Transportation Energy Use

Mechanical Engineering 694C

Seminar in Energy Resources, Technology and Policy

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Remind students to turn in homework.

This week's reading is pages 188 to 213 in Fay and Golomb

Next week's reading is pages 277 to 297 in Fay and Golomb and the NAS report on Global Warming that can be downloaded from the course web site on the schedule page.

Problems assigned today (due next week) 8.5 (assume a lifetime of 7 years a new vehicle cost of $30,000, a trade-in value of $8,000 and an effective interest rate of 8%. How much extra would you be willing to pay if you got 25 miles per gallon instead of 22?), 8.6, 8.7 and 8.10.

Outline

- Kinds of transportation energy
- Calculating vehicular energy use
- Considering the overall engine, drivetrain, vehicle system
- Fuel economy test procedures and regulations
- Trends in fuel economy

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As we have discussed previously, transportation energy use accounts for about 25% of the total energy use in the US. Almost all of this energy is petroleum and in 2000 transportation accounted for 68,1% of the petroleum consumed in the US. (ORNL Transportation Energy Data Book, Edition 21, Table 1.10.)

Sixty percent of the total transportation energy use is consumed in cars and light-duty trucks. The latter are usually defined either as trucks with only two axles and four tires or as trucks with a gross vehicle weight rating (GVWR) less than 8,500 pounds.

Because of the large share that cars and light-duty trucks have in the transportation energy picture, they have been subject to regulations that we will discuss as part of this lecture.

1999 Energy Data

- Transportation Energy Data Book total is 26.7 quads
- Look at different modes and fuel uses
- Main components of other category
  – Jet fuel for aircraft 2.5 quads
  – Residual fuel for ships 0.7 quads
  – Natural gas pipelines 1 quad (0.25 from electricity)

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Reference: Stacy C. Davis, “Transportation Energy Data Book,” US Department of Energy, Oak Ridge National Laboratory, Edition 21, ORNL-6966, September 2001. Tables available at http://www-cta.ornl.gov/cta/data/Chapter2.html

All data in trillion Btu; divide by 1000 to get quads.

1999 Domestic Transportation Energy Consumption by Mode and Fuel (trillion Btu)

	Gasoline	Diesel fuel	Other	Total
HIGHWAY	15,958.3	4,549.1	32.6	20,540.0
Light vehicles	15,430.2	330.1	9.6	15,769.9
Automobiles	9,044.9	81.2	0.0	9,126.1
Light trucks	6,358.9	248.9	9.6	6,617.4
Motorcycles	26.4		0.0	26.4
Buses	11.0	188.5	7.9	207.4
Transit	4.1	85.7	7.9	97.7
Intercity		33.4	0.0	33.4
School	6.9	69.4	0.0	76.3
Trucks*	517.1	4,030.5	15.1	4,562.7
OFF-HIGHWAY	110.0	570.1	0.0	680.1
Construction	22.2	178.5	0.0	200.7
Agriculture	87.8	391.6	0.0	479.4

(Table concluded on next page.)

*This is medium and heavy trucks (all trucks other than two-axle, four-wheel trucks)

Transportation Energy 1999

Category	Gasoline	Diesel	Other	Total
LDV	15.43	0.33	0.01	15.77
Truck/Bus	0.53	4.22	0.02	4.77
OffHwy	0.11	0.57		0.68
Air	0.04		2.50	2.55
Water	0.31	0.29	0.69	1.30
Pipeline			1.01	1.01
Rail		0.54	0.07	0.61
Total	16.42	5.95	4.31	26.68

1999 Domestic Transportation Energy Continued (trillion Btu)

	Gasoline	Diesel fuel	Other	Total
<u>NONHIGHWAY</u>	351.6	835.6	4,273.6	5,460.8
Air	41.5		2,504.1	2,545.6
General	41.5		130.6	172.1
Domestic air			2,004.0	2,004.0
International			369.5	369.5
Water	310.1	294.8	694.6	1,299.5
Freight		294.8	694.6	989.4
Recreational	310.1		0.0	310.1
Pipeline			1,009.2	1,009.2
Rail		540.8	65.7	606.5
Freight (Class I)	520.1		520.1	0.0
Passenger		20.7	65.7	86.4
Transit			44.7	44.7
Commuter		10.1	15.5	25.6
Intercityc		10.6	5.5	16.1
TOTAL	16,419.9	5,954.8	4,306.2	26,680.9

Vehicular Energy Use

- Energy required to overcome
  - Rolling friction forces
  - Aerodynamic drag forces
- Positive or negative energy transfer
  - Acceleration/deceleration
  - Climbing/descending a grade
  - Not fully recovered if brakes used

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Energy is provided to the drive wheels of a vehicle to overcome resistances due to rolling friction and aerodynamic drag. The energy used to overcome these forces is transformed into heat and cannot be recovered.

Energy used to accelerate the vehicle and energy used to climb grades can, in principle, be recovered through deceleration and descending grades. However, the ability to recover this energy is limited by the need to control the vehicle speed which requires application of brakes. Braking will transform the kinetic energy of the vehicle into heat and further consume the primary fuel source provided to the vehicle.

