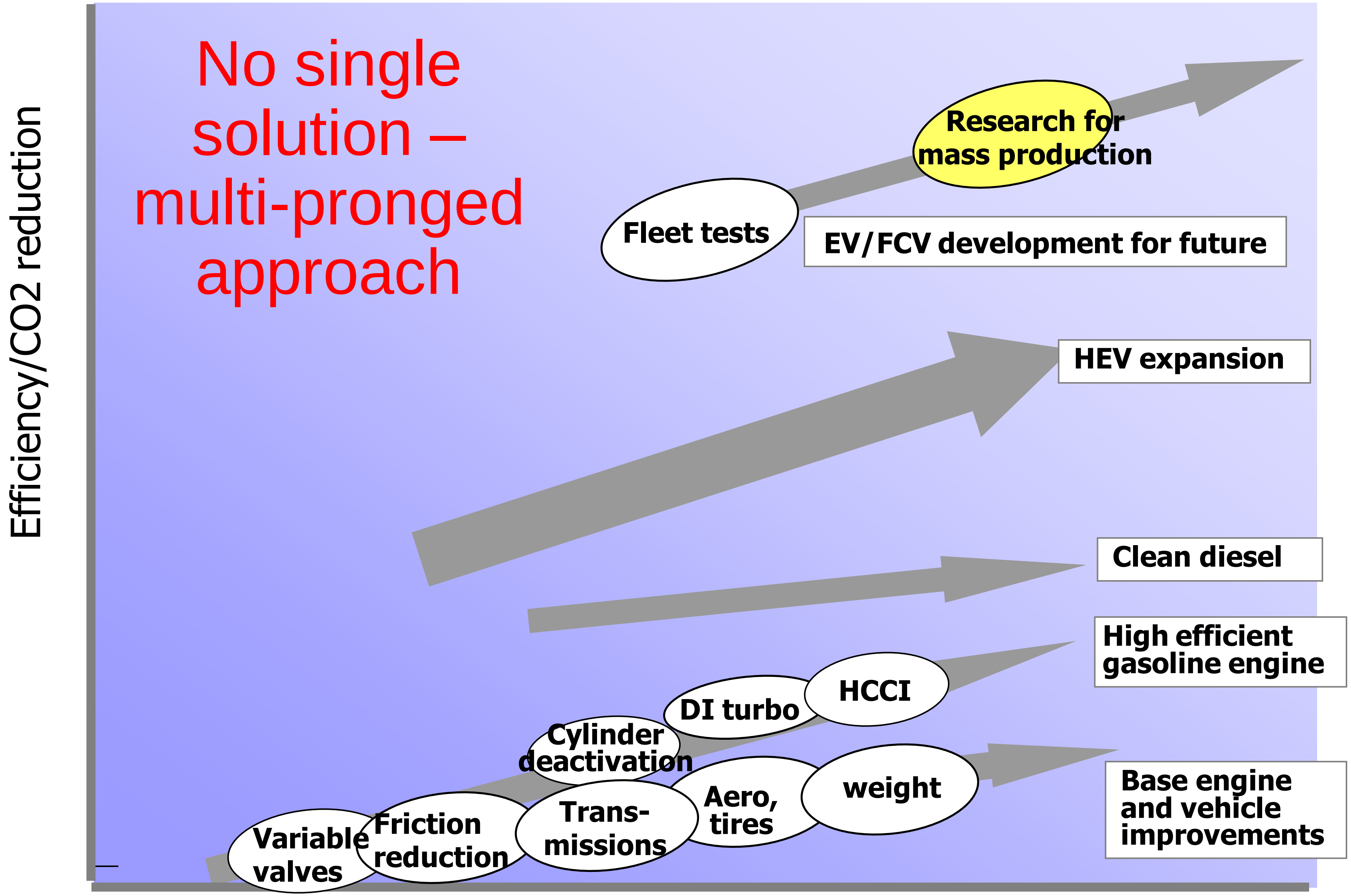
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Where Does the Energy Go?



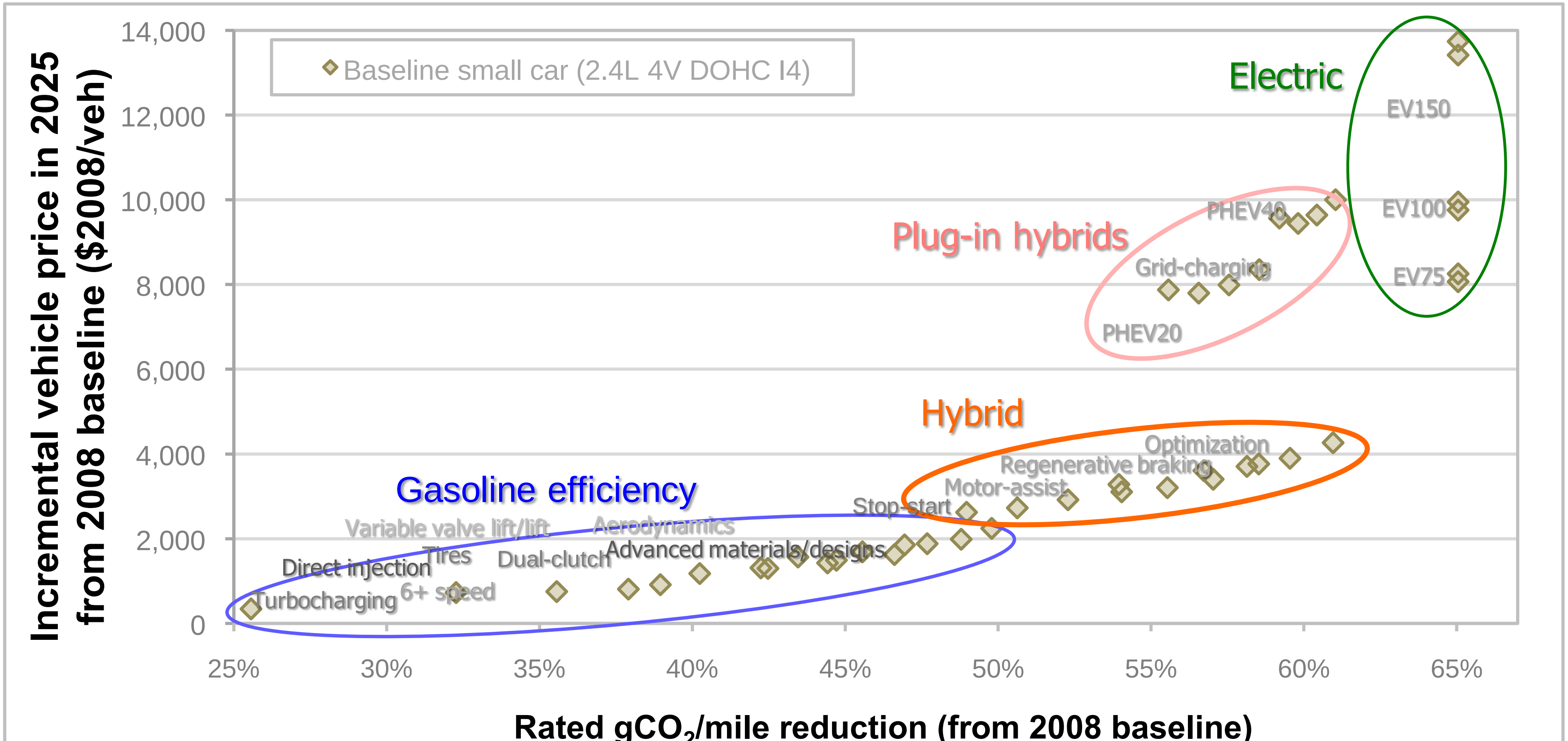
http://www.fueleconomy.gov/FEG/atv.shtml

Efficiency/CO2 Reduction Strategies



Joint-Agency TAR: Technology Packages

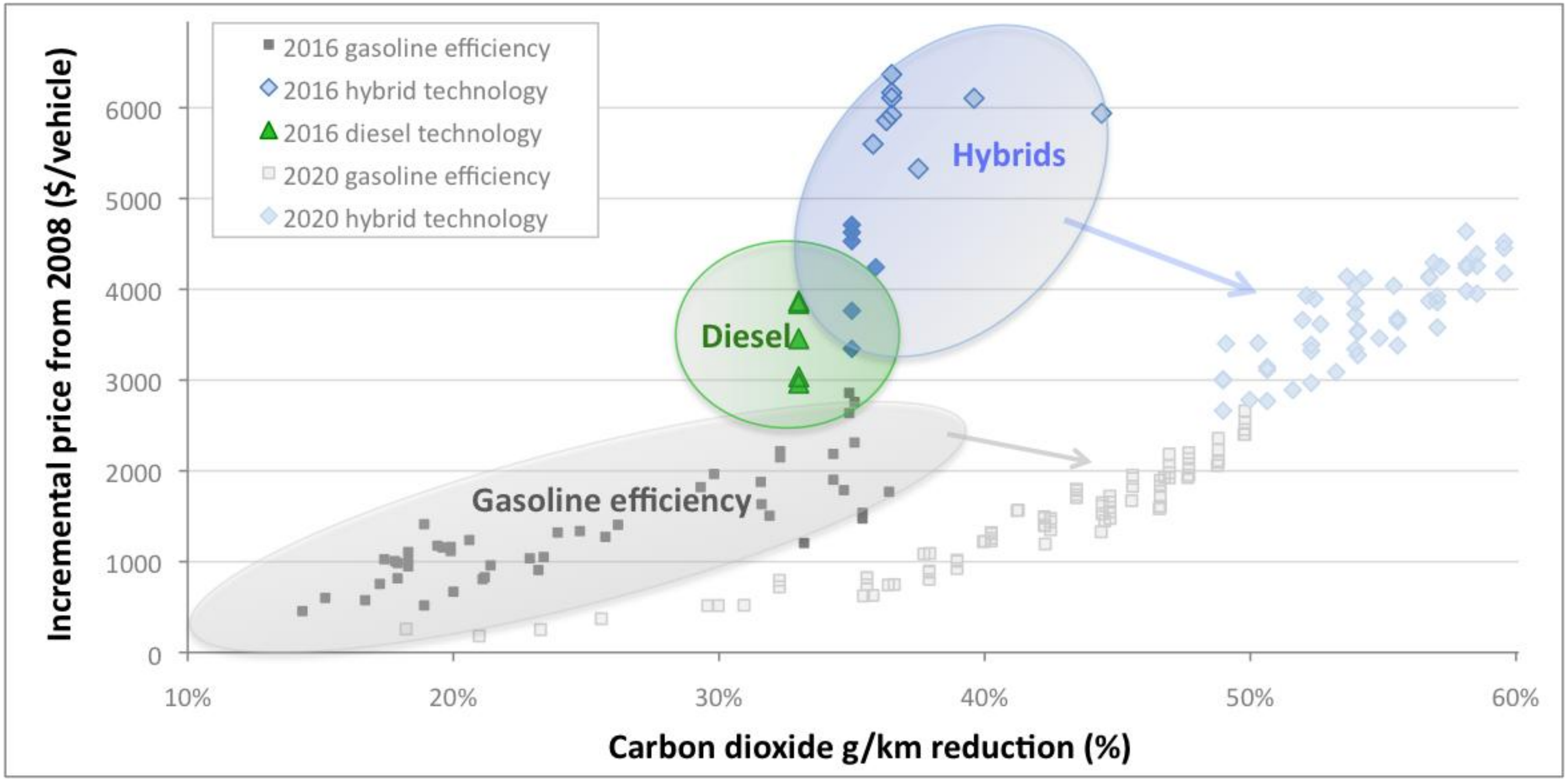
- Major CO_2-reduction potential from emerging technologies by 2025
  - US EPA's OMEGA used many technology packages, 19 vehicle classes to evaluate scenarios
  - Increasing costs from incremental efficiency, to hybrid, and to electric technology



Price in figure refers to the incremental cost to the consumer due to the new technology packages; technology packages include many different technologies; technology labels are approximate for illustration; grid electricity applies US EPA assumptions and accounting method for US electric grid (558 gCO_2e/kWh) for electric and plug-in hybrids

