Automotive Technologies and Fuel Economy Policy

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Outline

- Technology overview
- Policy overview

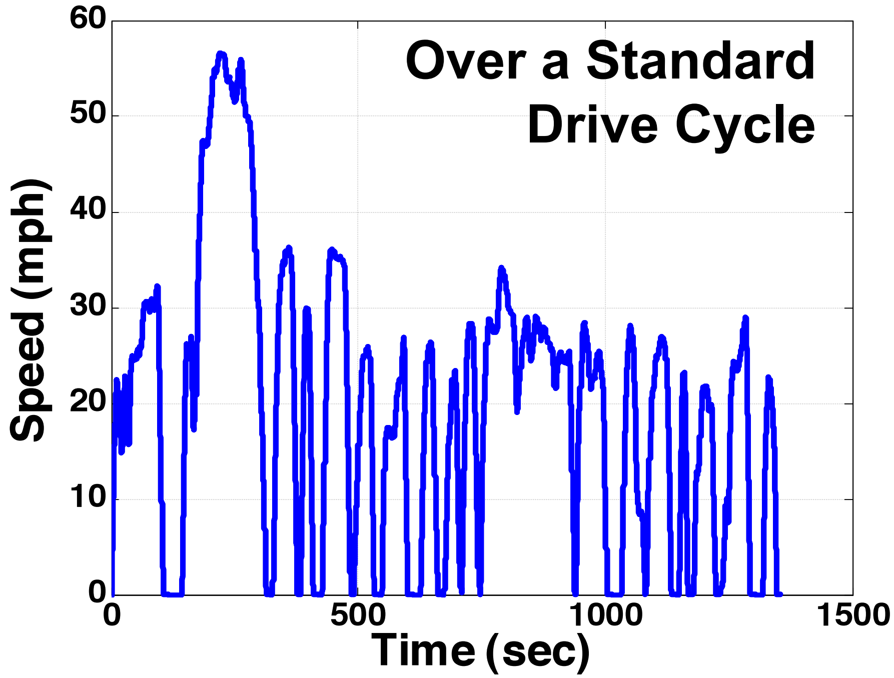
Technologies for Higher Fuel Economy

Credit for slides: Irene Berry

SM Mechanical Engineering / Technology and Policy, 2010

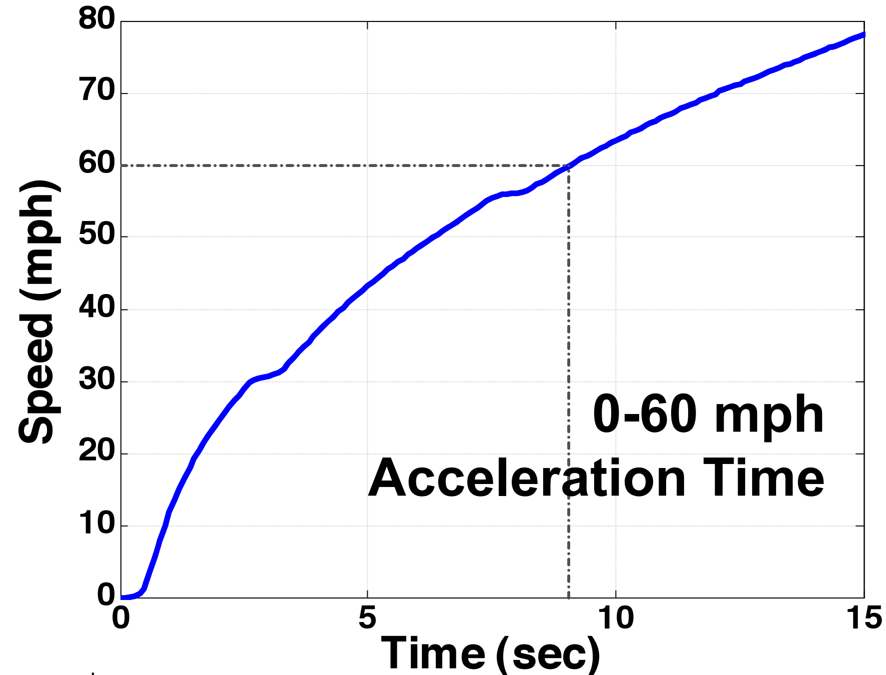
We frame vehicle design in terms of range and performance goals