Vehicular Power Equations

$$P_{engine} = \frac{P_{wheel}}{\eta_{drivetrain}} = \frac{P_{rf} + P_{aero} + P_{accel} + P_{grade}}{\eta_{drivetrain}}$$

$$P_{rf} = WfV \qquad P_{aero} = \frac{\rho_{air} C_D A_F V^3}{2}$$

$$P_{accel} = W\frac{a}{g}V \qquad P_{grade} = WV\sin(\theta) = \frac{WVb}{\sqrt{1+b^2}} \approx WVb$$

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The following symbols are defined in these equations. Both dimensions and SI units are shown.

P is the vehicle power (or its components) in watts

W is the vehicle weight (mass times acceleration) in kg-m/s^2 = N

V is the vehicle speed (length/time) in m/s

f is the rolling friction coefficient (dimensionless)

ρ_{air} is the density of air (mass/volume) ~1.2 kg/m^3

C_D is the aerodynamic drag coefficient (dimensionless)

A_F is the frontal area of the vehicle in m2; this is the area you would measure if you took a picture of the vehicle.

a is the vehicle acceleration (mass/time^2) in m/s^2

g is the acceleration of gravity = 9.81 m/s^2

θ is the angle of a grade

b = tan(θ) is the slope of a grade (the usual measure of a grade)

The final approximate for the power used in climbing a grade is often used. It has a small error, as shown in the table below, for most practical grades.

grade	0.01	0.02	0.05	0.1	0.2
sin(θ)	0.0099995	0.019996	0.049938	0.099504	0.196116
error	0.005%	0.020%	0.125%	0.499%	1.980%

In English engineering units the power is in hp, the weight in lb_f, the speed in mph or ft/s (30 mph = 44 ft/s), ρ_{air} ~ 0.765 lb_m/ft^3, g = 32.16 ft/s^2, and A_F is in ft^2. Unit conversion factors are required with these units.

Vehicular Fuel Use

- Based on usual definition of engine efficiency for conversion of heat to work

$$\dot{m}_{fuel} = \frac{P_{engine}}{\eta_{engine} Q_c} = \frac{P_{wheel}}{\eta_{engine} Q_c \eta_{drivetrain}}$$

- Equations on this chart and previous chart are for instantaneous values
- Look at average over various speeds and accelerations

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The equations for vehicle power on the previous slide and the equation above for the fuel use guide us seeking ways to reduce fuel use. Simply reduce all the items that are in the numerator and increase all the items that are in the denominator.

We will not consider the heat of combustion of the fuel as a factor. (From an energy perspective we want to reduce the product of the fuel flow rate times the heat of combustion, but most analyses of automotive fuel use focus on the fuel mass flow rate.)

We will not discuss the idea of reducing vehicular speed limits which has proven to be an unpopular measure.

Another idea that we will not discuss is the impact of congestion on fuel use. In congested traffic there is a significant amount of acceleration and braking. Improving traffic flow can improve the overall energy use by smoothing the traffic flow. The computation of the energy and emission benefits from such a strategy is a difficult one and various research groups are still trying to determine the best way to do this. Models that have been used for such calculations in the past are generally thought to lack sufficient accuracy.

Improving Fuel Economy

- Improve engine efficiency
- Improve drivetrain efficiency
- Reduce weight
- Reduce rolling friction coefficient
- Reduce aerodynamic drag coefficient
- Consider vehicle, engine, and drivetrain as system for efficiency considerations

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All of the ideas listed above follow from a simple consideration of the equations that are used to determine fuel consumption. However we have to examine the relationship among the engine, the drivetrain, and the vehicle to really see how the various components of fuel economy reduction interact.

In order to do this we will have to provide a simple introduction to some terms in automotive engineering.

Automotive Engineering

- Fuel economy (miles per gallon, km/L)
- Brake-specific fuel consumption (bsfc kg/kW or pounds per HPhr)
- Engine speed (N), torque (T) and power ($P = 2\pi NT$)
- Brake mean effective pressure (work per unit volume of displacement)

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Equations

$$Efficiency, \eta = \frac{\dot{W}}{\dot{Q}} = \frac{P}{\dot{m}Q_c} = \frac{1}{(bsfc)Q_c}$$

$$bmep = \frac{\dot{W}}{\dot{V}} = \frac{P}{\frac{NV_D}{n_R}} = \frac{2\pi T n_R}{V_D}$$