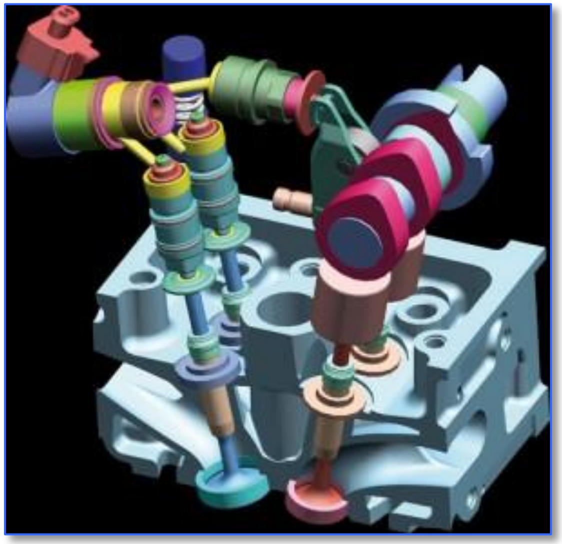
Technology costs: Near- vs. Long-term

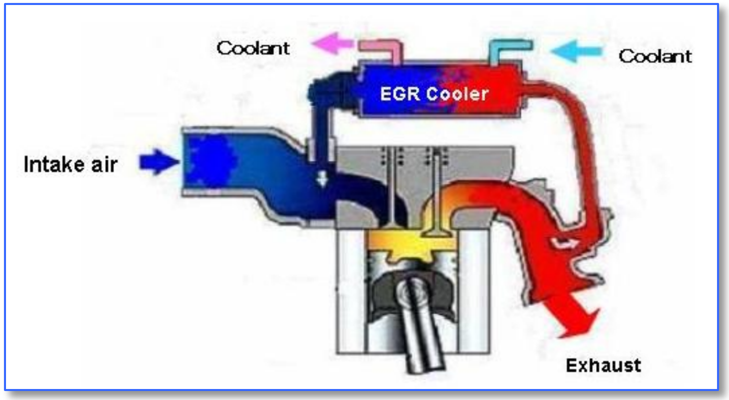
- Technology availability increases - and its costs decrease - over time
  - Incremental vehicle costs and percent improvements are in reference to MY2008 baseline
  - Data from US EPA/NHTSA 2012-2016 rulemaking and EPA/NHTSA/CARB *TAR* for 2020



Next-generation Gasoline Engines

Fiat MultiAir
Digital Valve Actuation



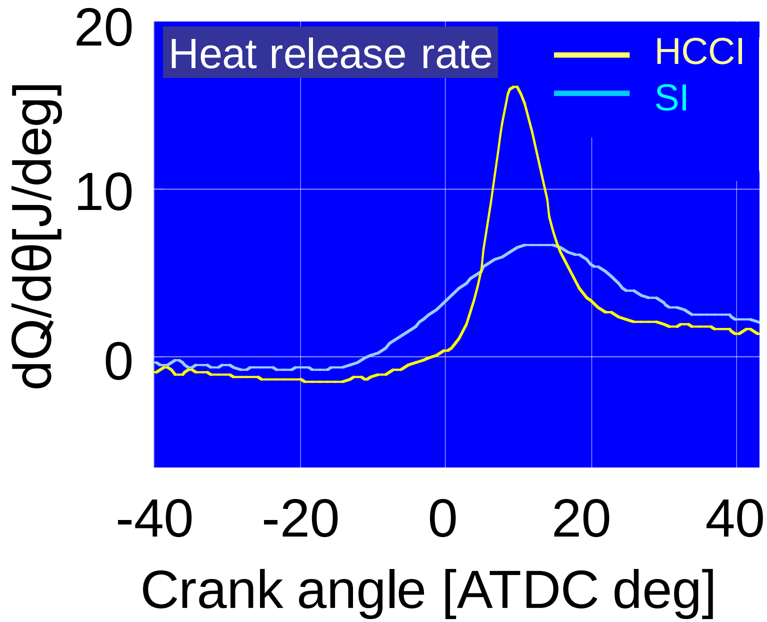


Dual-loop high/low pressure cooled exhaust gas recirculation

HCCI Engine

Improvement in fuel economy: 30%

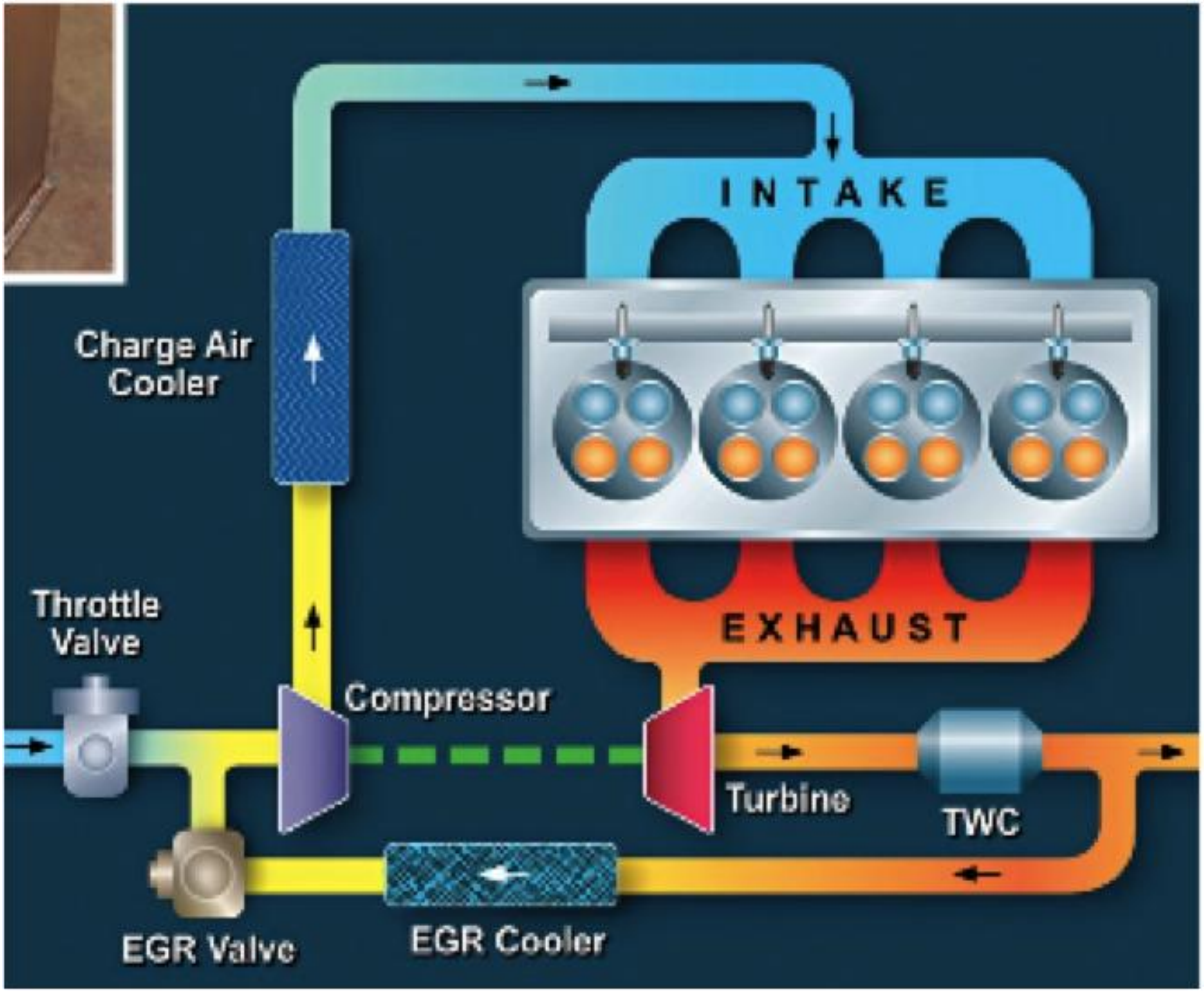
Honda Prototype Engine Base
(Electro-magnetic valve)



Requires increasing the self-ignition region

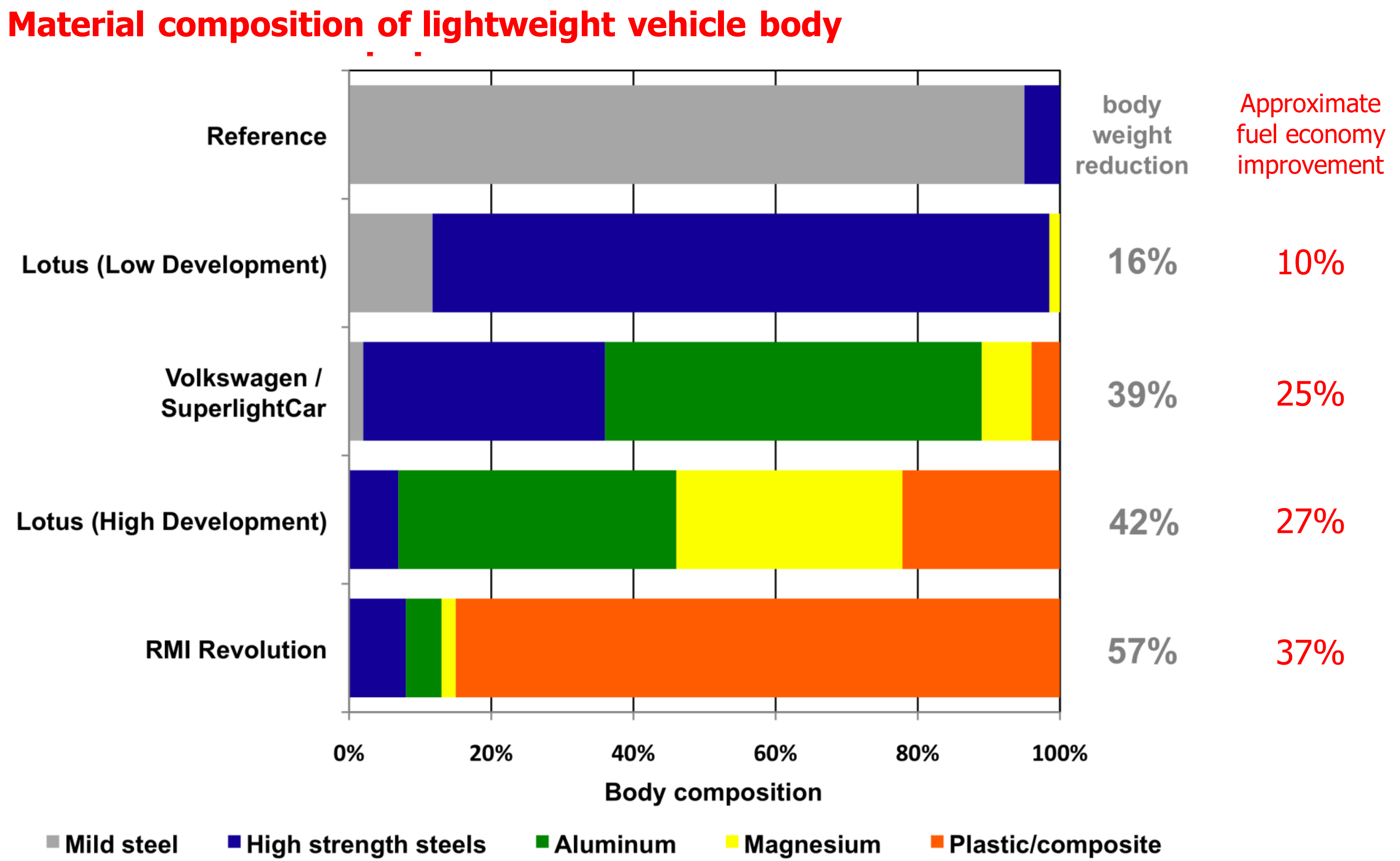
Turbo-Boosted EGR Engines

- Highly dilute combustion – considerable efficiency improvement
- Advanced ignition systems required



Terry Alger, Southwest Research Institute, “Clean and Cool”, Technology Today, Summer 2010