Range



Energy Specification

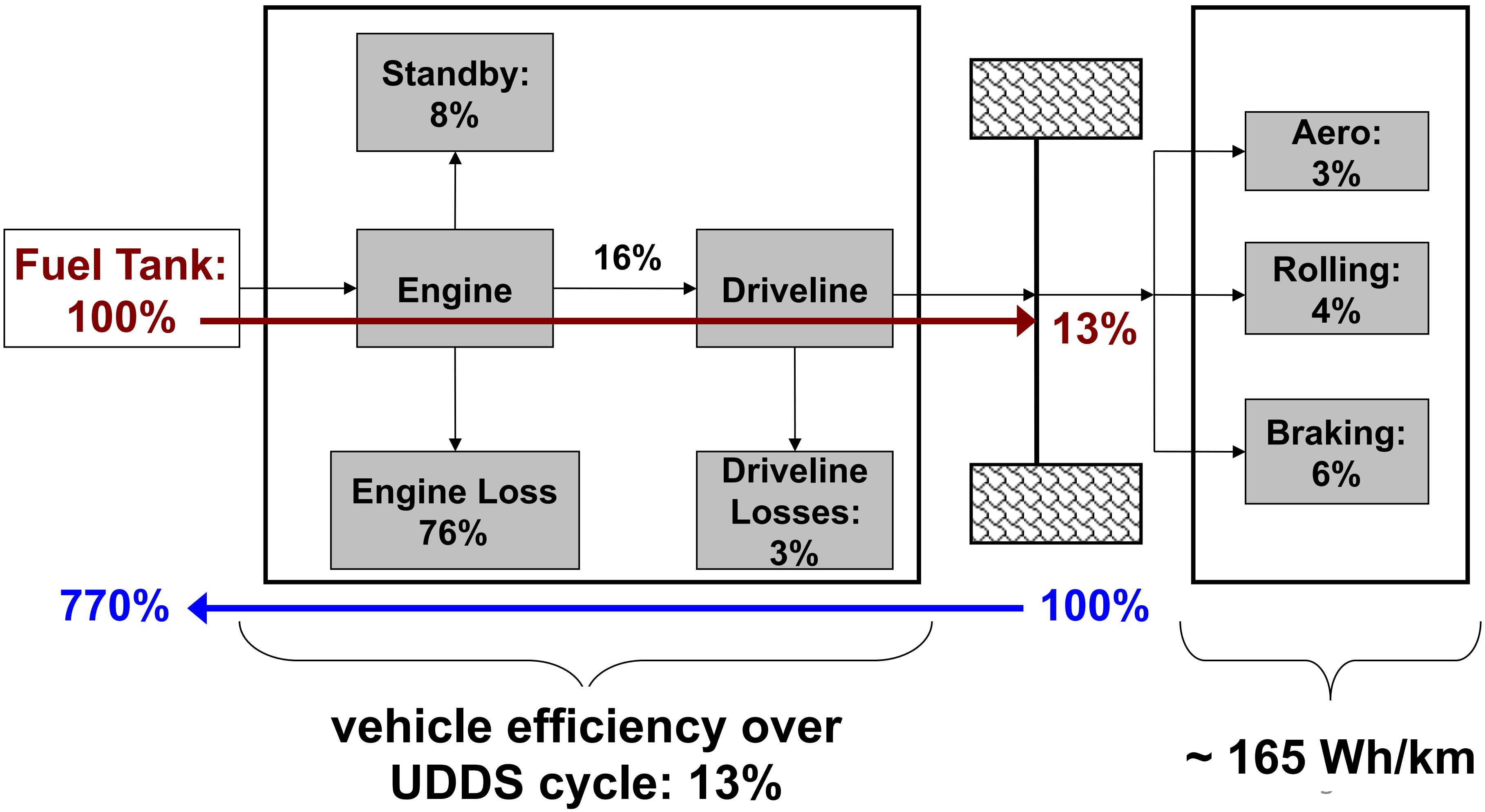
Performance



Power Specification

Range depends on the energy required at the wheels and vehicle efficiency

2005 3.0-L Toyota Camry over UDDS drive cycle



Performance depends on the peak power of the vehicle

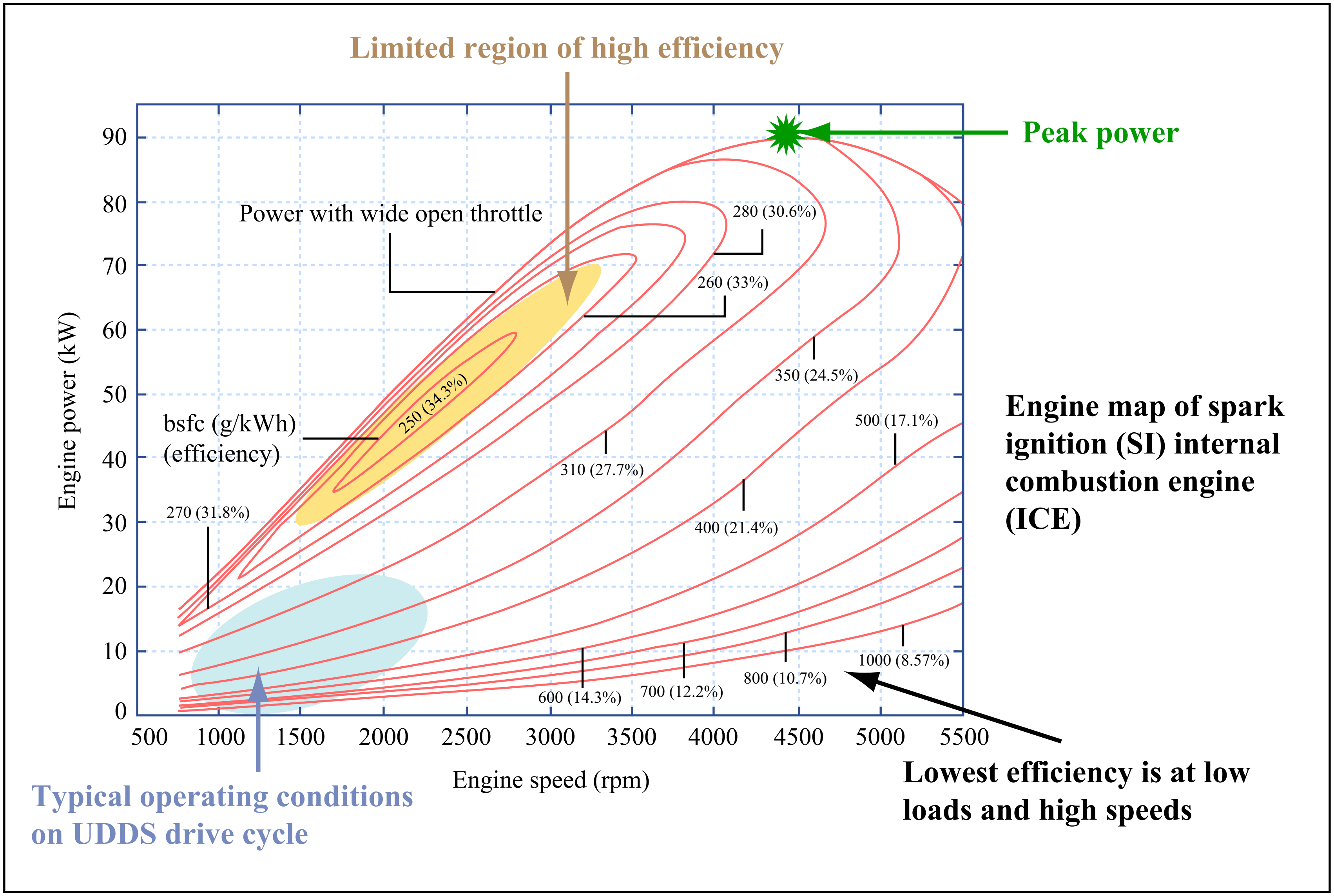
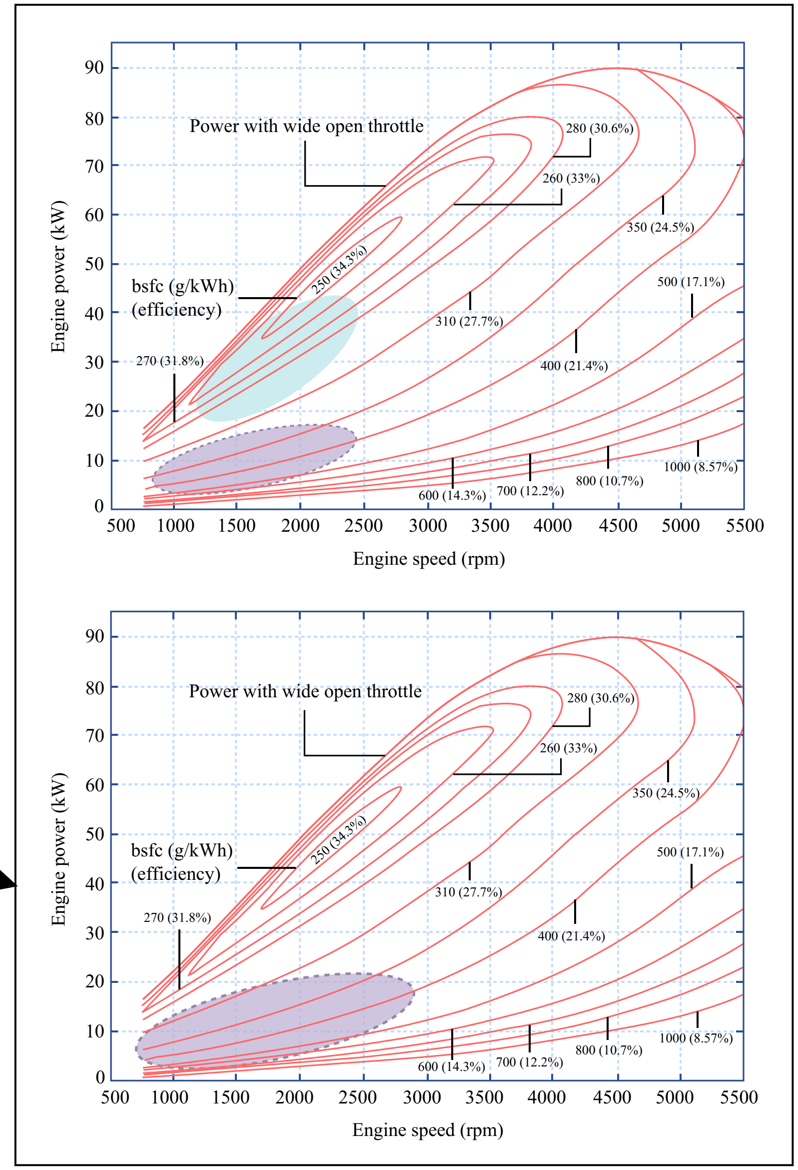


Image by MIT OpenCourseWare. Adapted from Ehsani, Mehrdad, et al. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design*. CRC Press, 2005. ISBN: 9780849331541.

So, we want to increase efficiency while meeting design goals

1. **Reduce load (energy required at the wheels)**
2. **Increase powertrain efficiency**
    1. **Increase efficiency of engine**
    2. **Shift engine operating points**
    3. **Use smaller engine (downsize)**



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[Ehsani et al 2004]

Reducing the load at the wheels reduces fuel consumption

- **Reduce weight**
- **Reduce aerodynamic drag**
- **Reduce accessory loads**

Please see any description of Volkswagen's 1-Litre concept car and Siuru, Bill. "5 Facts: Vehicle Aerodynamics." GreenCar, October 13, 2008.

↓

These reductions also allow for downsizing

Diesel engines are more efficient, but heavier and more expensive

<u>Compression Ignition (vs. Spark Ignition)</u>

- Only air is compressed
  - Higher compression ratio
- Fuel is injected into the compressed air and self-ignites
  - Direct injection

<u>Diesel (vs. Gasoline) Fuel</u>

- Higher energy content
- Higher emissions from combustion

These engine technologies increase engine efficiency and/or power

Technology	Mechanism	Efficiency gain
Variable valve timing	Optimizes efficiency for both high and low engine speeds	5%
Cylinder deactivation	Increases low load efficiency	7.5%
Turbo- or super-charge	Increases engine power per size: allows downsizing	7.5%
Direct Injection	More efficient fuel delivery and combustion	5-10%
Advanced after-treatment	Allows engine to produce more emissions	N/A

www.fueleconomy.gov

These transmission technologies allow better control of engine speed

Technology	Mechanism	Efficiency gain
CV transmission	Optimize engine speed	6%
Dual-clutch transmission	Optimize engine speed	7%

www.fueleconomy.gov

Different combustion cycles also offer efficiency improvements

Technology	Mechanism	Efficiency gain
Miller cycle	Trade power for efficiency	5%
Atkinson cycle	Trade power for efficiency	5%
HCCI	More efficient at low load	7.5%