$$P = 2\pi NT = 2\pi N \frac{bmep}{2\pi n_R} V_D = V_D \frac{N}{n_R} bmep$$

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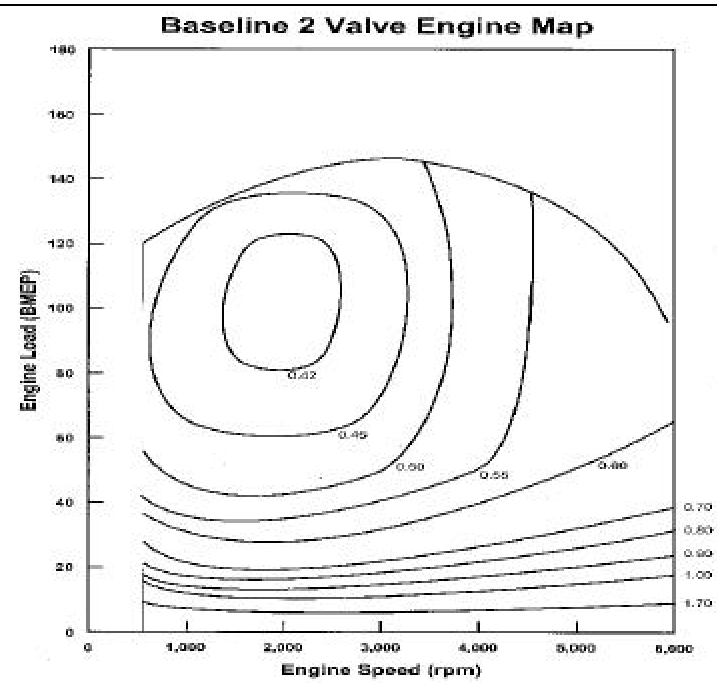
In these equations we have introduced two new variables. The first, V_D, is the displacement volume, the volume swept by the piston. This is the volume that we would plot on a thermodynamic P-v diagram.

The other new variable is n_R. This is the number of crankshaft revolutions per power stroke for one cylinder. n_R equals two for four-stroke cycles and two for two-stroke cycles. (Thus N/n_R) is the number of times the displacement volume is swept out per power stroke.

The bmep is a variable that usually has a maximum value between 100 and 200 psi for gasoline engines. We can increase the power output of an engine by increasing its size (i.e., the displacement volume) or its rotational speed, N. However, the bmep definition divides the power by both of these factors. Thus an increase in either of these will not increase the maximum bmep. Thus an engine with a high maximum bmep is considered to be one with effective design for high power.

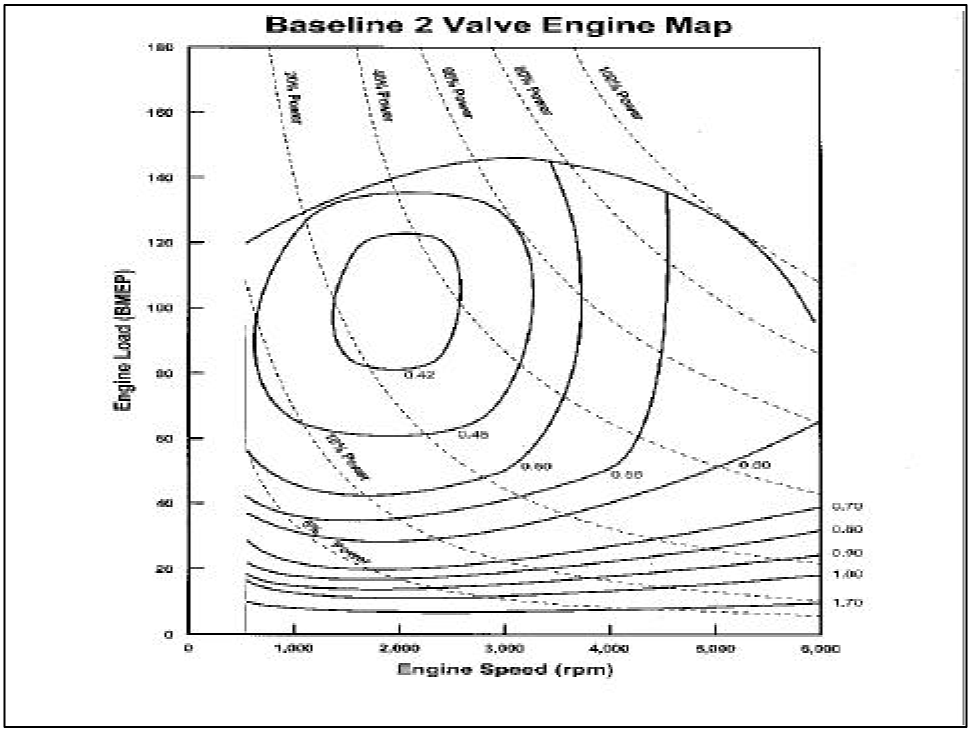
The final equation shows that we can compute the engine power in terms of the rotational speed, the bmep and the displacement. Notice that if the power is constant the equation relating N and bmep is a hyperbola.



Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles," Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

This is a typical plot of engine efficiency (or rather the inverse of efficiency as measured by the bsfc), known as an engine map. This one is for a typical mid-size vehicle such as a Ford Tarus. The actual data for the engine map is taken from composite data from various manufacturers that were averaged to maintain confidentiality.

The efficiency improves as we get to higher loads (expressed as the bmep). Note that the efficiency is especially poor at low loads.



Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, “Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles,” Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