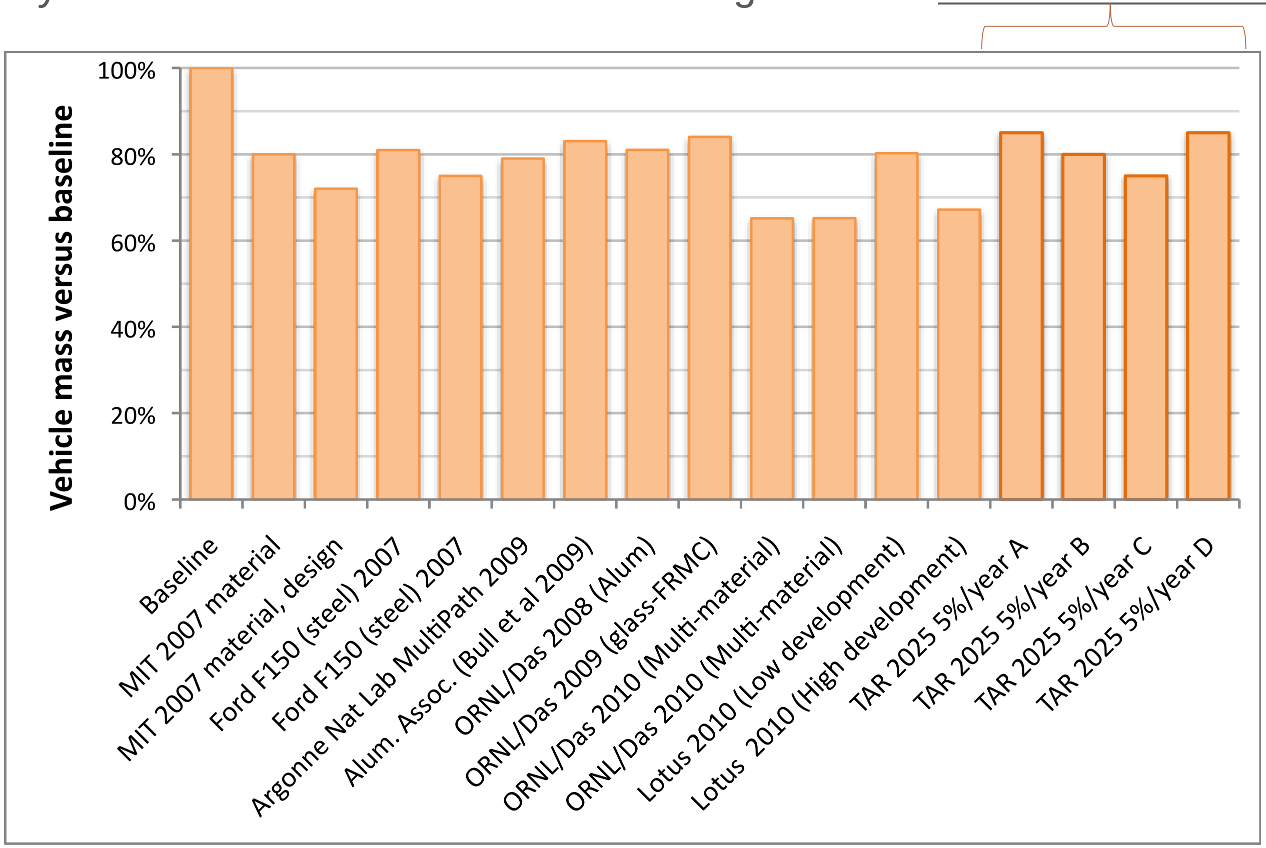
Lightweight materials offer great potential



Also incremental improvements in aerodynamics and tire rolling resistance

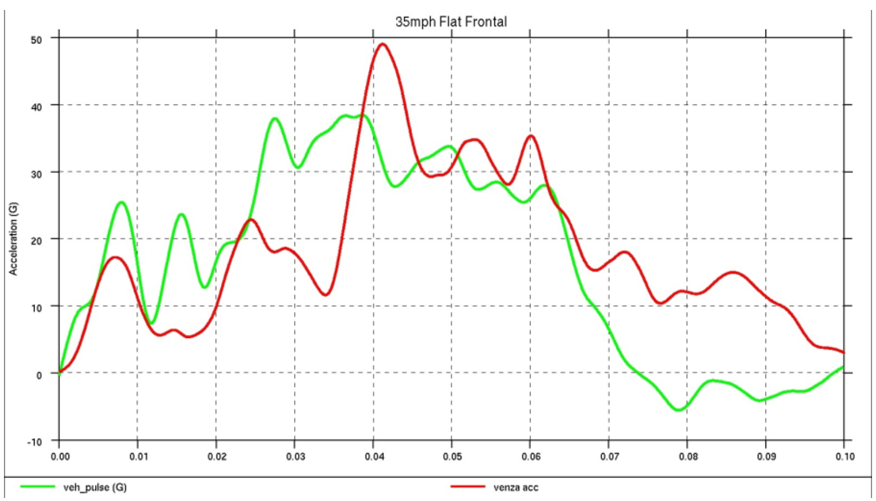
US Joint-Agency TAR: Mass Reduction

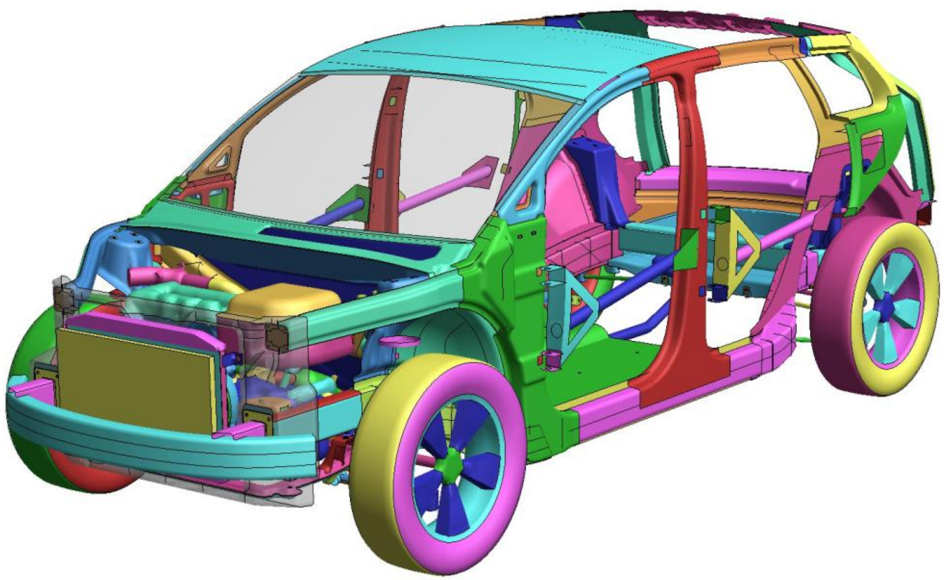
- In 2020-2025 timeframe, mass-reduction will be a core technology
  - Looked at many studies (e.g., US DOE, Sierra Research, MIT, Lotus)
  - Mass reduction typically deployed before hybrid; with increasing cost
  - Various technical studies suggest feasible levels of mass reduction of 20-35%
    - Every *TAR* scenario for 2025 found average vehicle *mass reduction of 14-26%*



Post-TAR: Ongoing Work

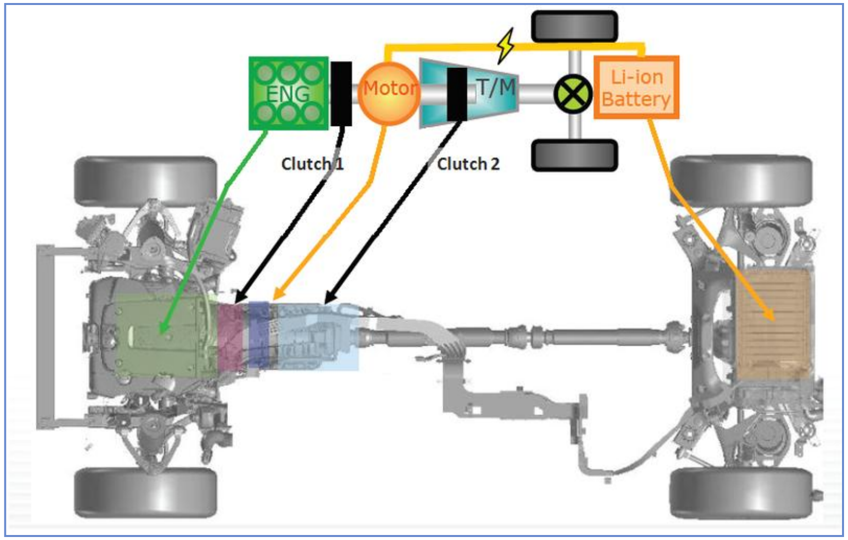
- Lotus/FEV mass-reduction crash simulation work
  - CARB/EPA/NHTSA collaboration
  - Computer-Aided Engineering (CAE)
  - Simulate vehicle in front, side, offset crashes
  - Lotus: Validate crashworthiness of 30%+ mass-reduced vehicle (high development case)
  - FEV: Validate crashworthiness of HSS vehicle (low development case)
  - Completion in winter/spring 2011
- FEV also updating cost assessments



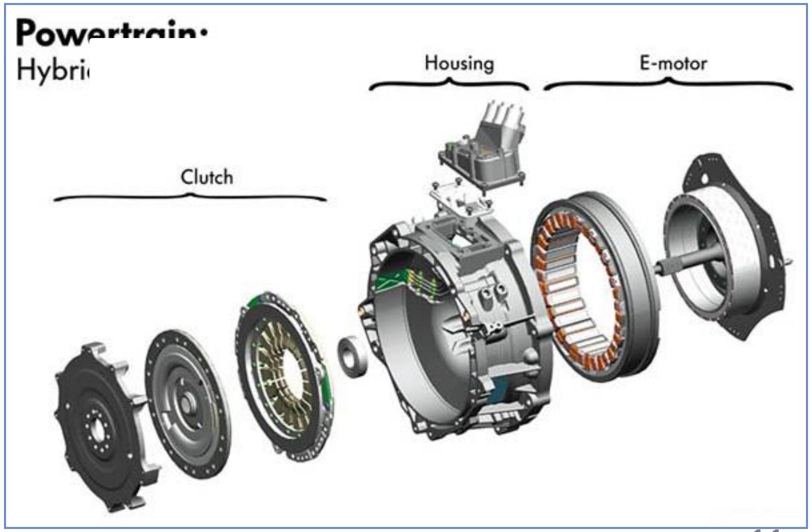


Hybrid Technology Advances

- Synergies with other technologies and optimized control strategies
  - Engine (Atkinson, Miller, lean-cruise, digital valve); optimization of engine and transmission operation; mass-reduction; dual-clutch transmission
- New P2 hybrid – single motor with two clutches
  - Pre-transmission clutch: engine decoupling and larger motor
  - Nissan, VW, Hyundai, BMW, and Mercedes
  - Approximately 1/3 lower cost than input powersplit with 90-95% of benefits
- High-power Li-ion batteries – smaller, lighter, and lower cost