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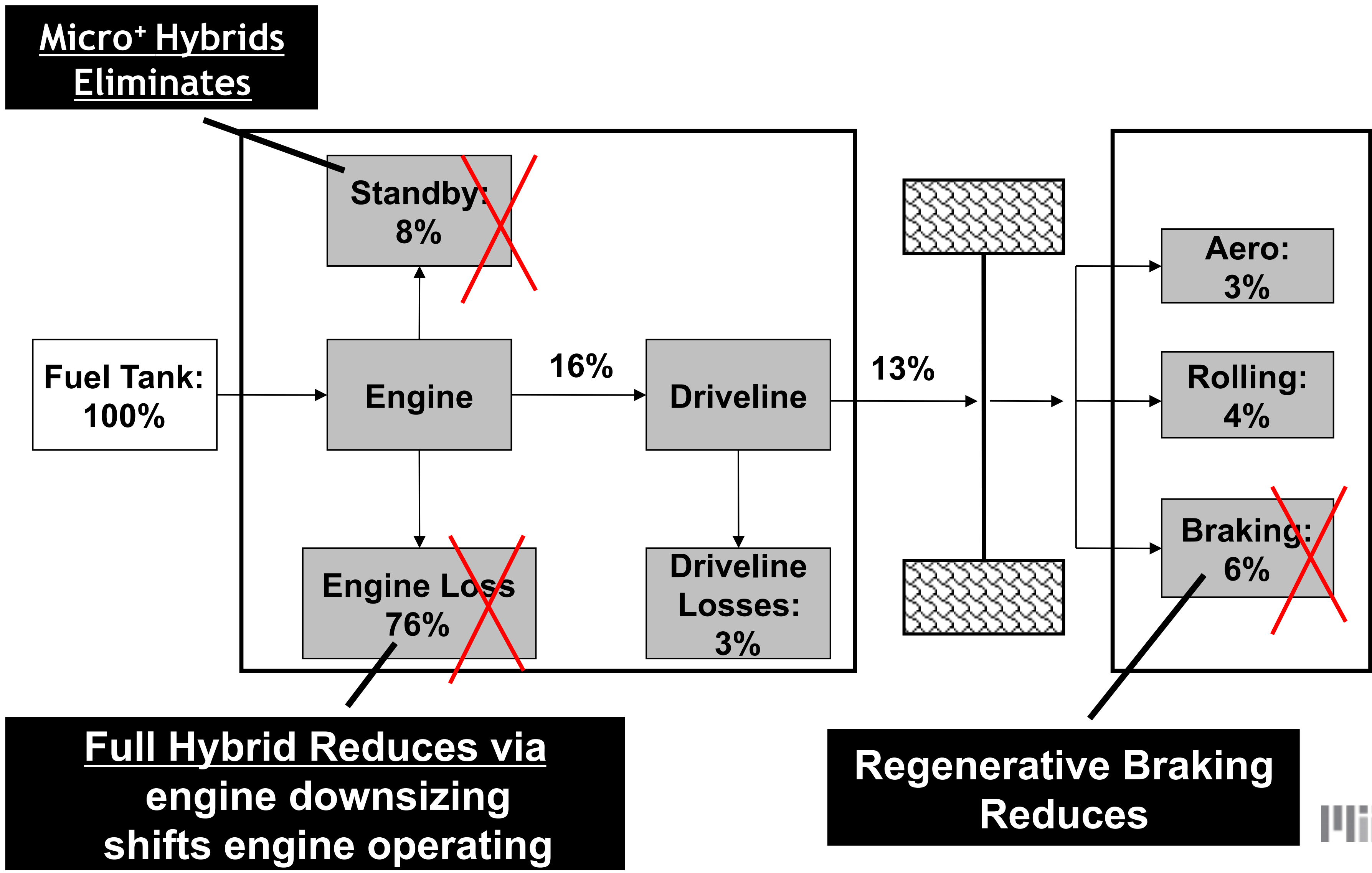
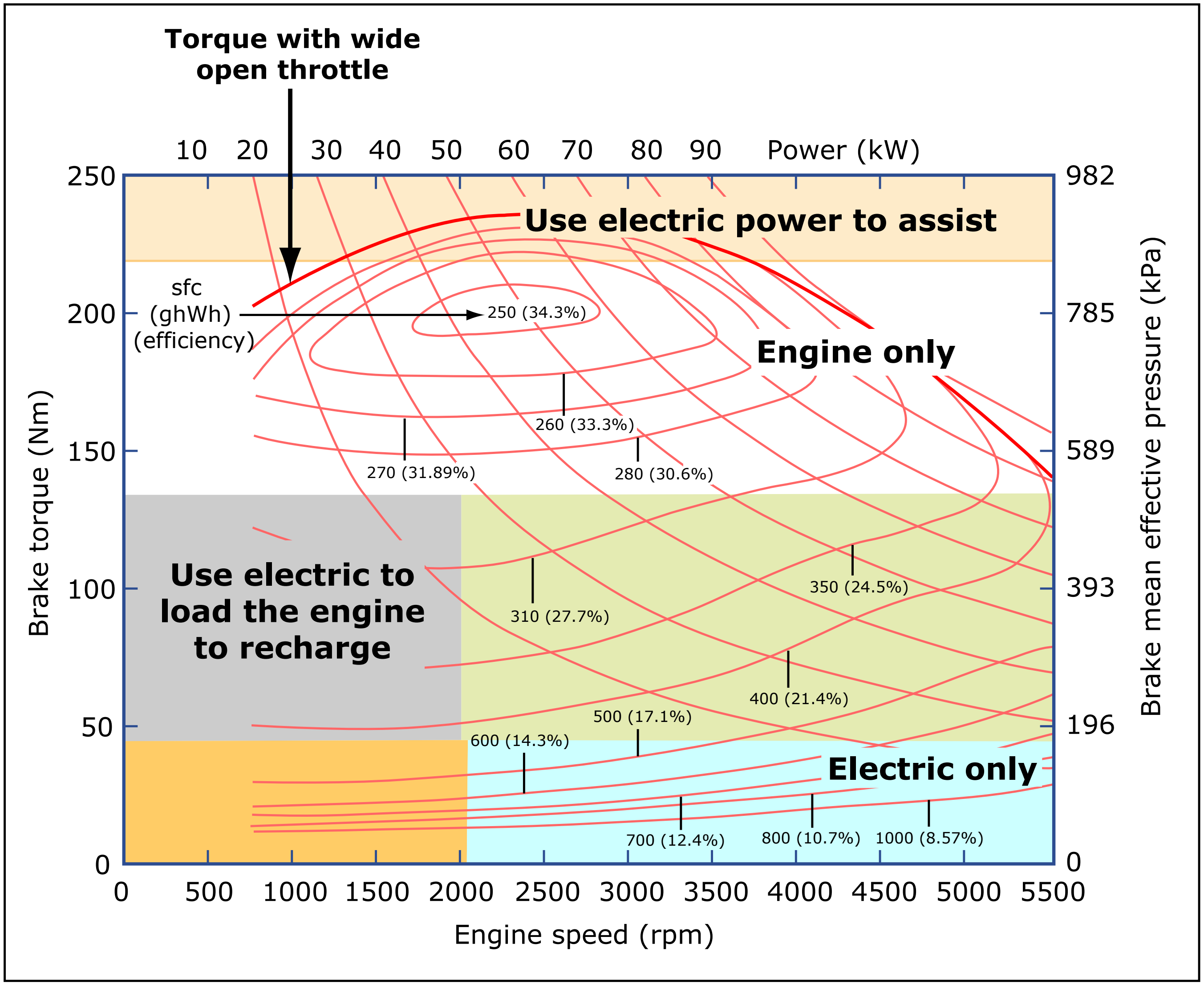
There are additional opportunities for energy savings through hybridization