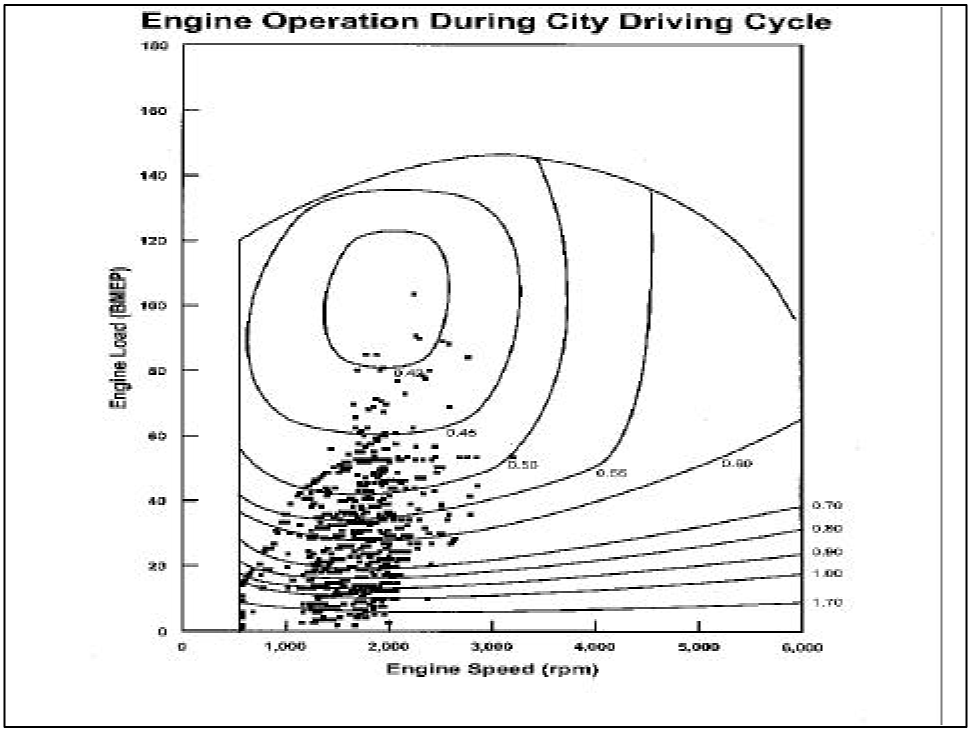
This diagram is the same as the other one except that contours of constant power have been plotted.

On the slide before the previous one we said that the line of constant power on a bmep-rpm plot would be a hyperbola. Here we see that to be the case.

As the engine speed increases it becomes harder to get a full cylinder of air. Thus the bmep drops off. However the increase in speed gives the maximum power somewhere past the peak bmep point. (The peak bmep point is the same as the peak torque point.

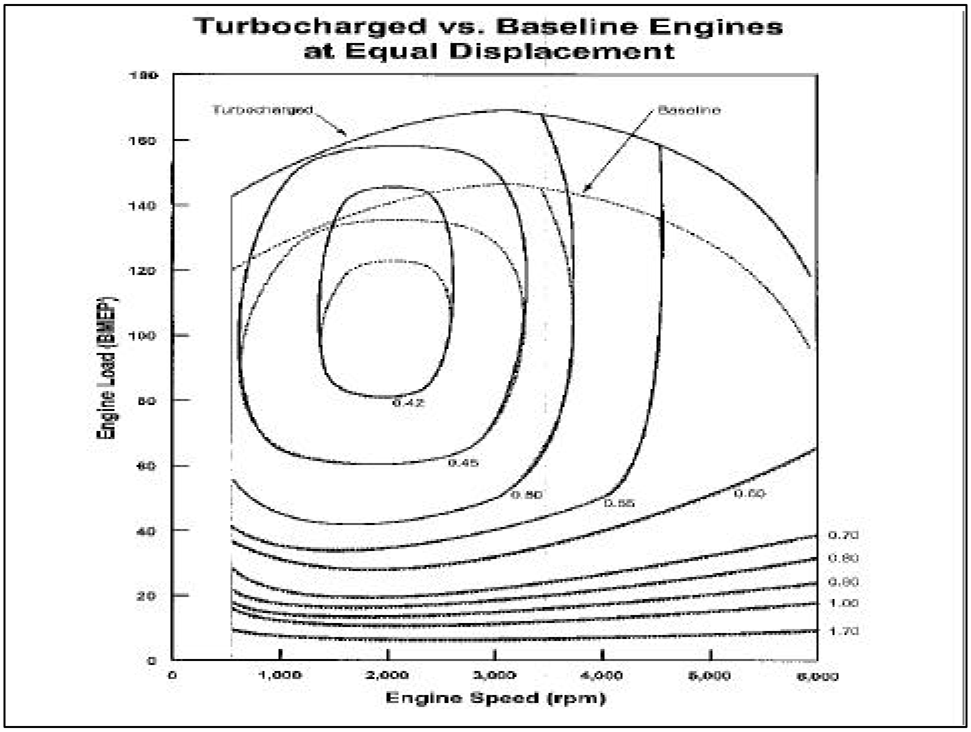
When we have a car with a large amount of power, typically measured as the power-to-weight ratio, it will have high performance as measured by top speed and acceleration times. However, it will require a small fraction of power to operate during normal road load conditions. This means that is will spend a large amount of time operating under conditions where the efficiency is poor.

Techniques that increase the maximum engine power without requiring larger displacement are useful in improving the average operating efficiency of the engine. Two of these techniques are four-valve engines that allow higher bmep operations at high engine rpm and turbocharging. We will see the impact of these on the next few slides.