Nissan Fuga/M35 parallel hybrid layout

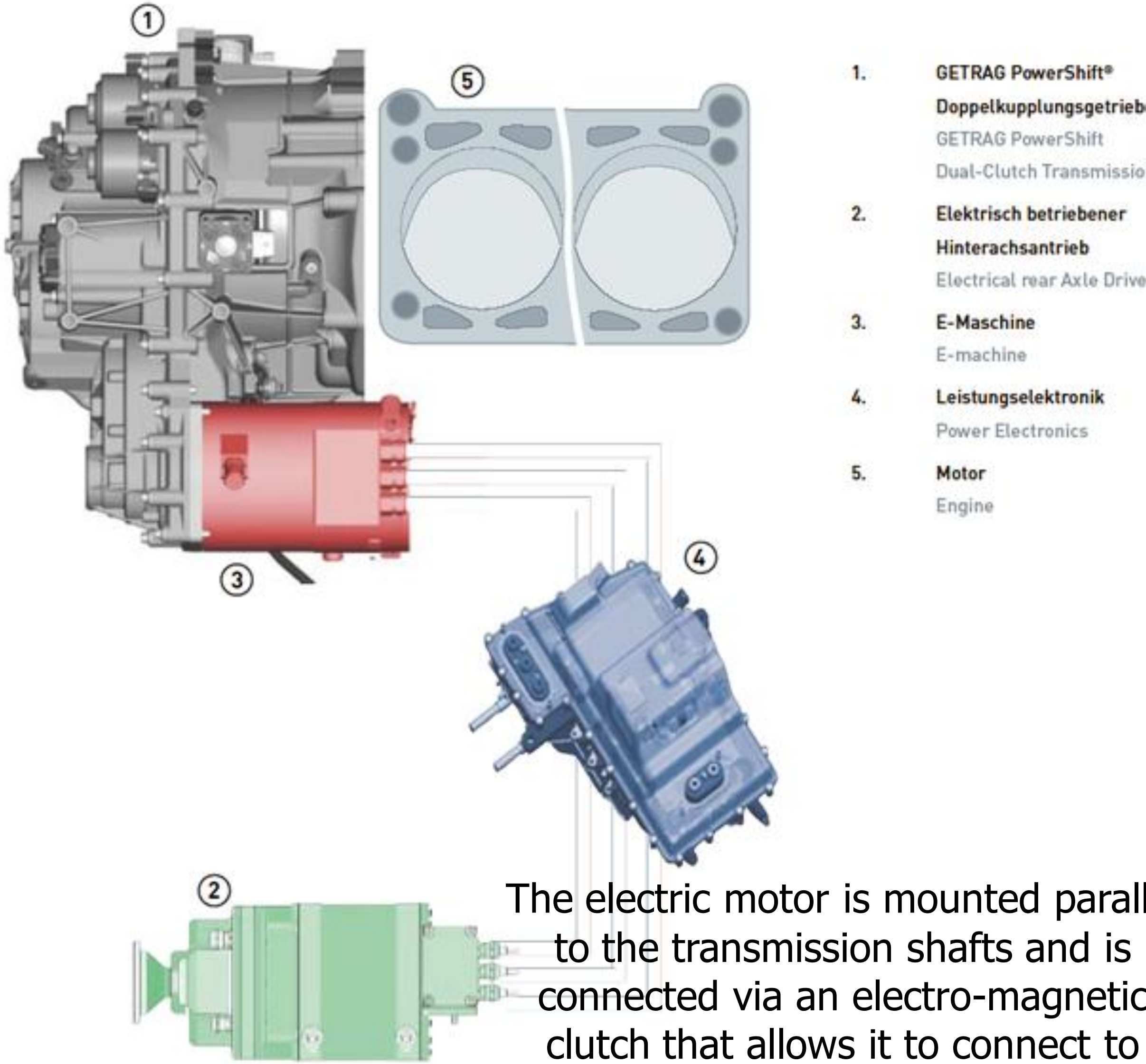


VW Touareg hybrid module

Synergies Between Parallel Hybrid and DCT

DCT: Dual-clutch automated manual

Problem	Solution
DCT has problems launching the vehicle	Launch vehicle using high torque from electric motor
Limited space for electric motor between engine and transmission	Mount motor on the rear of the DCT



The electric motor is mounted parallel to the transmission shafts and is connected via an electro-magnetic clutch that allows it to connect to either of the two gear sets.

EPA/NHTSA 2025 Technology Assessments

Scenario: 2025 Levels	Technology Path Focus	Mass Reduction	HEV Penetration	PHEV Penetration	EV Penetration	Preliminary Per-Vehicle Cost Estimates ($)	Monetary estimate of lifetime fuel saving ($)	Payback Period (years)
3%/year 47 mpg 190 gCO_2/mi	HEV	15%	11%	0%	0%	$930	$5,930	1.6
	All	18%	3%	0%	0%	$850	$5,950	1.5
	ICE & lightweight	18%	3%	0%	0%	$770	$5,970	1.4
	PHEV/EV/HEV	15%	25%	0%	0%	$1,050	$5,950	1.9
4%/year 51 mpg 173 gCO_2/mi	HEV	15%	34%	0%	0%	$1,700	$7,600	2.5
	All	20%	18%	0%	0%	$1,500	$7,500	2.2
	ICE & lightweight	25%	3%	0%	0%	$1,400	$7,600	1.9
	PHEV/EV/HEV	15%	41%	0%	4%	$1,900	$7,200	2.9
5%/year 56 mpg 158 gCO_2/mi	HEV	15%	65%	0%	1%	$2,500	$9,000	3.1
	All	20%	43%	0%	1%	$2,300	$9,000	2.8
	ICE & lightweight	25%	25%	0%	0%	$2,100	$9,100	2.5
	PHEV/EV/HEV	15%	49%	0%	10%	$2,600	$8,100	3.6
6%/year 62 mpg 143 gCO_2/mi	HEV	14%	68%	2%	7%	$3,500	$9,700	4.1
	All	19%	43%	2%	7%	$3,200	$9,800	3.7
	ICE & lightweight	26%	44%	0%	4%	$2,800	$10,200	3.1
	PHEV/EV/HEV	14%	55%	2%	14%	$3,400	$9,100	4.2

EPA/NHTSA Joint NOI Regarding Light-duty Vehicle Standards for the 2017-2025 Model Years

Are We Looking the Wrong Way?

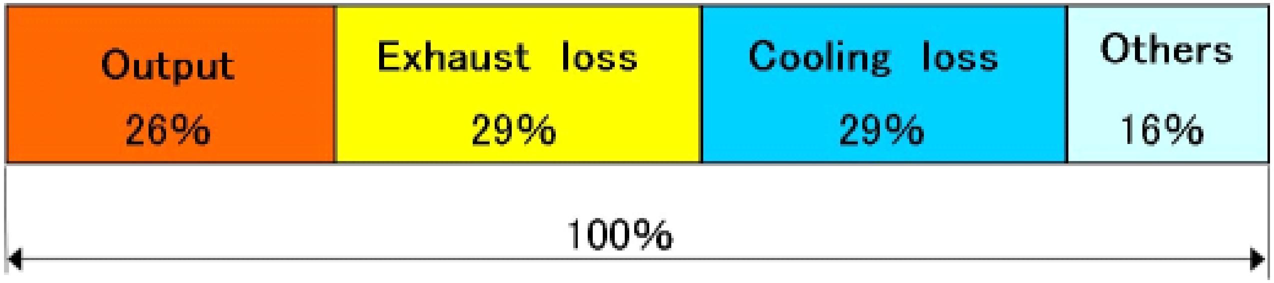
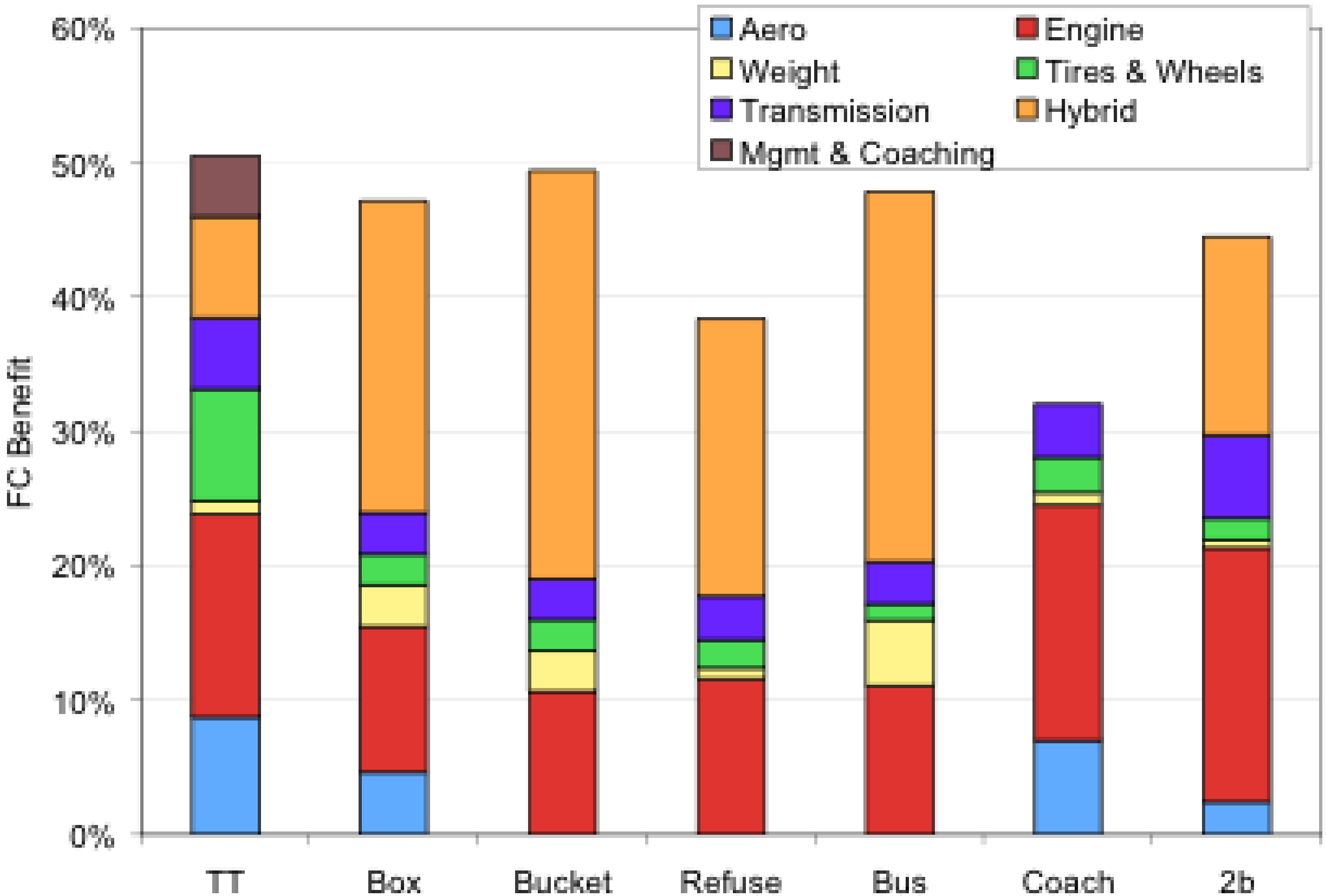


Fig. 2 Example of heat balance in a conventional engine

- 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**

HD: National Academy of Sciences study

- NAS study (March 2010) was commissioned as a result of the 2007 EISA
- Fuel consumption reduction potential close to 50% for most vehicle types