Hybrid optimization shifts the engine operating points to higher efficiency



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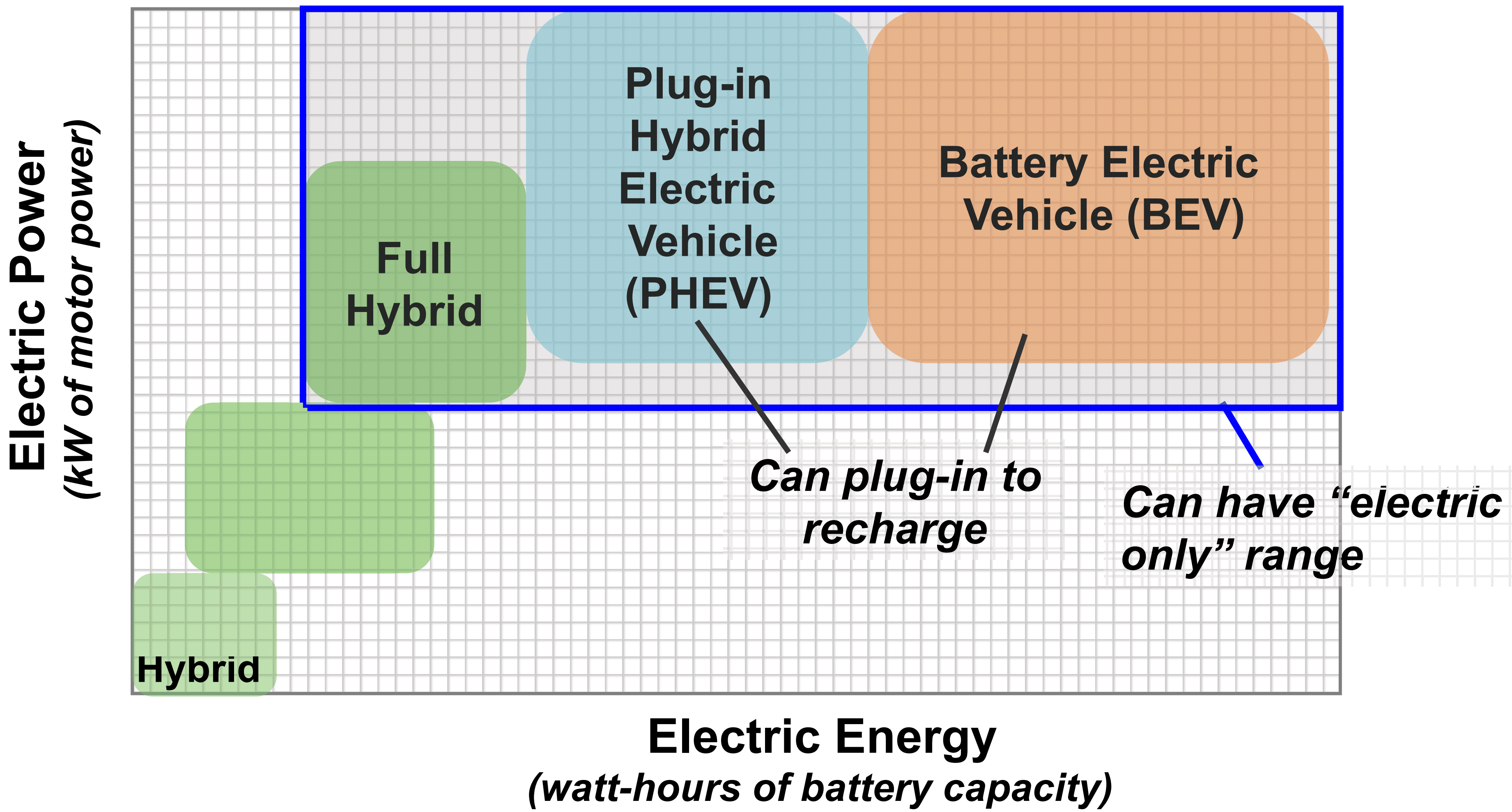
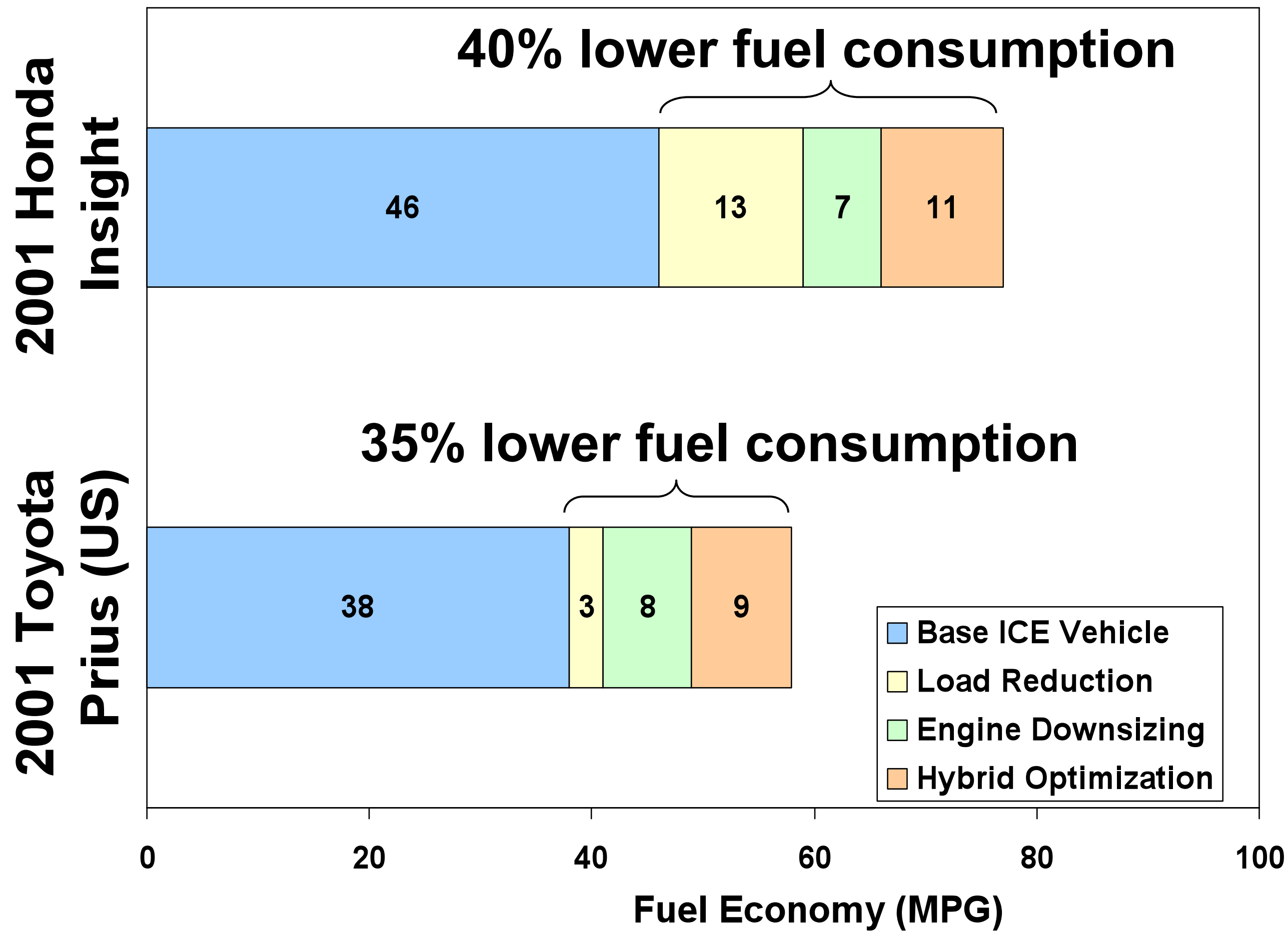
[Ehsani et al 2004]

Hybrids and electric vehicles are classified by degree of electrification



Hybrids achieve fuel savings through multiple efficiency mechanisms



Data from: An et al 2001

Battery electric vehicle are fully electric, which has both pros and cons

Advantages

- ✓ Electricity
  - ✓ Any energy source
  - ✓ Potentially less emissions
  - ✓ Single emissions source
- ✓ Electric drive
  - ✓ More energy efficient
  - ✓ Higher low-speed torque
  - ✓ Lower operating costs
  - ✓ Less maintenance

Disadvantages

- ✗ Batteries
  - ✗ Long charge times
  - ✗ High cost
  - ✗ Low energy content relative to gasoline
  - ✗ Limited range
  - ✗ Concerns over life
- ✗ Electric drive
  - ✗ Different operating and driving feel