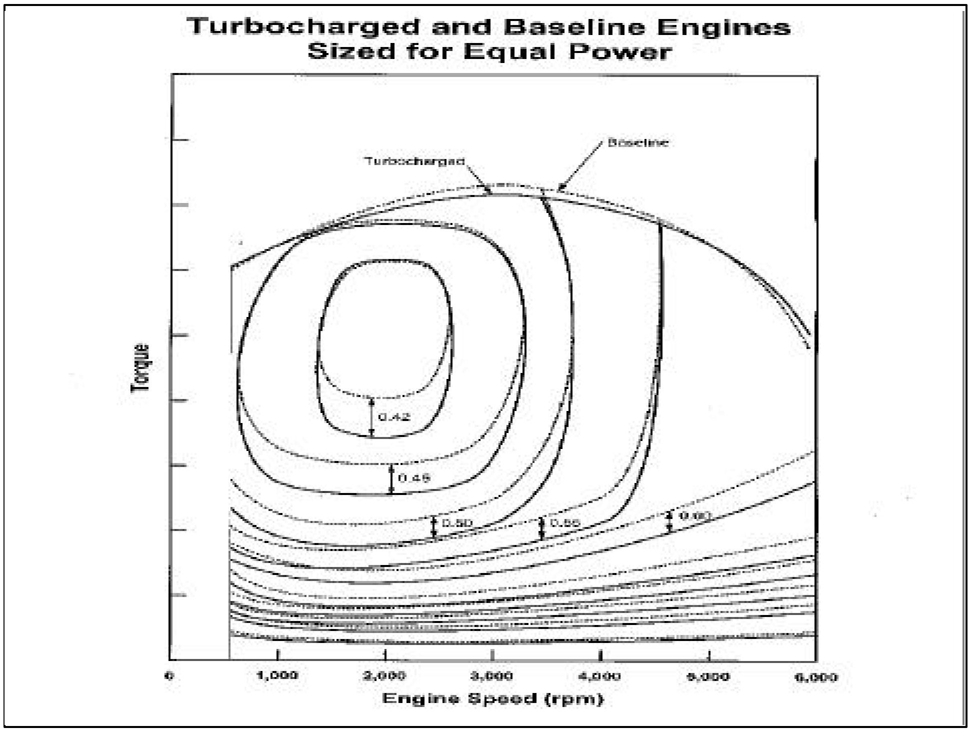
Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, “Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles,” Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

This chart shows the second-by-second operating points on the EPA urban driving cycle that is used for measuring fuel economy. The chart was generated using the actual speed versus time trace to define the load on a vehicle. (This cycle is shown later in this presentation.)



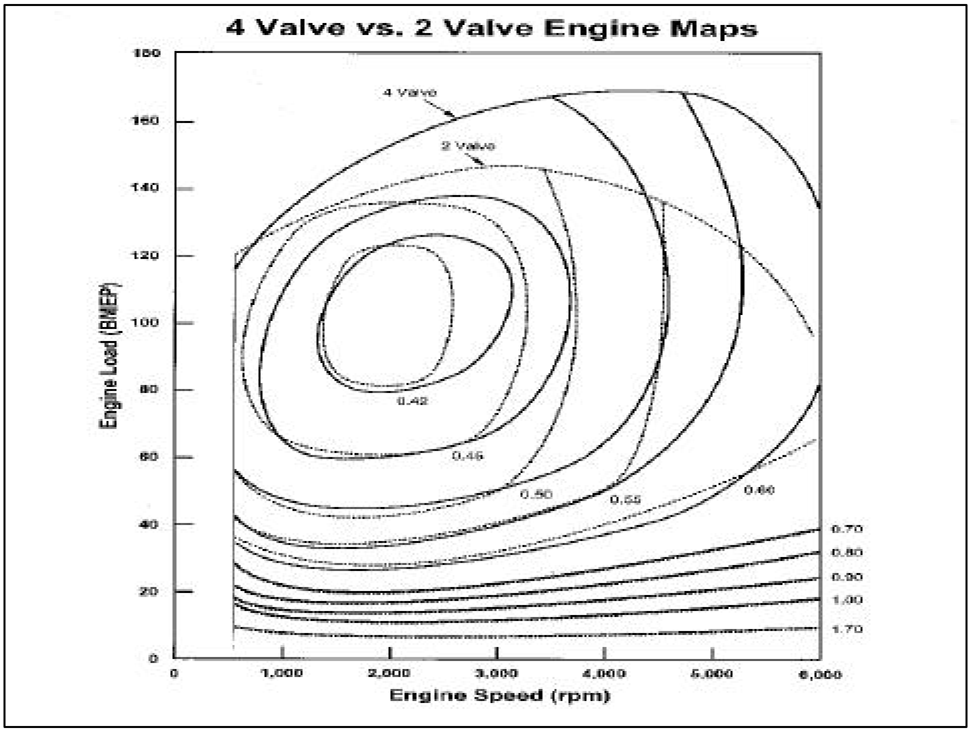
Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles," Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

This chart shows the effect of adding a turbocharger to an engine. It is able to process more air and this produce more power than a naturally aspirated engine. This chart is based on the assumption that a turbocharger is added to the engine and no other changes are made in the size of the engine. This would increase the peak power of the vehicle, but would not make any significant change in the fuel economy.