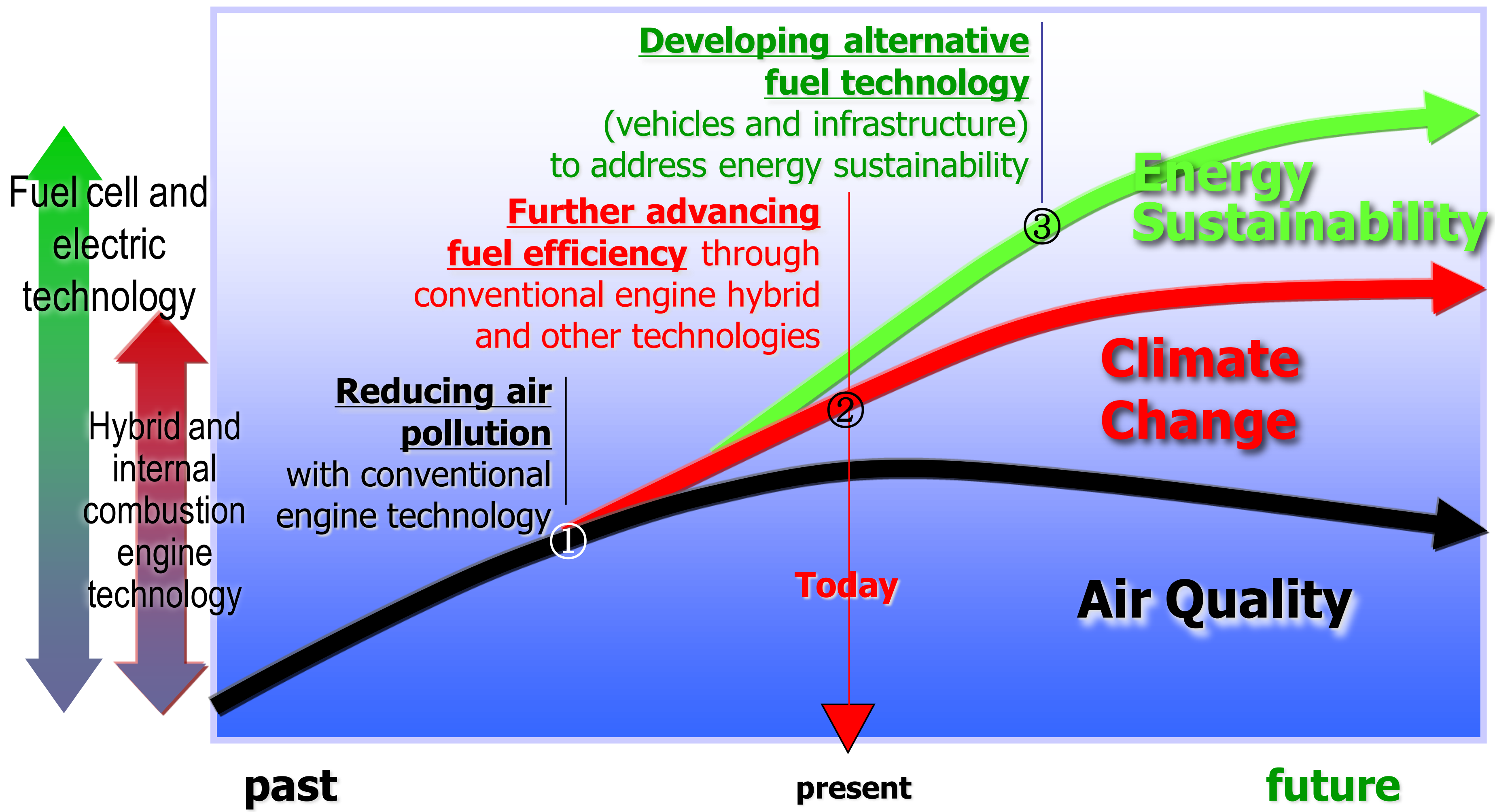


Potential fuel savings for new vehicles in 2015-2020

Source: TIAX (2009) Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles

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



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%

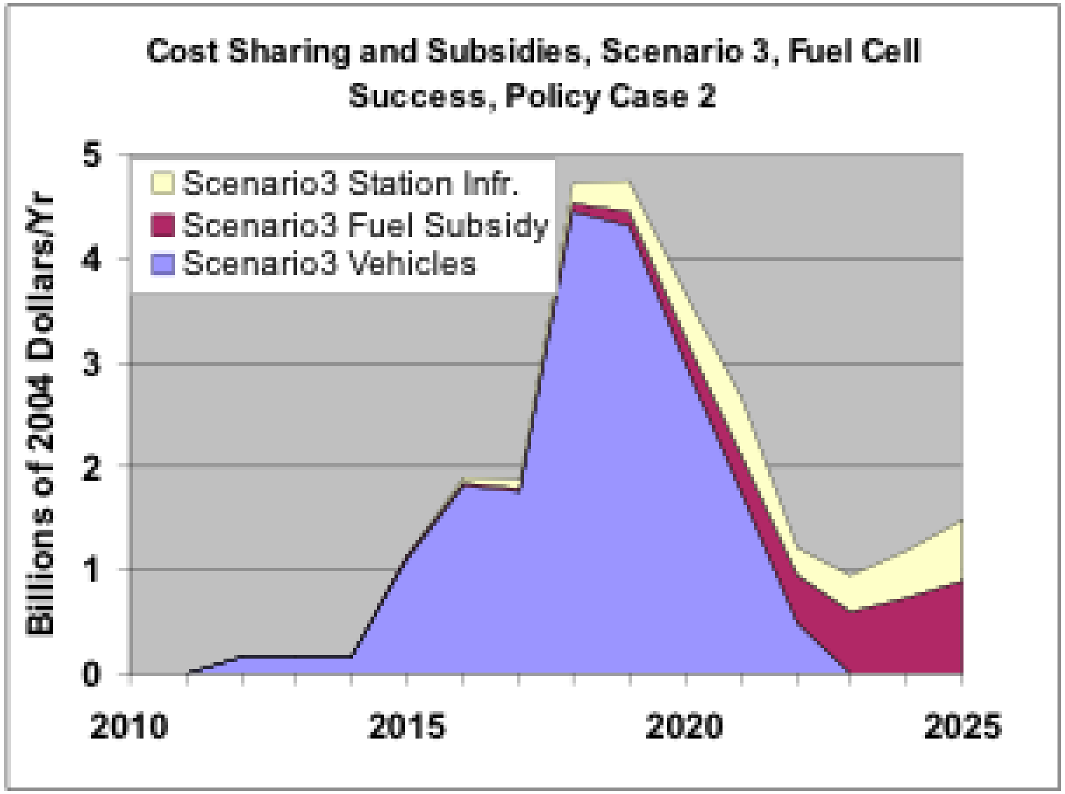
Electricity versus Hydrogen

- 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

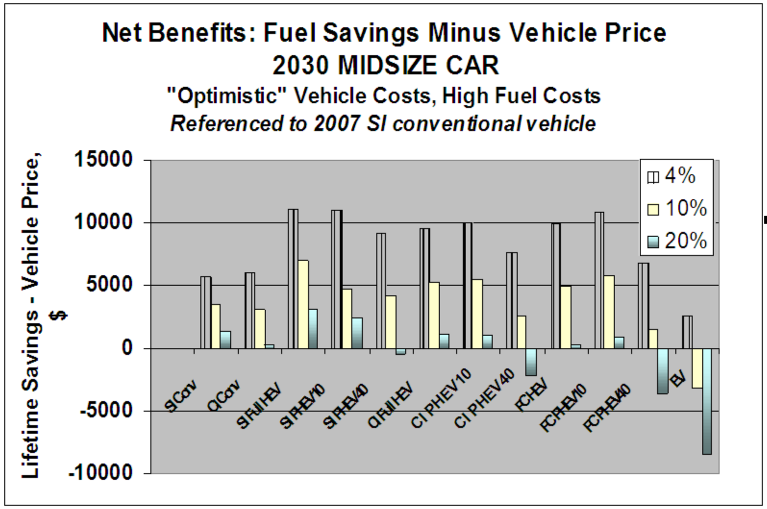
Natural Market Barriers

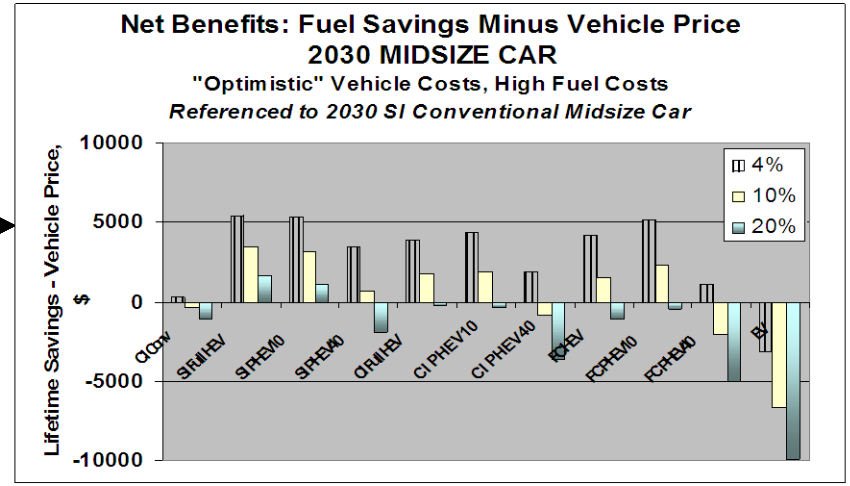
- **Need for technological advances**
- **Learning by doing**
- **Scale economies**
- **Resistance to novel technologies**
- **Lack of diversity of choice**
- **Chicken or egg?**
  - **Lack of fuel availability**
  - **Lack of vehicles to use new fuel**

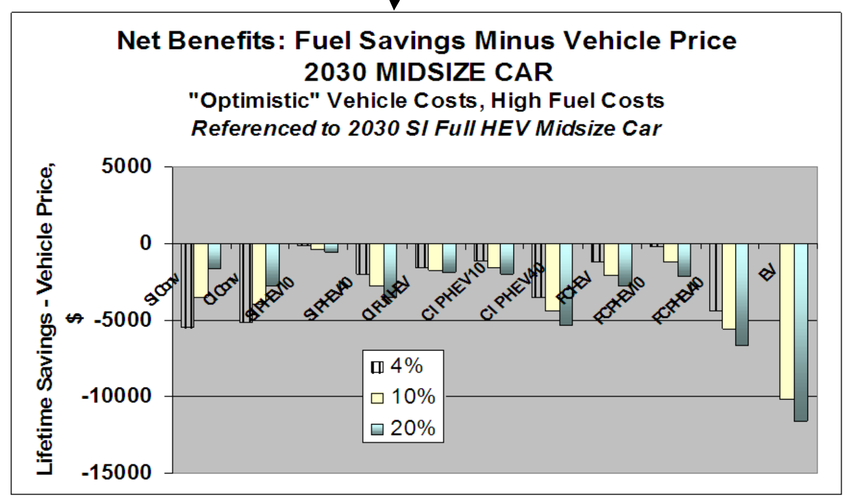


DOE's hydrogen study estimated transition costs of$25-40 billion

In gauging the potential for advanced vehicles, remember that the competition is changing….







What looks good against today's (conventional) car may not look so good against tomorrow's.

Slide from Steve Plotkin, Argonne National Lab, based on ANL's Multi-Path project

Fuels

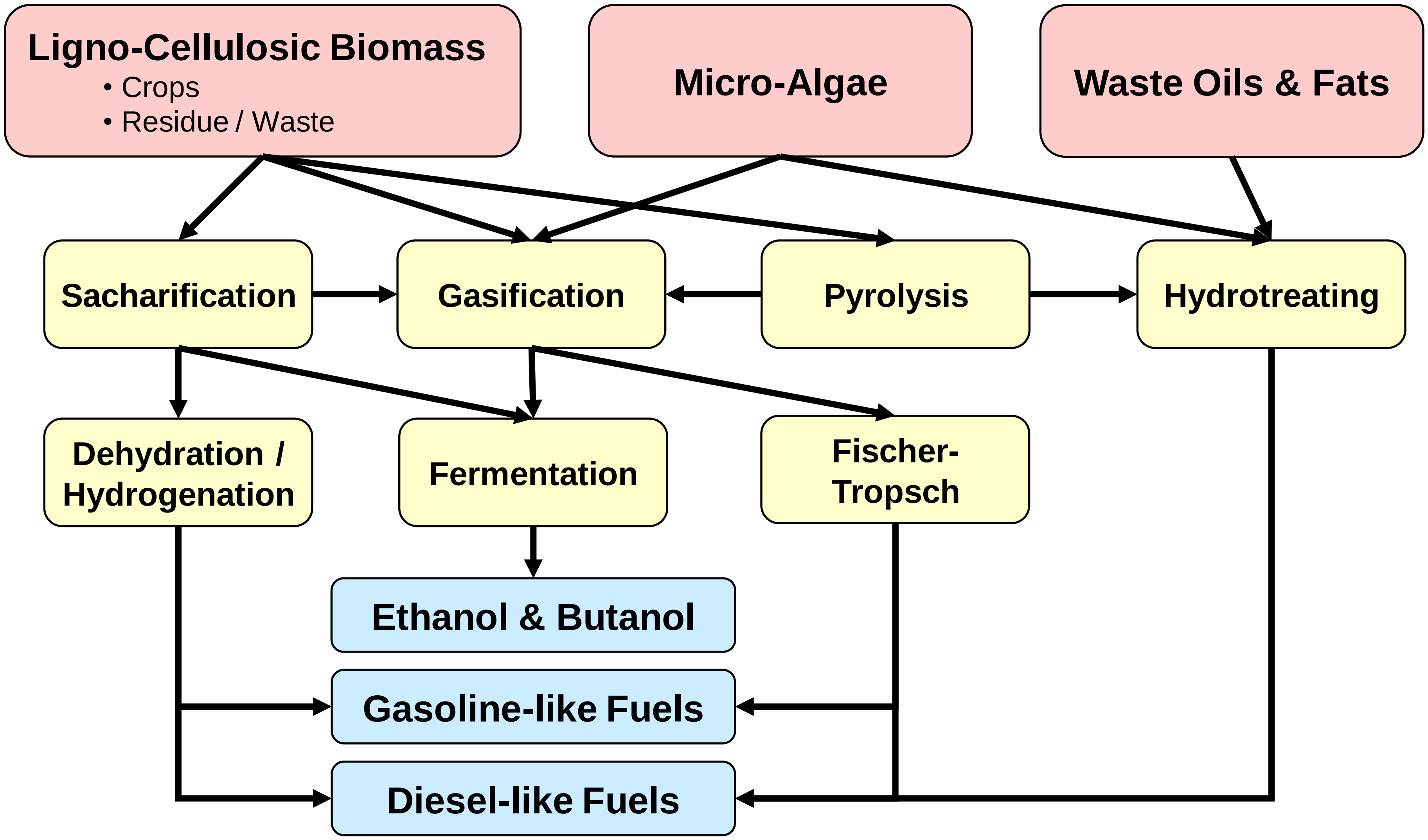
A Critical Barrier to E85……Reduced Energy Density

	Fuel Type				
Performance Specification	Diesel	Gasoline	E10	E85	Butanol
Megajoules/litre	40.9	32.0	28.06	19.59	29.2
BTU/U.S. gallon	147,000	125,000	120,900	84,400	104,800
RON		91-98	93	129	96
MON		81-89	85	96	78

300 mile range on gasoline drops to 215 miles on E85

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.