To compare different fuels, consider well-to-wheels energy and emissions

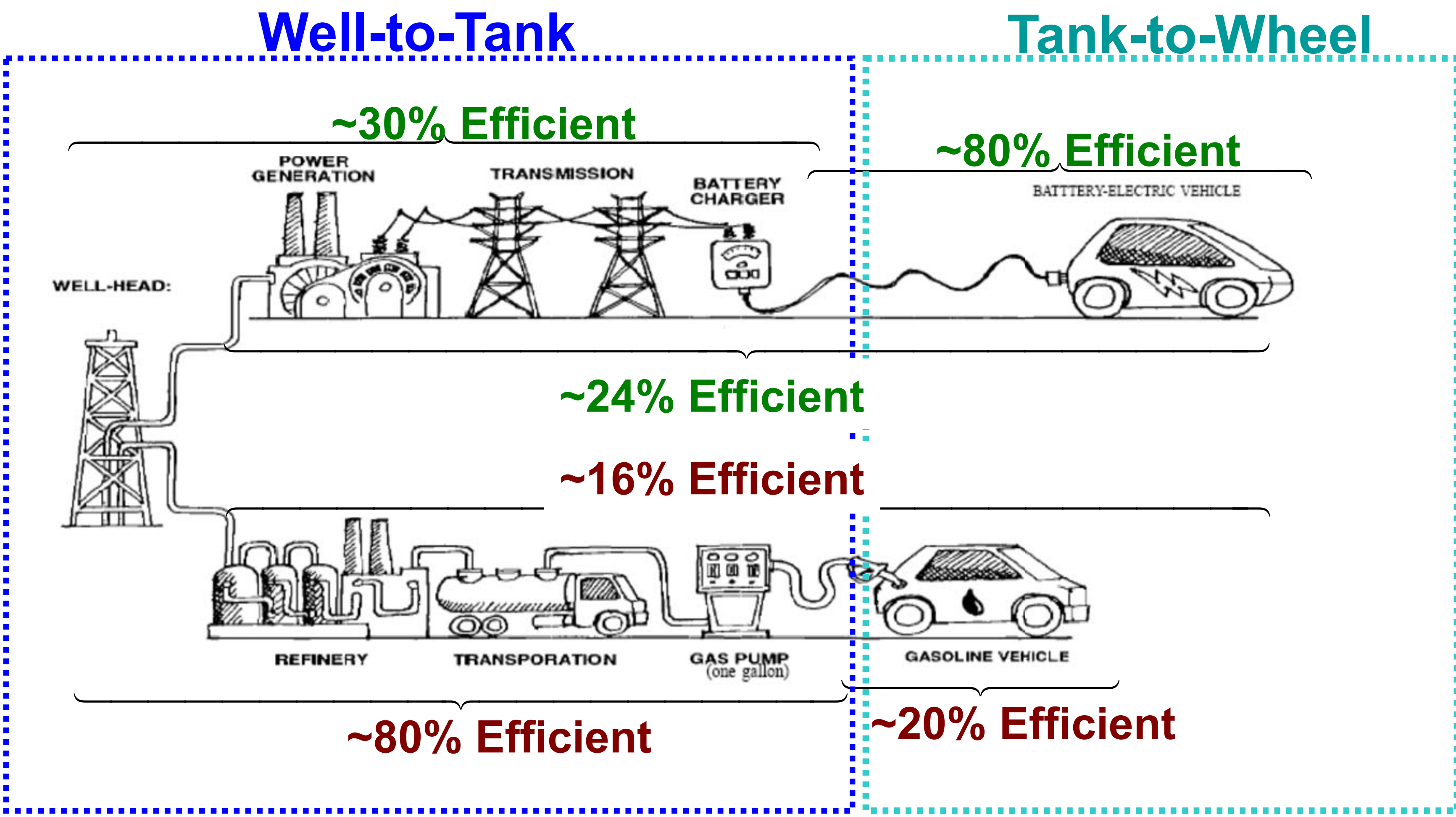


Image from "Getting Around Without Gasoline." Northeast Sustainable Energy Association, 1995.

[http://www.nesea.org/]

Automotive Fuel Economy Policy in the U.S.

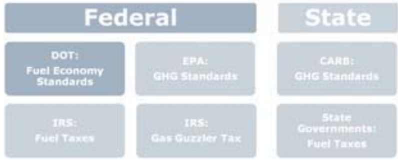
Massachusetts Institute of Technology
Engineering Systems Division

Overview of Institutions and Policies

Federal		State
DOT: Fuel Economy Standards	EPA: GHG Standards	CARB: GHG Standards
IRS: Fuel Taxes	IRS: Gas Guzzler Tax	State Governments: Fuel Taxes

Cap & Trade

Feebates



Corporate Average Fuel Economy

- Administered by National Highway Traffic Safety Administration (NHTSA, part of the DOT)

- Sets minimum **average** level of fuel economy that new light-duty* vehicles sold by each manufacturer must meet each year

$$CAFE = \frac{\sum_i Sales_i}{\sum_i \frac{Sales_i}{MPG_i}}$$

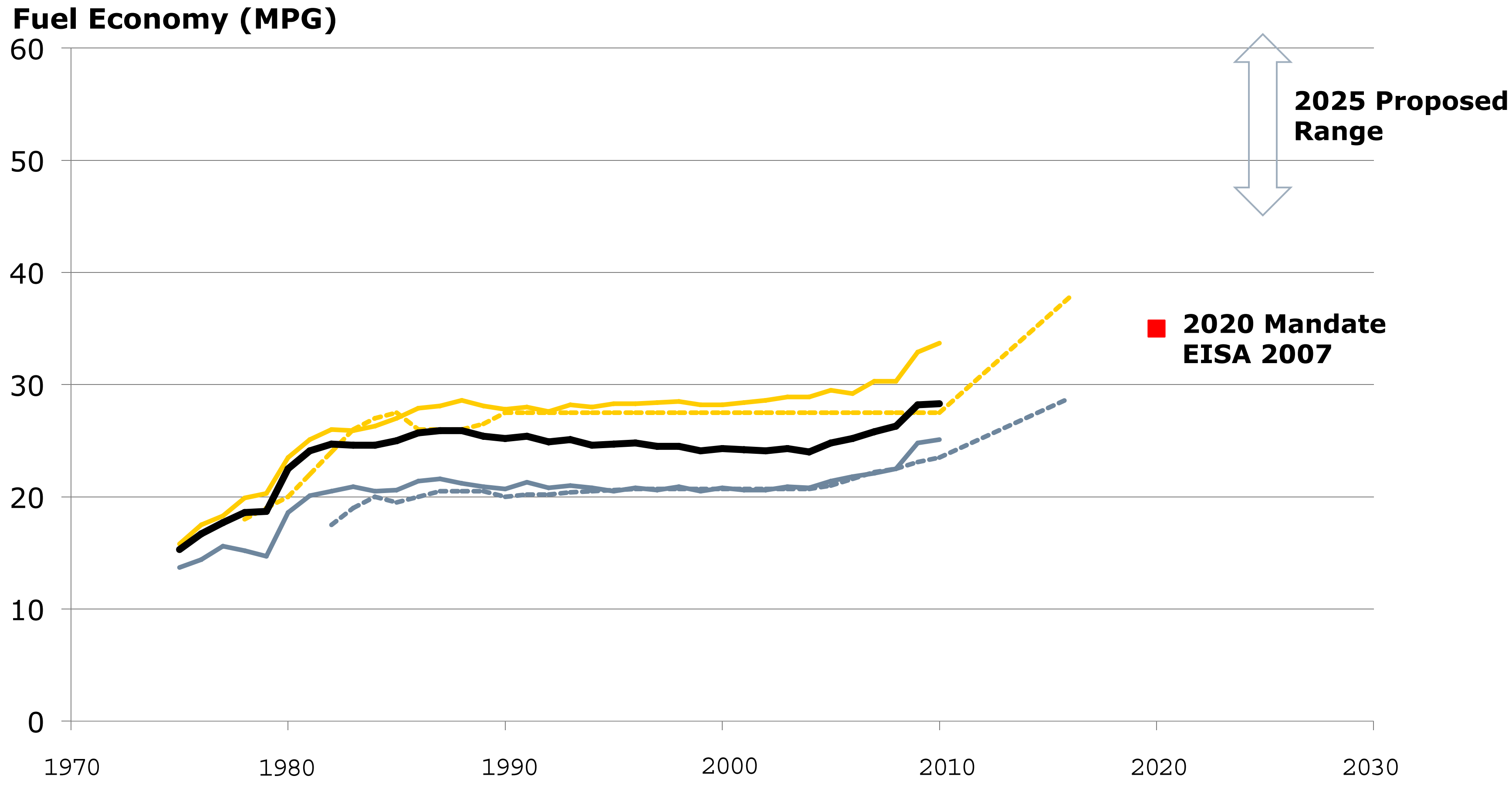
- Fuel economy is based on a test procedure from the 1970s
  - ~30% higher than real-world values or “window sticker” estimates

* Light-Duty means a gross vehicle weight rating ≤ 8,500 lbs.