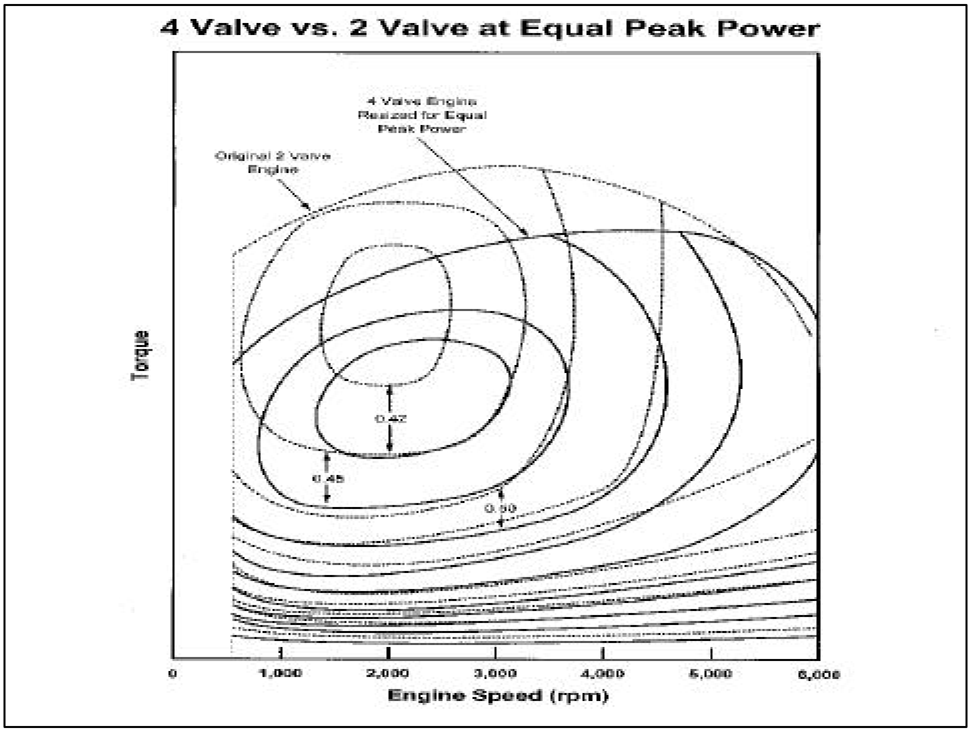
Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, “Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles,” Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

This chart shows the effect of adding a turbocharger to an engine that has been redesigned to produce the same power as an engine without a turbocharger. In this case the engine has higher efficiency when operating at low load points.



Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, “Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles,” Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

This chart is similar to the next to last chart. That chart showed the effect of adding a turbocharger to an engine without changing its size. It is able to process more air and this produce more power than a naturally aspirated engine. Here we assume that we add two additional valves to the engine without changing its displacement. The added valving allows the engine to process more air. This increases the peak power of the engine, but does not improve the fuel economy.

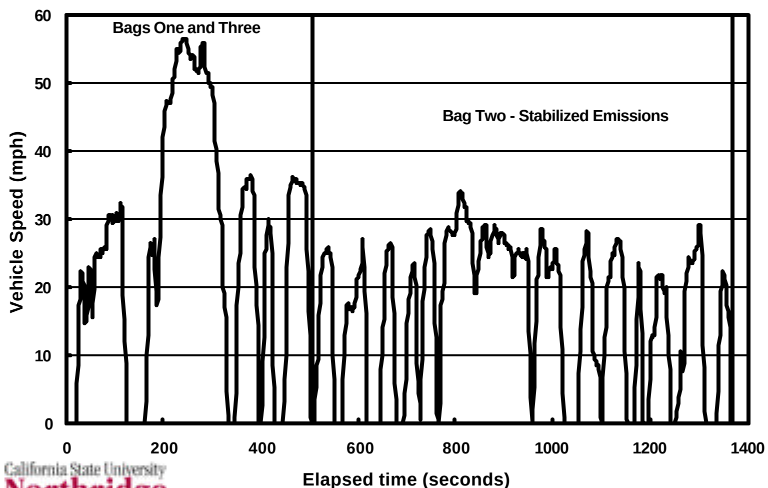


Reference: T. C. Austin, R. G. Dulla, and T. C. Carlson, "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles," Prepared for the Transportation Table Subgroup on Road Vehicle Technology and Fuels, Transport Canada, Sierra Research, Sacramento, CA, July 8, 1999. See http://www.tc.gc.ca/envaffairs/subgroups1/vehicle_technology/study2/Final_report/Final_Report.htm

This chart is similar to the one that showed the effect of adding a turbocharger to an engine that has been redesigned to produce the same power as an engine without a turbocharger.

Here we consider a four-valve engine that has been resized (i.e. designed with a lower displacement volume) to produce the same peak power as an equivalent two-valve engine. In this case the engine has higher efficiency when operating at low load points.