New Customer Discounting of Fuel Economy Benefits

Turrentine & Kurani, 2004

In-depth interviews of 60 California households' vehicle acquisition histories found *no evidence* of economically rational decision-making about fuel economy.

- 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.

Consumers are, in general, LOSS AVERSE

2002 Nobel Prize for Economics

(Tversky & Kahnemann, J. Risk & Uncertainty 1992

- Uncertainty about future fuel savings makes paying for more technology **a risky bet**
  - What MPG will I get (your mileage may vary)?
  - How long will my car last?
  - How much driving will I do?
  - **What will gasoline cost?**
  - What will I give up or pay to get better MPG?

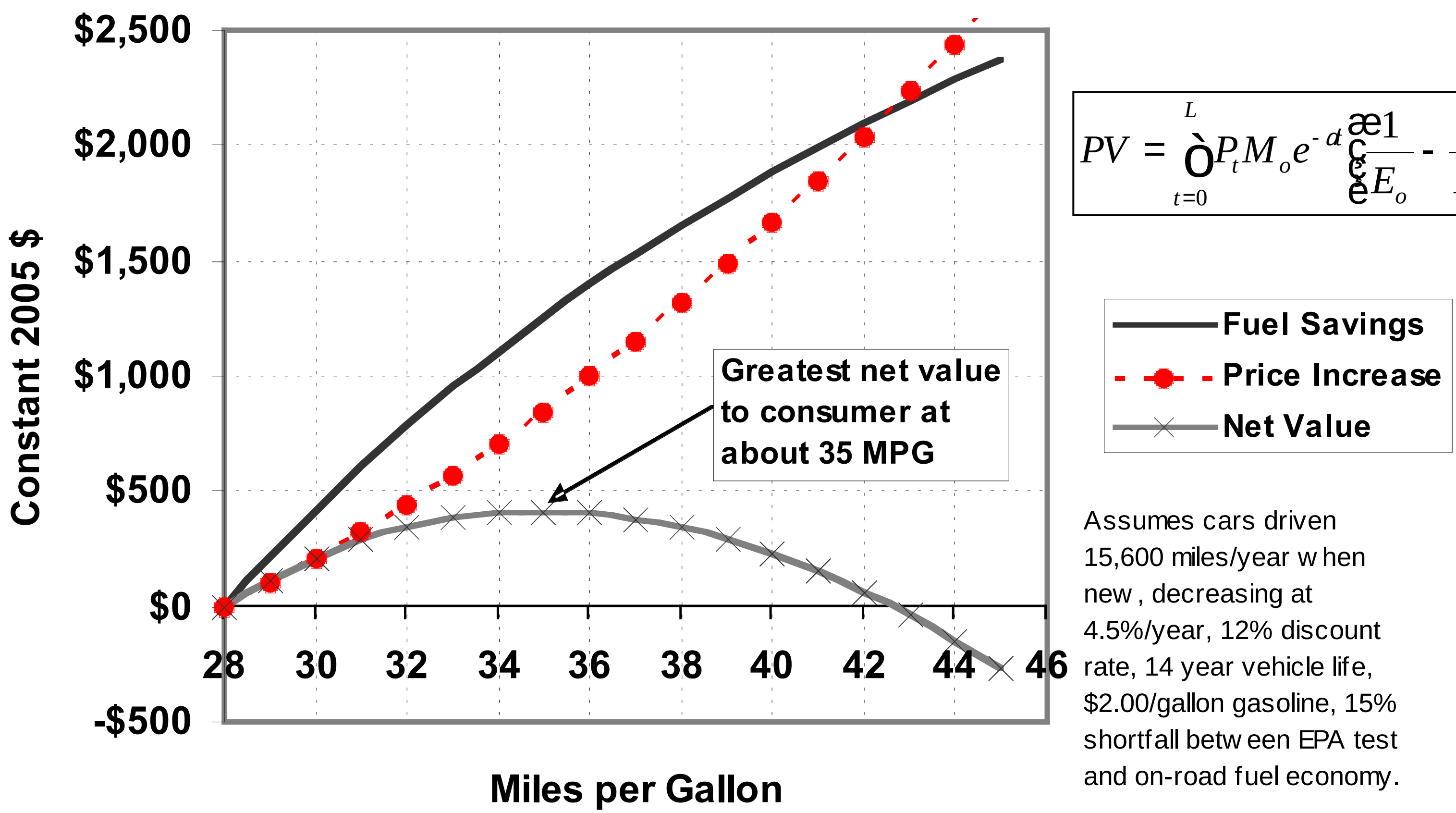
"A bird in the hand is worth two in the bush."

Causes the market to produce less fuel economy than is economically efficient

“Energy Paradox”

2002 NAS/NRC CAFE Report Technology Cost Curves

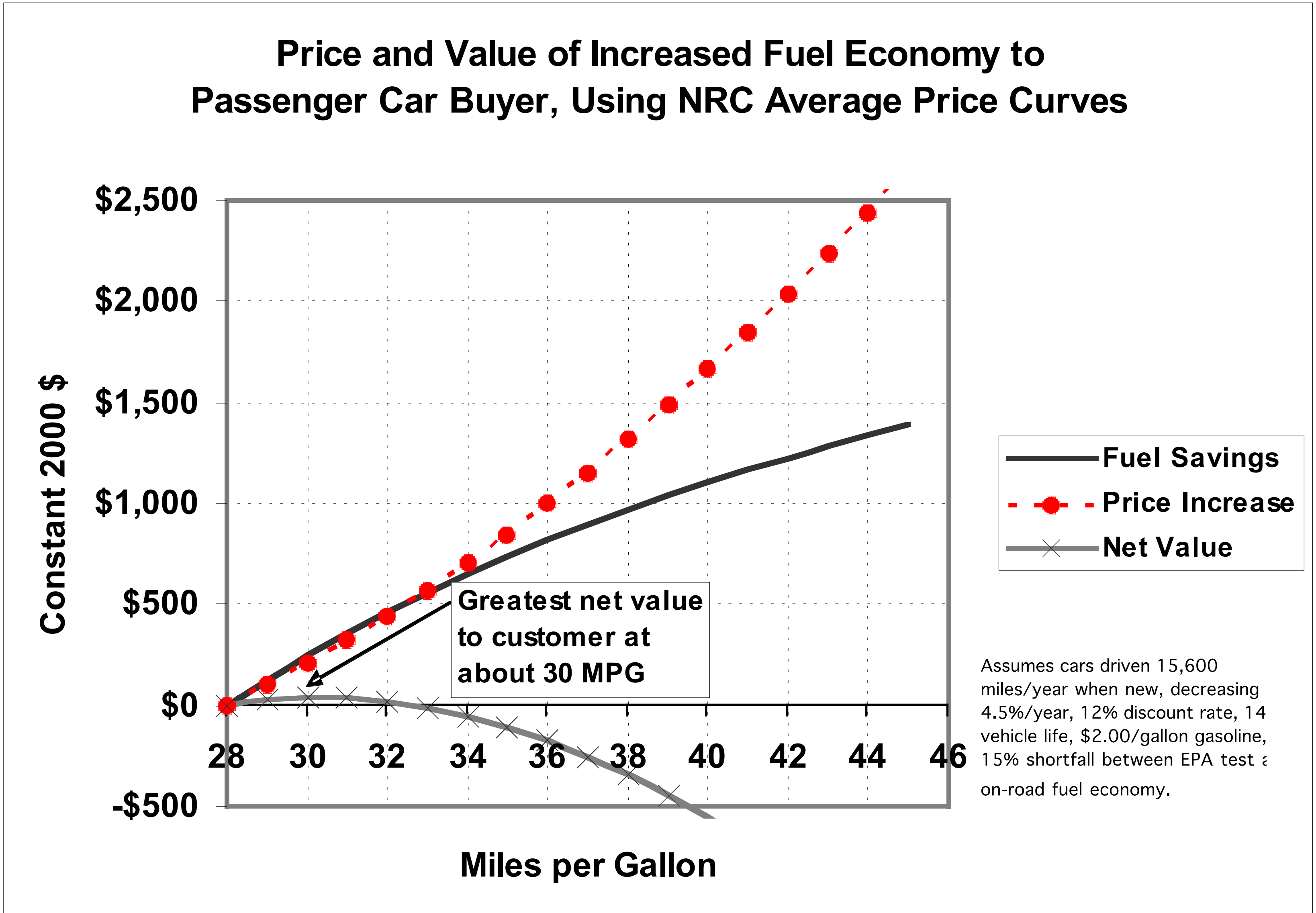
Price and Value of Increased Fuel Economy to Passenger Car Buyer, Using NRC Average Price Curves



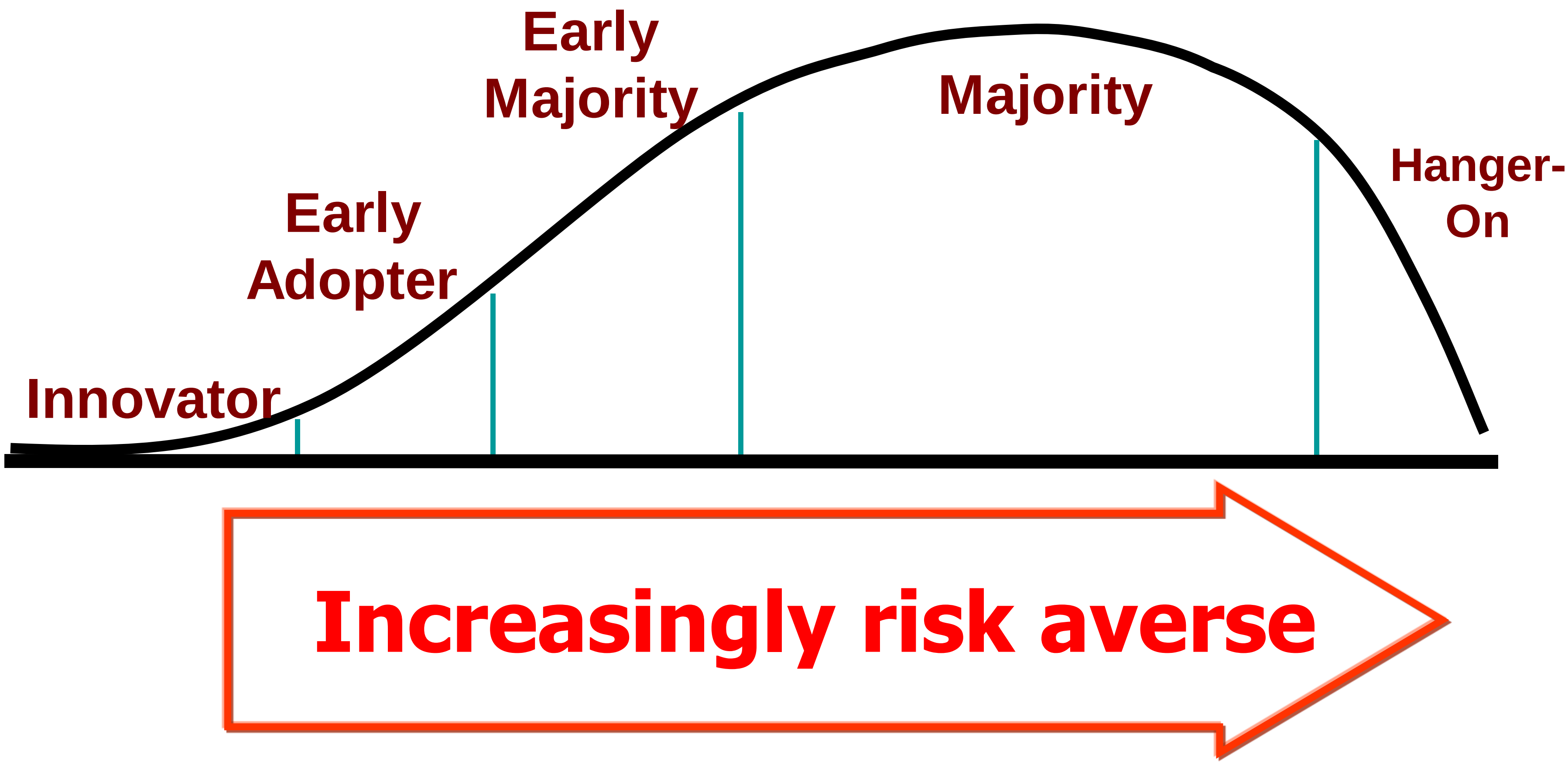
$$PV = \int_{t=0}^{L} P_t M_o e^{-\delta t} \left(\frac{1}{E_o} - \frac{1}{E_1} \right) e^{-rt} dt$$

Assumes cars driven 15,600 miles/year when new, decreasing at 4.5%/year, 12% discount rate, 14 year vehicle life, $2.00/gallon gasoline, 15% shortfall between EPA test and on-road fuel economy.