http://www.cornerstonemcm.org/Cafe_Outdoor_Light_Box.jpg

Corporate Average Fuel Economy

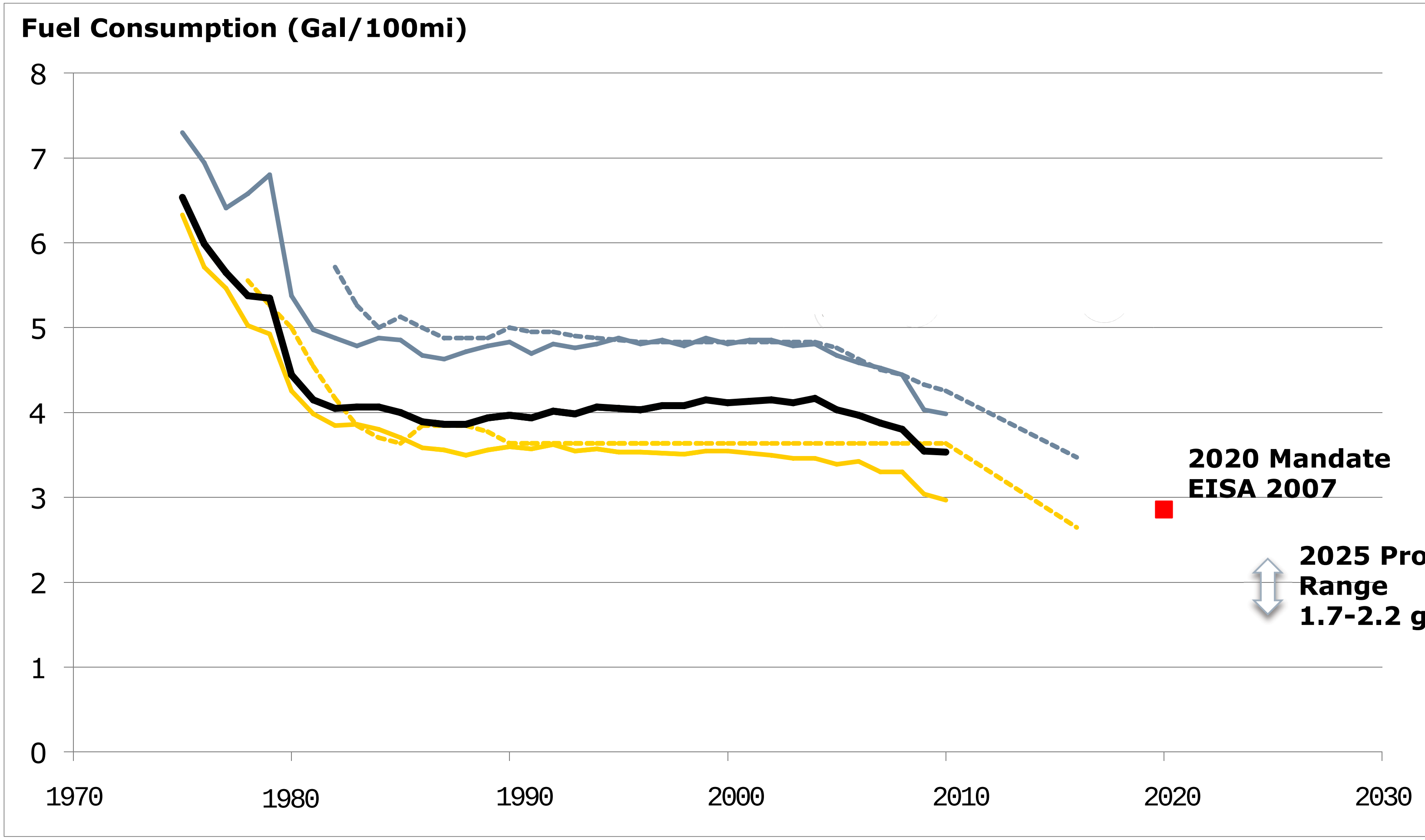
- Separate standards & calculations for cars and “light trucks”



The MPG Distortion

- MPG is inverse of metric that matters: fuel consumption

2025 Prop
Range



Corporate Average Fuel Economy

Some Details

- Electric Vehicle Credited MPG = (Energy-Equivalent MPG) / 0.15
- Credits for overcompliance can be “banked” from past 5 years or “borrowed” from next 3 years
- Flexible-fuel and bi-fuel vehicles capable of using alternative fuels earn ~60% bonus credit on fuel economy rating
  - Total benefit capped at 1.2 mpg each year
- Penalty for noncompliance = $55/mpg/vehicle

http://gas2.org/files/2009/07/flexfuel.jpg

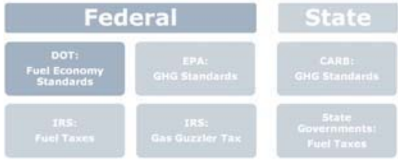
Corporate Average Fuel Economy

Recent Changes

- NHTSA now required to set *attribute-based standards*
  - Different standards for each manufacturer, based on product mix
  - Intended to reduce equity issues of regulatory cost
  - Effectively negates downsizing as a compliance strategy
- Credits can now be traded between fleets and between manufacturers
  - Subject to certain restrictions

http://gas2.org/files/2009/07/flexfuel.jpg

Corporate Average Fuel Economy



Size-Based Standards

$$Standard = \frac{\sum_i Sales_i}{\sum_i \frac{Sales_i}{f(footprint_i)}}$$

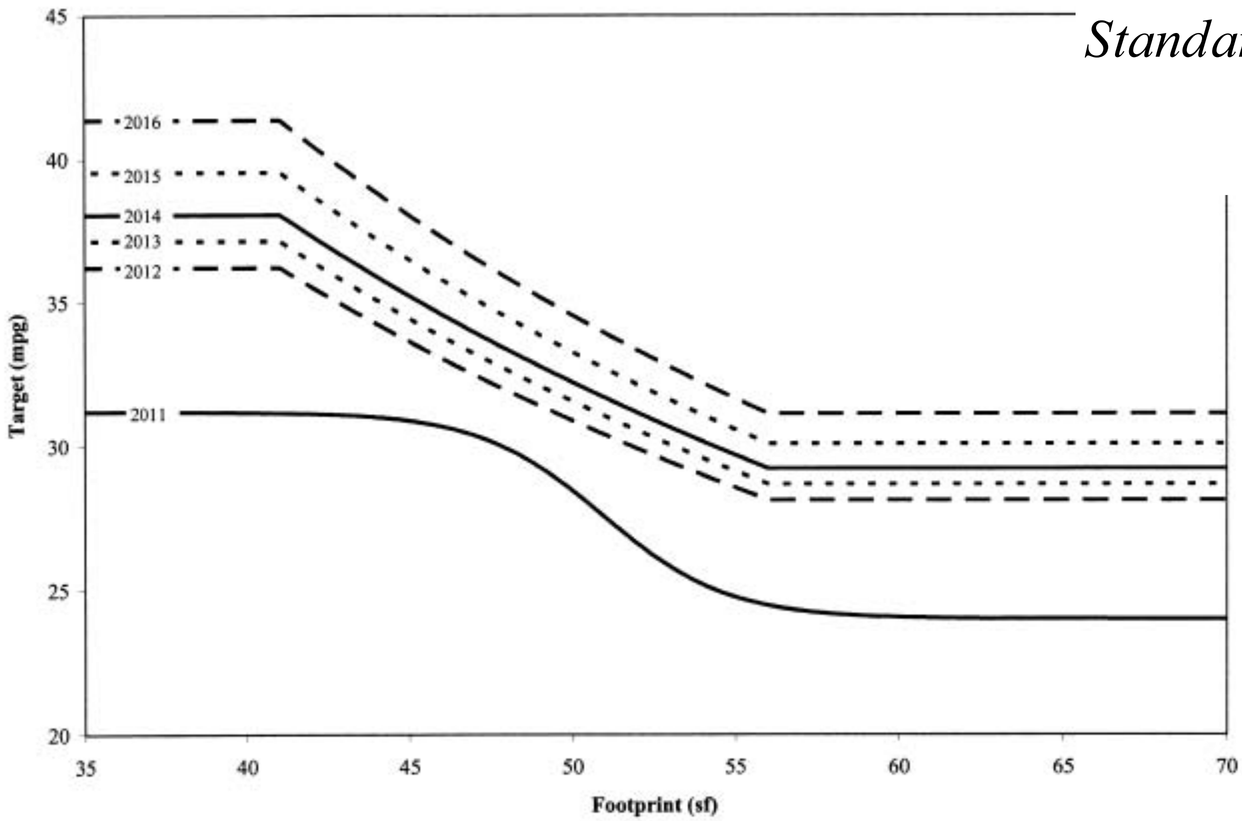


Figure I.D.3-1 Final MY 2011 and Proposed MY 2012-2016 Passenger Car Fuel Economy Targets

Federal Register / Vol. 74, No. 186 / Monday, September 28, 2009 / Proposed Rules