City Fuel Economy Test



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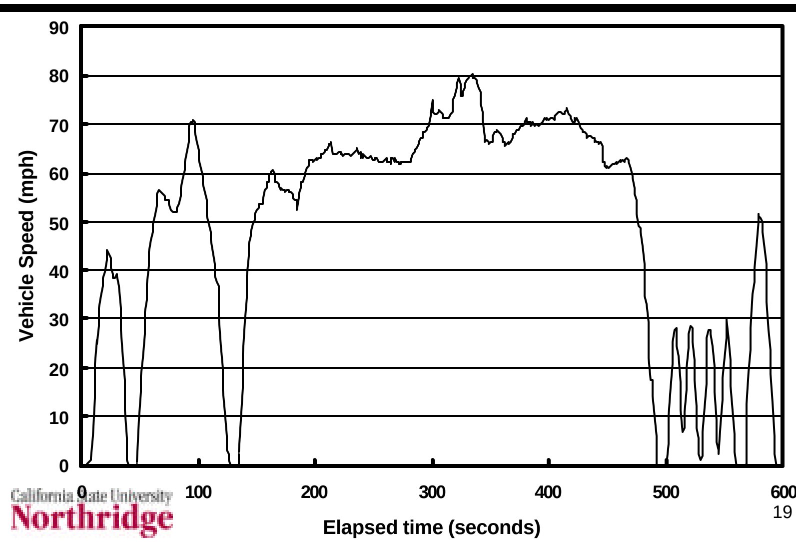
This chart shows the driving cycle that is used for the city fuel economy test. It was originally developed for testing cars and light duty trucks for emissions in a typical urban environment.

The test cycle simulates driving a route of 7.5 miles with an average speed of 19.6 mph. A cold-start (twelve hours engine-off time or soak time) and a hot-start (10 minutes soak time) trip over this route are weighted equally in computing the overall emissions. In practice, the trip is divided into two parts. The first part represents transient emissions after start. The test for this part lasts for 505 seconds and covers 3.59 miles. The second part represents stabilized emissions with a warmed engine and catalyst. This part lasts 867 seconds and covers 3.91 miles. The average speeds of the transient and stabilized parts are 25.6 mph and 16.2 mph. The overall average speed is 19.6 mph.

In the actual measurement, the stabilized part is measured only one time and the results of this measurement are assumed to apply to both the hot-start and the cold-start trips. The measured emissions consist of three parts: bag one, represents the cold start transient emissions; bag two represents the stabilized emissions after the engine is warm; bag three, represents the hot-start transient emissions.

Only the hot start emissions are considered in the standard fuel economy test for city driving.

Supplementary Cycle



This cycle has nothing to do with fuel economy. It was added to the emissions test procedure starting with the 2002 model year. This cycle will test vehicles in high power operation to ensure that they meet the emission standards in real-world driving.

The certification emissions from the federal test procedure (FTP), shown on the previous slide, are computed in the following manner:

Average Emissions = 43% (cold-start trip) + 57% (hot-start trip)

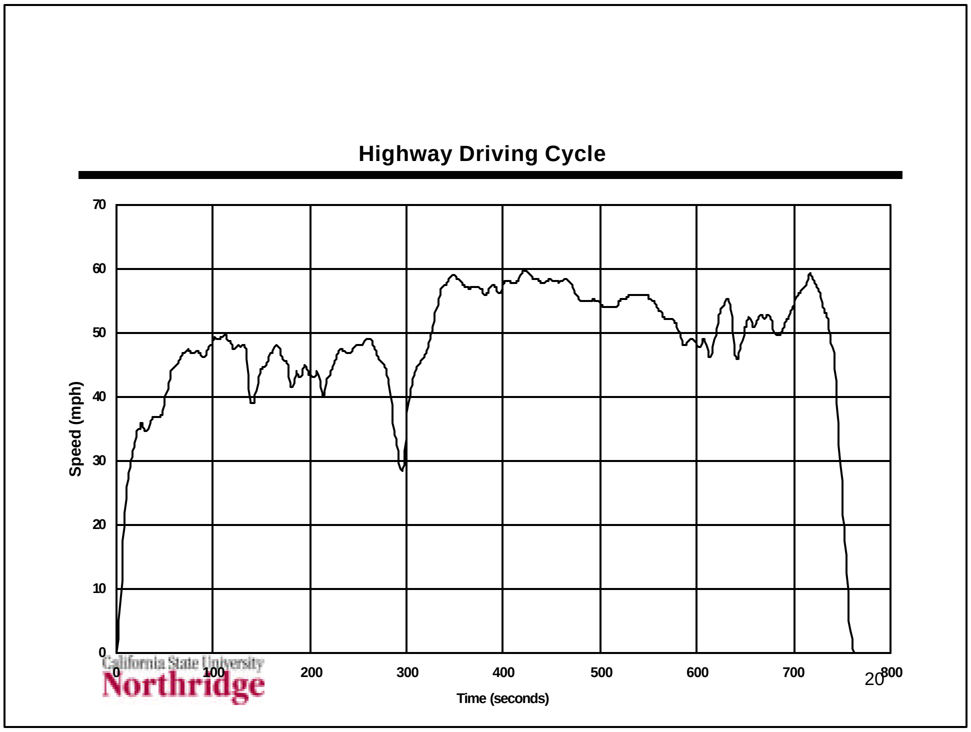
Cold-start trip (g/mi) = [(3.59 miles) (cold-start phase g/mi) +
(3.91 miles) (stabilized phase g/mi)] / (7.5 miles)

Hot-start trip (g/mi) = [(3.59 miles) (hot-start phase g/mi) +
(3.91 miles) (stabilized phase g/mi)] / (7.5 miles)

Combining these three equations gives the final weights for each phase in the certification test procedure.