The implications of a 3-year payback requirement and uncertainty+loss aversion are the same.

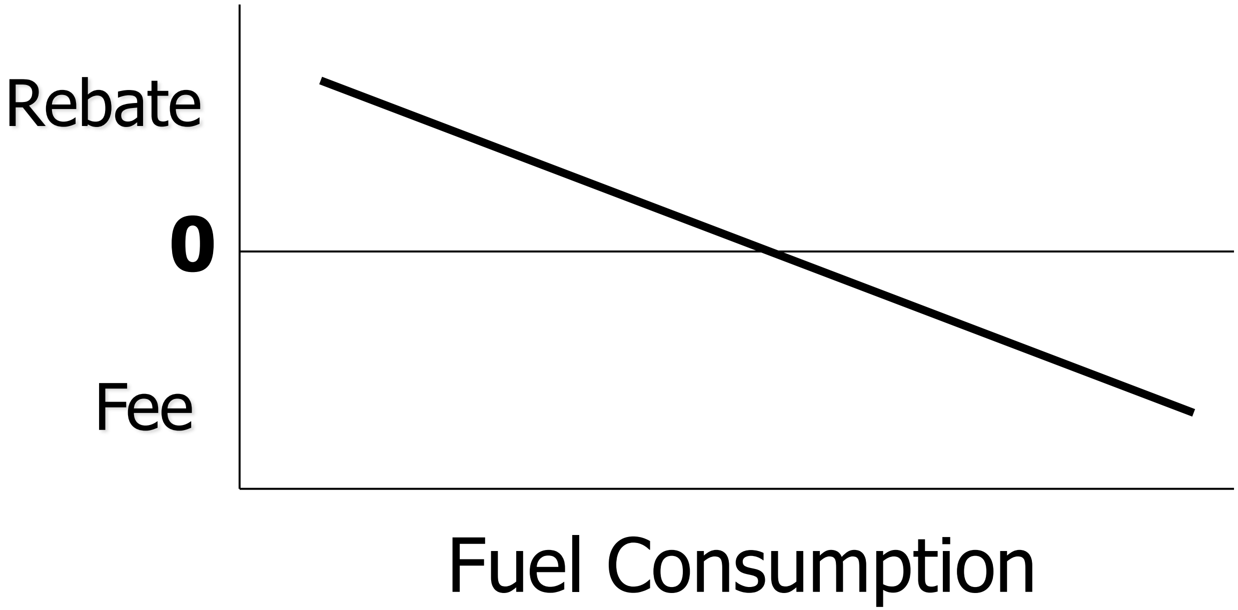


New Customer Profile



New Consumer Discounting is Fixable

- Increase fuel taxes
- Feebates: Pay manufacturers and consumers up front for value of the fuel savings



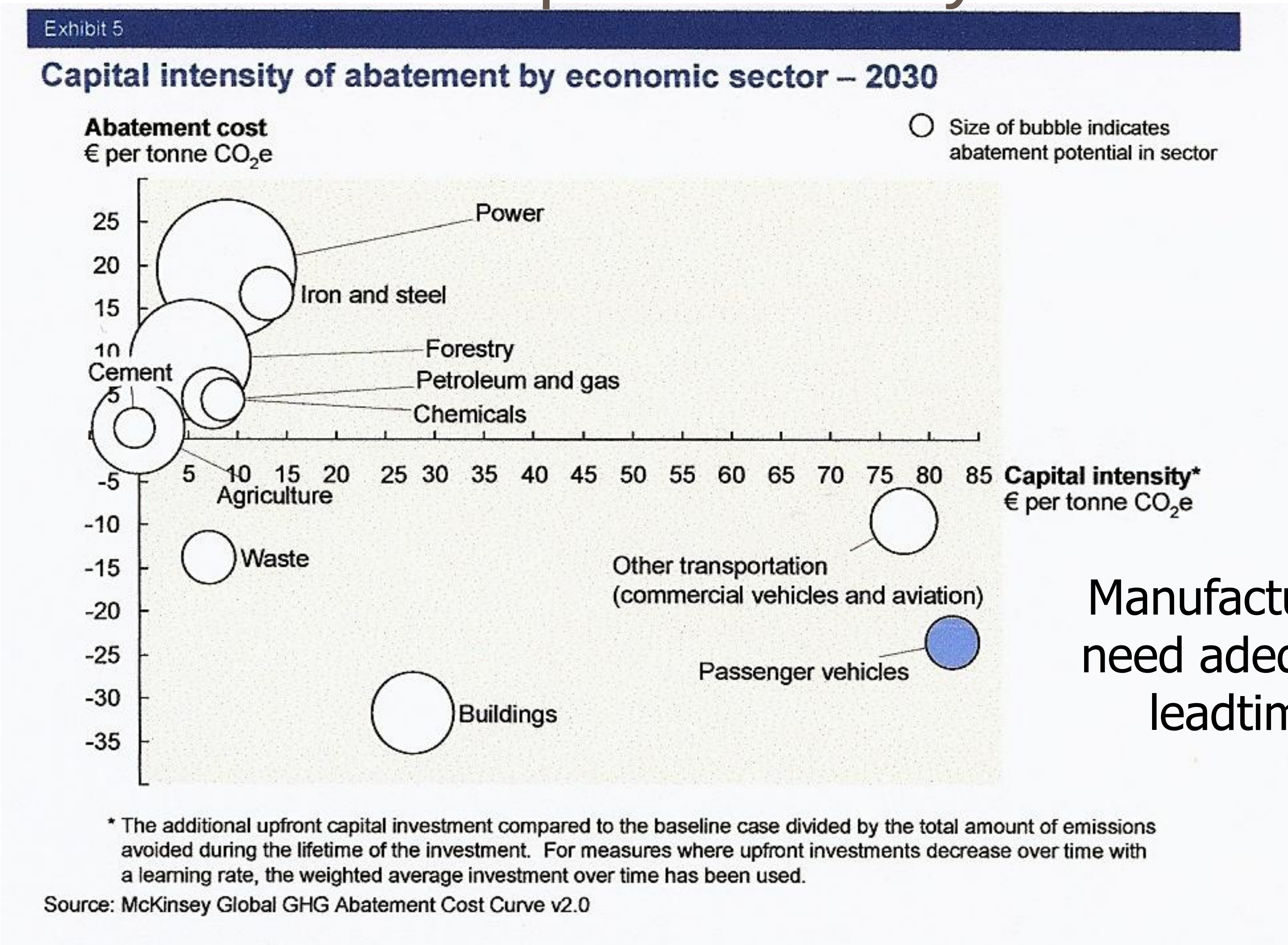
Uncertainties Larger Barrier for PHEVs

- How much am I going to save on fuel?
- How much will I pay for electricity?
- How often do I need to plug in?
- How much hassle will it be to plug in?
- Can I be electrocuted in the rain or if I work on my vehicle?
- What will it cost to install recharging equipment?
- How long will the battery last?
  - And how much will it cost to replace it?
- How reliable will the vehicle be?
- What will the resale value be?
  - Especially since the next owner also has to install recharging equipment
- What kind of PHEV is best for me?
  - Would a blended strategy be better than electric-only operation?
  - What amount of AER would be best for my driving?
  - What if I move or change jobs?

It's bad enough to spend $300 on a Betamax - but $30,000+ ?

Capitol Investments and Leadtime

Capitol Intensity



Manufacturers need adequate leadtime

The Real Barrier - Leadtime

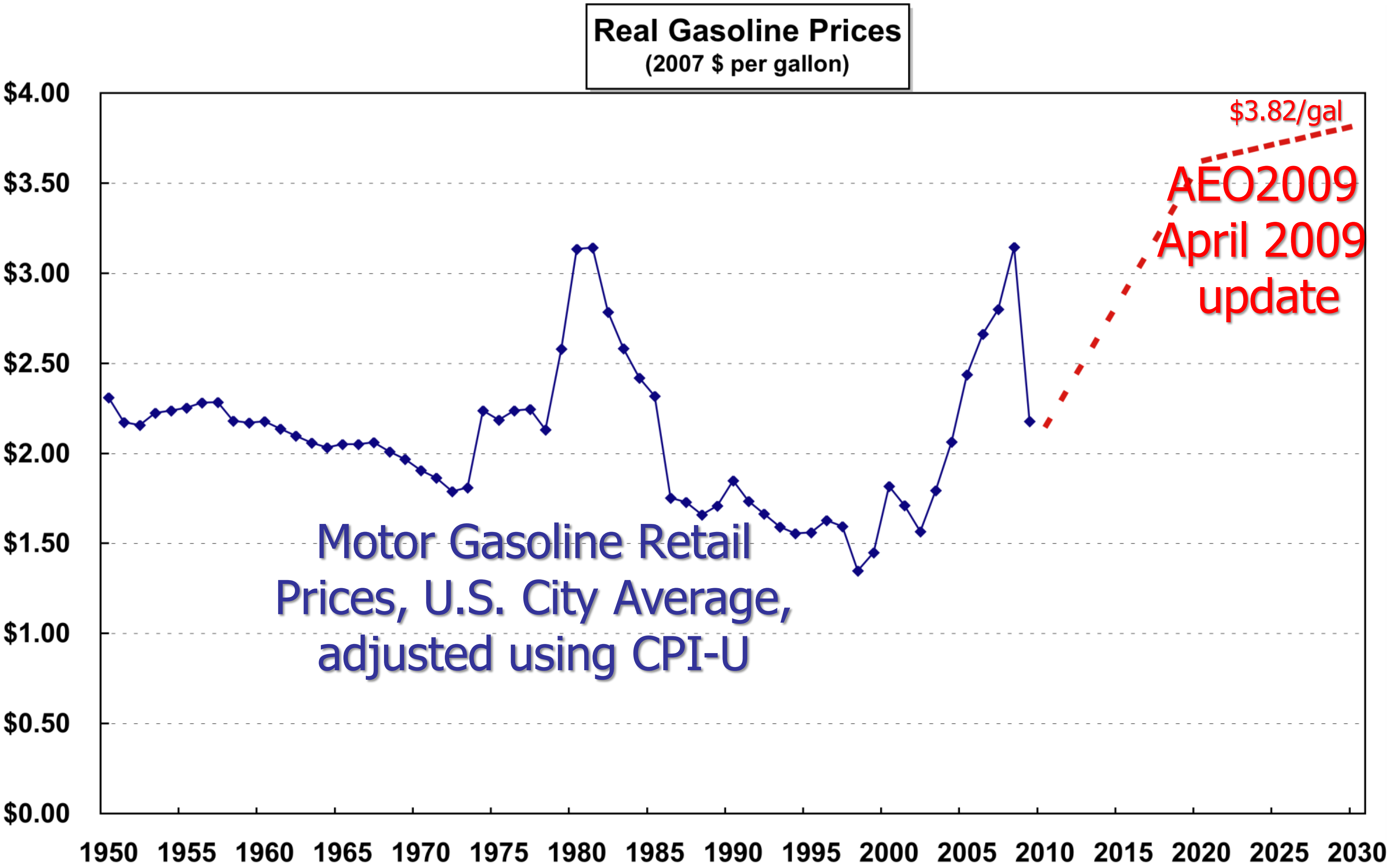
- Too many technology options, each with uncertain costs and benefits

- Must allow time to ensure quality and reliability
  - Rigorous product development process
  - Prove in production on a limited number of vehicles
  - Spread across fleet – 5-year minimum product cycles
  - Enormous capitol costs