Corporate Average Fuel Economy

Size-Based Standards

$$Standard = \frac{\sum_i Sales_i}{\sum_i \frac{Sales_i}{f(footprint_i)}}$$

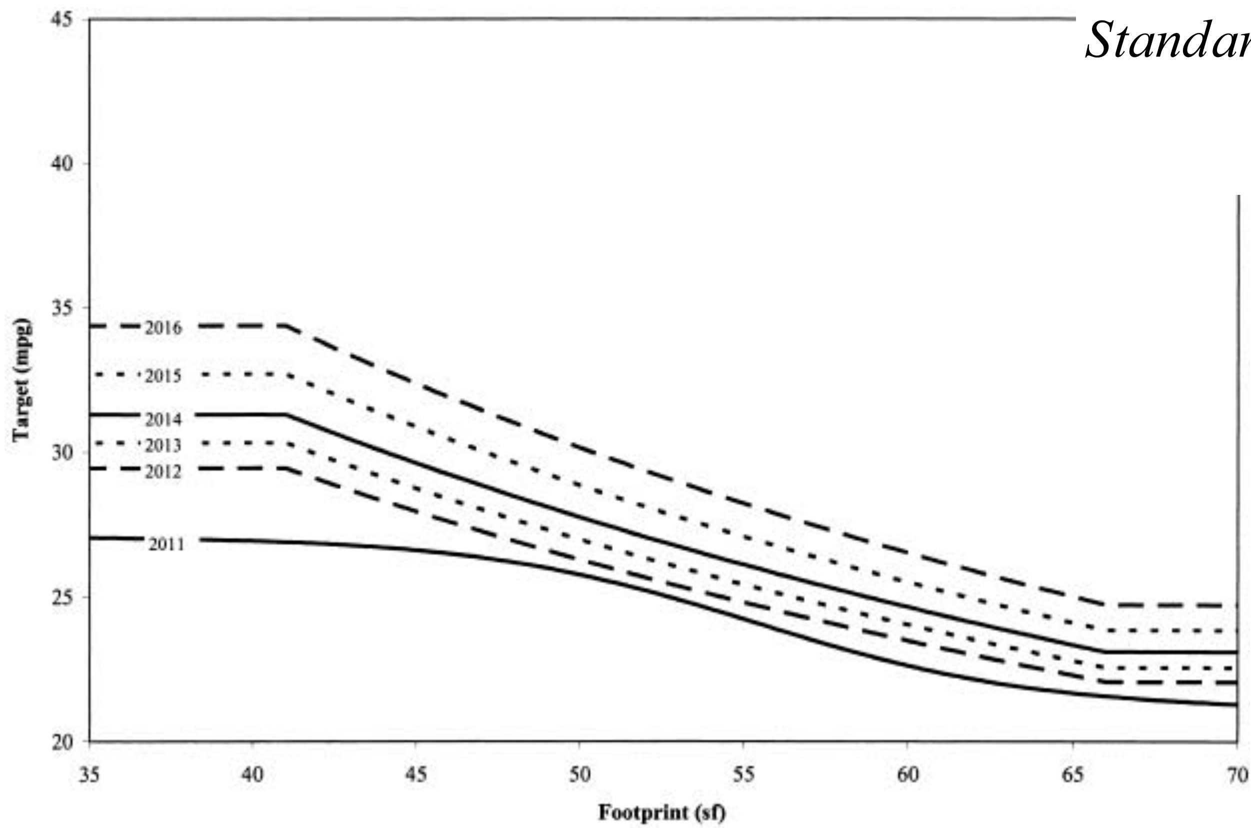


Figure I.D.3-2. Final MY 2011 and Proposed MY 2012-2016 Light Truck Fuel Economy Targets

Federal Register / Vol. 74, No. 186 / Monday, September 28, 2009 / Proposed Rules

Corporate Average Fuel Economy

How Standards are Set

- Cost-benefit analysis including discounted lifetime fuel expenses, estimated technology costs, monetized values of non-financial costs and benefits
- Applies efficiency-enhancing technologies in order of cost effectiveness, subject to judgment-based constraints
- Equalizes marginal cost of more technology with marginal benefit

World’s biggest black box?

Vehicle GHG Standards

- **(2002)** "Pavley" GHG standards required by California Assembly Bill 1493, to be implemented by California Air Resources Board
  - 13 other states opt in to California's standards under Clean Air Act provisions
- **(2004)** Auto manufacturers, trade associations, dealers sue, citing principle that GHG regulation is tantamount to fuel economy regulation, explicitly preempted by CAFE law
- **(2007)** Supreme Court rules in Massachusetts v EPA that GHGs are pollutants under the Clean Air Act
- **(2007)** Bush Administration denies California "waiver" from federal preemption (waiver needed to implement regulations)
- **(2009)** Obama administration grants waiver, brokers truce between manufacturers and states, announces harmonized state & federal standards. Dealers continue to sue.

Federal		State
DOT: Fuel Economy Standards	EPA: GHG Standards	CARB: GHG Standards
IRS: Fuel Taxes	IRS: Gas Guzzler Tax	State Governments: Fuel Taxes

Vehicle GHG Standards

$$Standard = \frac{\sum_i Sales_i \cdot f(footprint_i)}{\sum_i Sales_i}$$

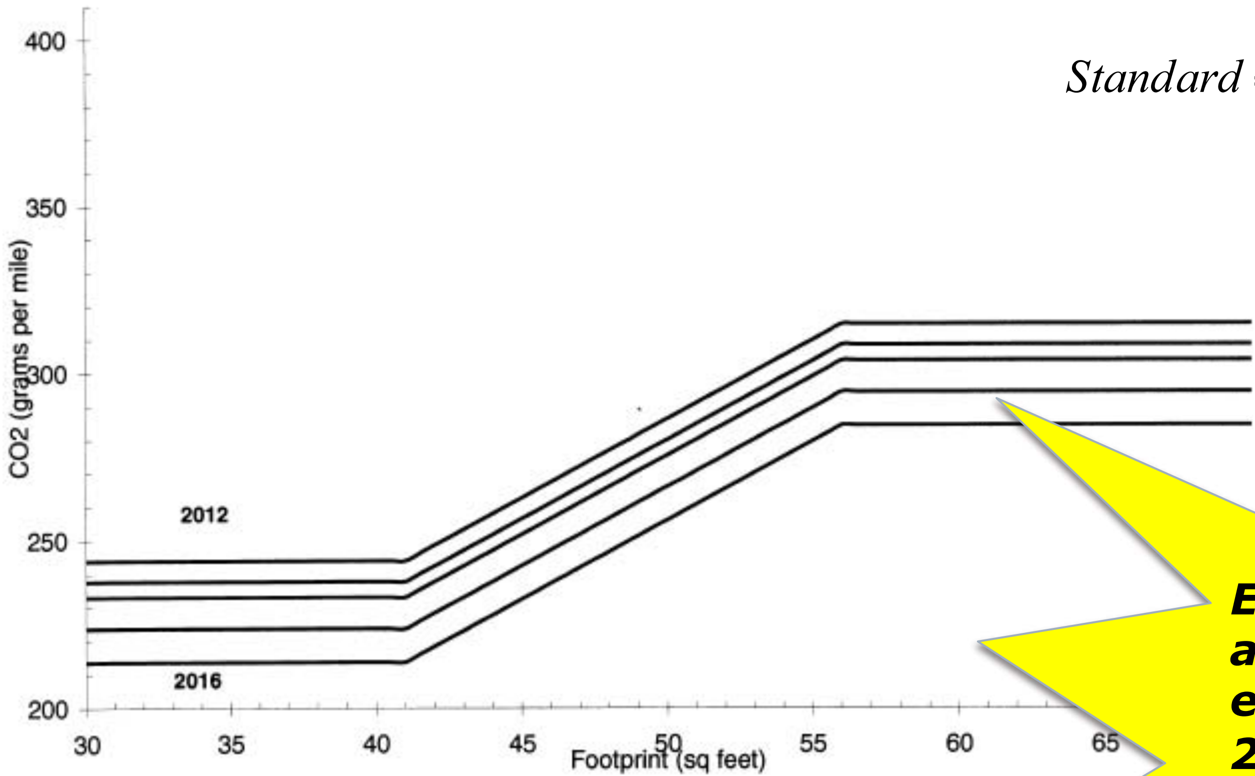


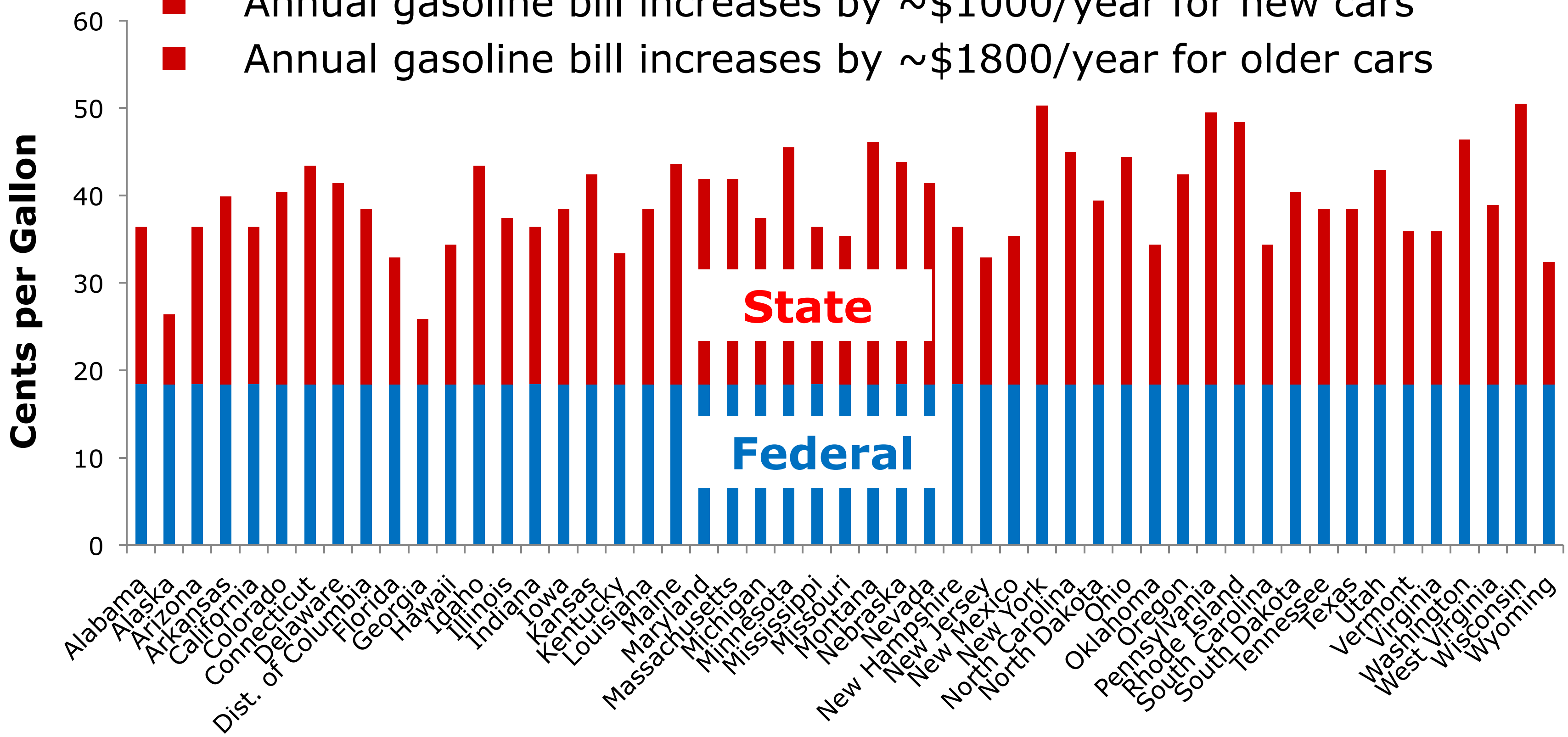
Figure I.D.3-3. CO2 (g/mi) Car standard curves.

Electric vehicles assumed to have zero emissions, up to first 200,000-300,000 produced.

Federal Register / Vol. 74, No. 186 / Monday, September 28, 2009 / Proposed Ru

Gasoline Taxes

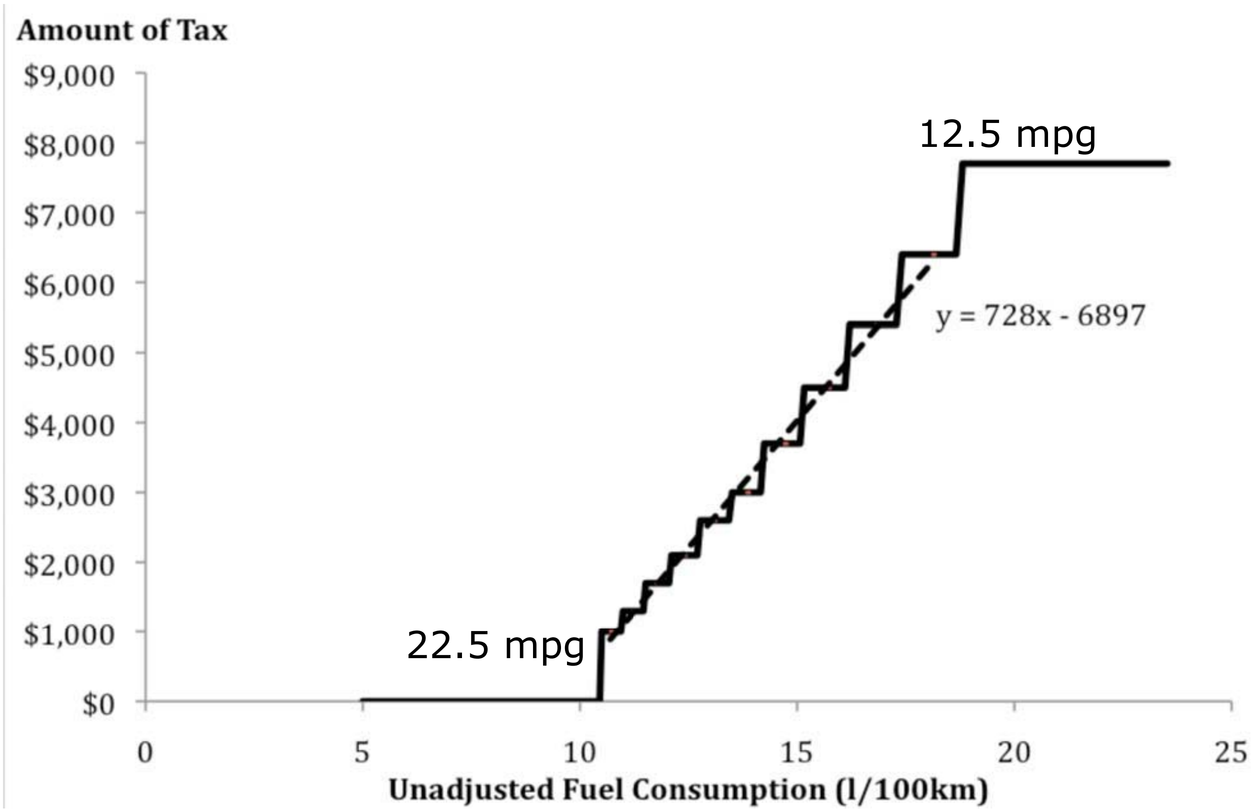
- 10% increase in fuel price → 3.3% increase in MPG (long term)
- To go from 26 → 35 MPG:
  - Need gas to go from $2/gal to ~$5/gal
  - Annual gasoline bill increases by ~$1000/year for new cars
  - Annual gasoline bill increases by ~$1800/year for older cars



http://www.gaspricewatch.com/usgastaxes.asp

Gas Guzzler Tax

- Applies only to cars, not light trucks



Other Policies

- Feebates
  - Fee + Rebate, purchase incentive system
  - Greater cost certainty, less emissions certainty relative to CAFE
  - Recently adopted in France, initial results promising
- Cap & Trade
  - Would effectively be a gas tax
  - \$10 / tonne CO_2 ~ \$0.10 / gallon
- Cash for Clunkers
  - Not energy/carbon policy
    - \$200+ per ton of avoided emissions (Knittel, 2009)
  - More effective if goals are criteria pollutant emissions
  - *Maybe* effective as economic stimulus

Knittel, C. 2009. *The implied cost of carbon dioxide under the cash for clunkers program.* Centel Cl t0e Study C Enelgy Malkets, Univelsity C Cali Clnia Enelgy Institute. CSEM WP 189. Belkeley.

Advantages and Disadvantages of Policies

	Pros	Cons
Standards	+Emissions certainty +Well-established	-Rebound effect takes back ~10% of benefits, increases other externalities -Uncertain costs -No incentive to exceed standard -Disparate impact on manufacturers
Incentives	+Cost certainty +Stimulates continuous improvement	-Little experience -Reduced operating cost → rebound effect
Fuel Taxes	+Drives reductions throughout system	-Hits consumers hardest, especially w/ older vehicles -Politically difficult

Current Issues…

…being dealt with

- How to include electric vehicles & plug-in hybrids
- State versus Federal regulation

… and not being dealt with

- How to sustain increases in fuel economy over the long term
- Cost to manufacturers of meeting regulations