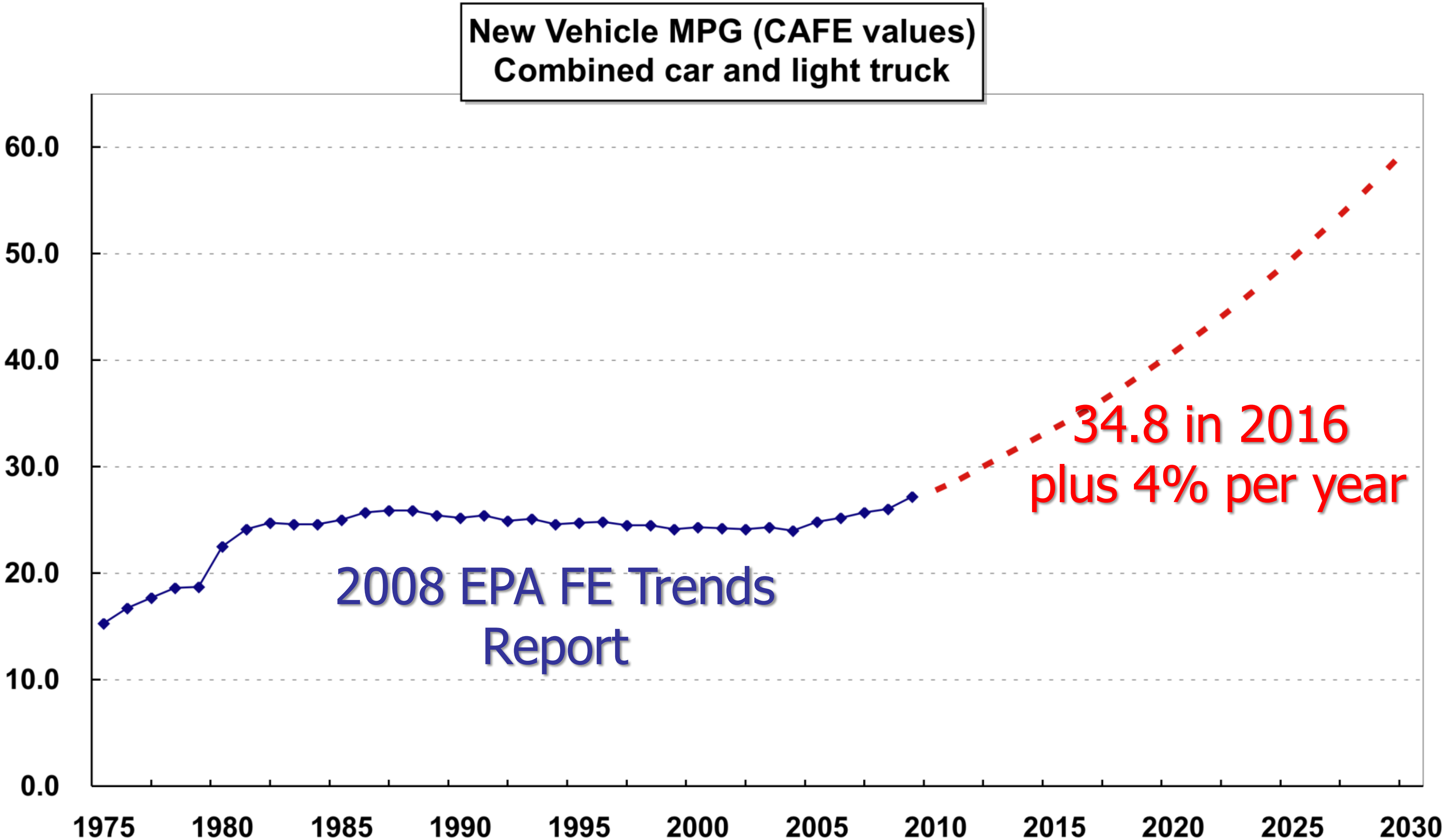
- Longer leadtime is needed for new technologies

Real Cost of Driving

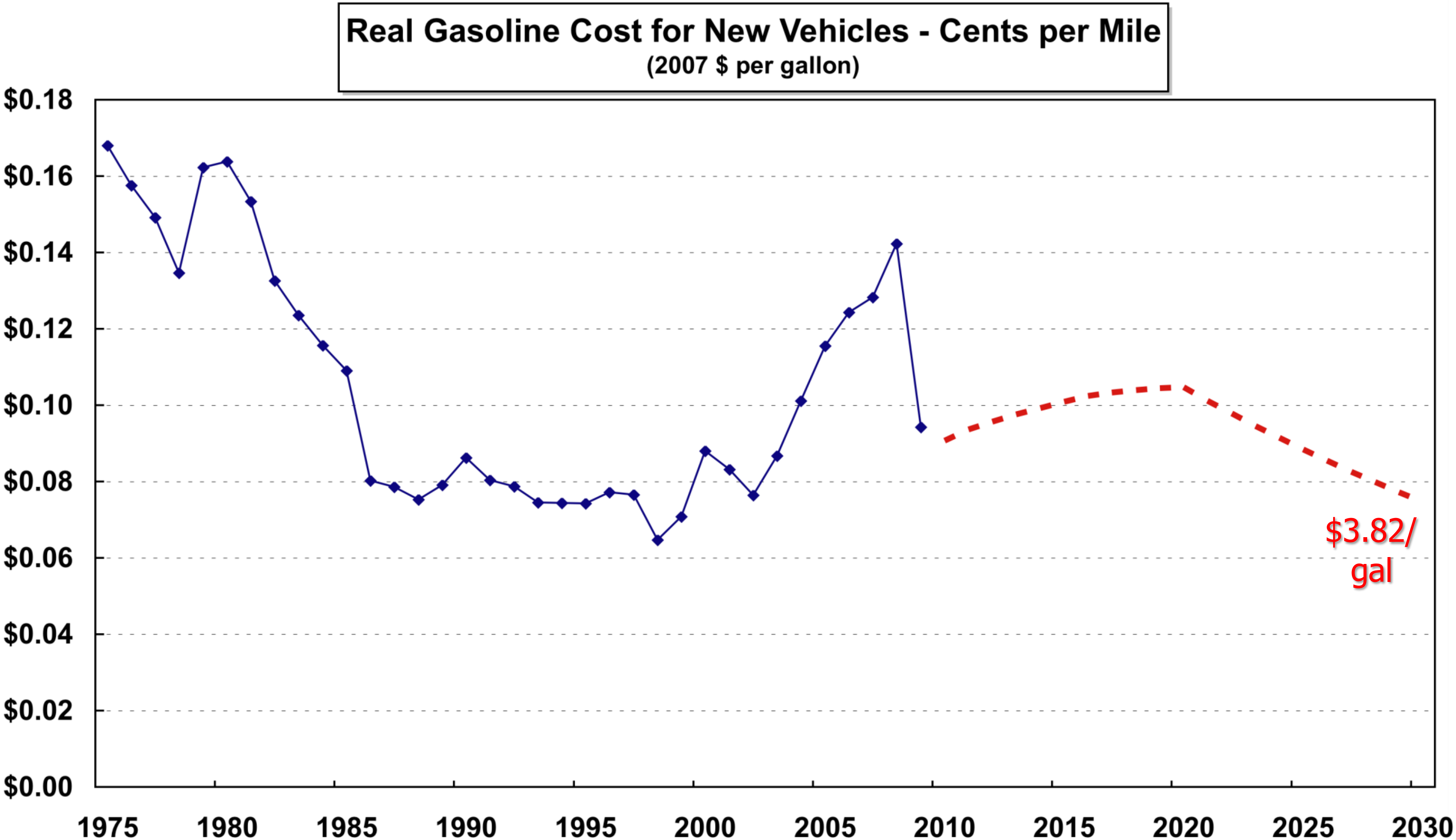
Real Gasoline Price



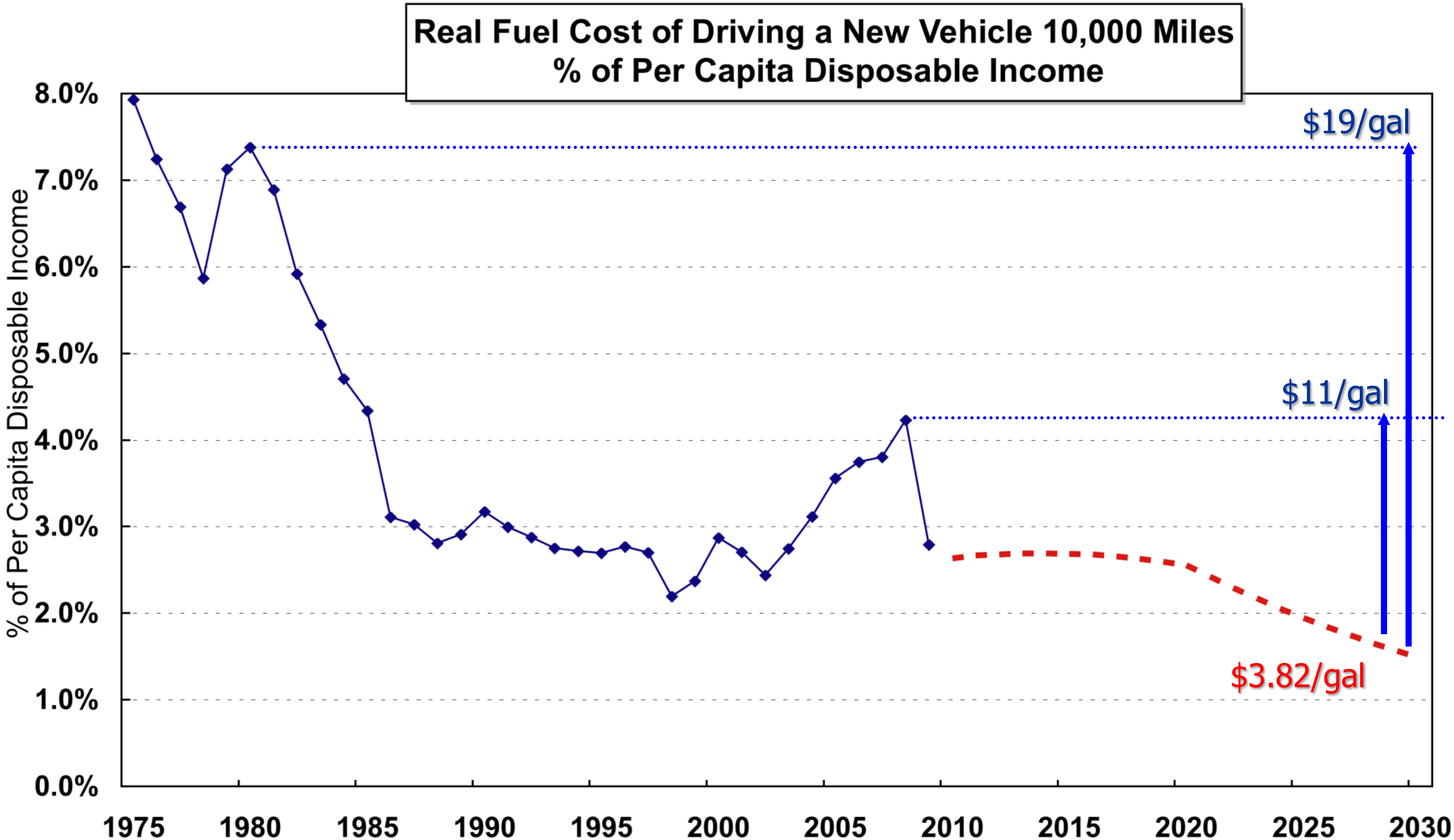
New Vehicle Fuel Economy



New Vehicle Gasoline Cost per Mile



Real Fuel Cost - % of Disposable Income



Forecasted Per Capita Disposable Income from AEO2009 April 2009 update

Future Directions

- Hybrid costs are dropping and synergies are developing
  - Mass market acceptance likely within 15 years
- **Gasoline engines and gasoline-electric hybrids are improving rapidly – raising bar for other technologies**
  - Especially a problem for diesels & PHEVs
- No silver bullet
  - Energy and GHG so immense we must do everything – avoid trap of single solutions
- Consumer risk/loss aversion challenges:
  - Most customers will continue to value performance, features, and utility higher than fuel savings
  - More difficult to implement advanced technology

Technology du jour

- **25 years ago – Methanol**
- **15 years ago – Electric vehicles**
- **10 years ago – Hybrid/electric vehicles**
- **6 years ago – Fuel cell vehicles**
- **4 years ago – Ethanol**
- **Today – BEVs and PHEVs**
- **What's next?**

Extremely disruptive and wasteful

Thank You

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