Average Emissions = 0.206 (Cold-start phase) + 0.521 (Stabilized phase)
+ 0.273 (Hot-start phase)

These average emissions are the ones usually reported for vehicle emission standards. Separate standards for the supplemental cycle, known as the supplemental federal test procedure or SFTP are handled separately



This is the cycle used for the highway fuel economy test. You can see that it has very little high speed driving that is encountered on a typical modem freeway outside an urban area (or inside an urban area outside of rush hours.) The discrepancy between the operation over this cycle and actual highway driving leads to an adjustment in the reported fuel economy that is only 78% of the fuel economy measured on this cycle.

Fuel Economy Regulations

- Fuel economy regulations are based on measured fuel economy
- Required labels on new cars have adjustments to account for actual driving conditions
  - City mpg multiplied by 90%
  - Measured highway mpg multiplied by 78%

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The Secretary of Transportation is required to administer a program for regulating the fuel economy of new passenger cars and light trucks in the United States market. The authority to administer the program was delegated by the Secretary to the Administrator of NHTSA, 49 C.F.R. 1.50(f).

NHTSA's responsibilities in the fuel economy area include: (1) establishing and amending average fuel economy standards for manufacturers of passenger cars and light trucks, as necessary; (2) promulgating regulations concerning procedures, definitions, and reports necessary to support the fuel economy standards; (3) considering petitions for exemption from established fuel economy standards by low volume manufacturers (those producing fewer than 10,000 passenger cars annually worldwide) and establishing alternative standards for them; (4) enforcing fuel economy standards and regulations; and (5) responding to petitions concerning domestic production by foreign manufacturers, and other matters.

NHTSA is authorized to amend fuel economy standards, and it has established light truck standards each year. Congress mandated through the DOT Appropriations Acts for fiscal years 1996 through 2001, no increase from the MY 1996 value of 20.7 mpg for model years 1998 through 2003 trucks. The Congressional freeze on CAFE was repealed in mid-December 2001. All fuel economy standards through MY 2003 are listed in Table I-1.

Manufacturers perform their own fuel economy tests of new car models and submit the results to EPA. EPA is responsible for conducting its own tests or verifying the manufacturers dynamometer tests. EPA also is responsible for compiling the production data from manufacturers reports and furnishing CAFE results to NHTSA.

EPA and the department of energy are responsible for producing the fuel economy guide for consumers and maintain a web page (www.fueleconomy.gov) on fuel economy topics for consumers.

Computing Fuel Economy

- (Harmonic) average is used for individual car and corporate fleet

$$\text{Average MPG} = \frac{1}{\dfrac{0.55}{\text{City MPG}} + \dfrac{0.45}{\text{Highway MPG}}}$$

$$\text{Corporate Average} = \frac{1}{\displaystyle\sum_{\text{models}} \frac{\text{Model sales}}{\text{Model average MPG}}}$$

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The equation for the average fuel economy is derived as follows. The basic definition is simply the total miles divided by the total gallons. We then separate the fuel use in gallons into city and highway portions.

$$Average\ MPG = \frac{Total\ miles}{Total\ gallons} = \frac{Total\ miles}{City\ gallons + Highway\ gallons}$$

We can write both the city and highway fuel use as the miles in each portion divided by the fuel economy (miles per gallon or mpg). Following this we can divide the equation, top and bottom, by the total miles. These two steps give.

$$Average\ MPG = \frac{Total\ miles}{\dfrac{City\ miles}{City\ MPG} + \dfrac{Highway\ miles}{Highway\ MPG}}$$

$$Average\ MPG = \frac{1}{\dfrac{City\ miles}{Total\ miles}\dfrac{1}{City\ MPG} + \dfrac{Highway\ miles}{Total\ miles}\dfrac{1}{Highway\ MPG}}$$

The miles in each mode divided by total miles is defined as the weight for each mode.

$$City\ weight = \frac{City\ miles}{Total\ miles} \qquad Highway\ weight = \frac{Highway\ miles}{Total\ miles}$$

From the definition of the weights we see that the sum of the two weights equals one. If we substitute these definitions into the equation for the average miles per gallon, we obtain the following result.

$$Average\ MPG = \frac{1}{\dfrac{City\ weight}{City\ MPG} + \dfrac{Highway\ weight}{Highway\ MPG}}$$

Fuel Economy Standards

- Corporate Average Fuel Economy (CAFE) standards for cars and trucks
  - 27.5 mpg for cars 1996-2003
  - 20.7 mpg for trucks 1996-2003
- Credits carried forwards or backwards for three years
  - Penalty of $55 / mpg / vehicle
  - Gas guzzler tax

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The CAFE is a sales weighted calculation of the fuel economy of all vehicles sold by a manufacturer in a given year. The calculation uses a weighted harmonic mean similar to that used for the calculation of the average fuel economy for one vehicle.

The gas guzzler tax is collected by the IRS. The table below shows the gas guzzler tax rate which has been in effect since January 1, 1991. This tax applies only to passenger cars, not to minivans, sport utility vehicles, or pick-up trucks.

at least 22.5 mpg No tax

at least 21.5, but less than 22.5 mpg $1000

at least 20.5, but less than 21.5 mpg $1300

at least 19.5, but less than 20.5 mpg $1700

at least 18.5, but less than 19.5 mpg $2100

at least 17.5, but less than 18.5 mpg $2600

at least 16.5, but less than 17.5 mpg $3000

at least 15.5, but less than 16.5 mpg $3700

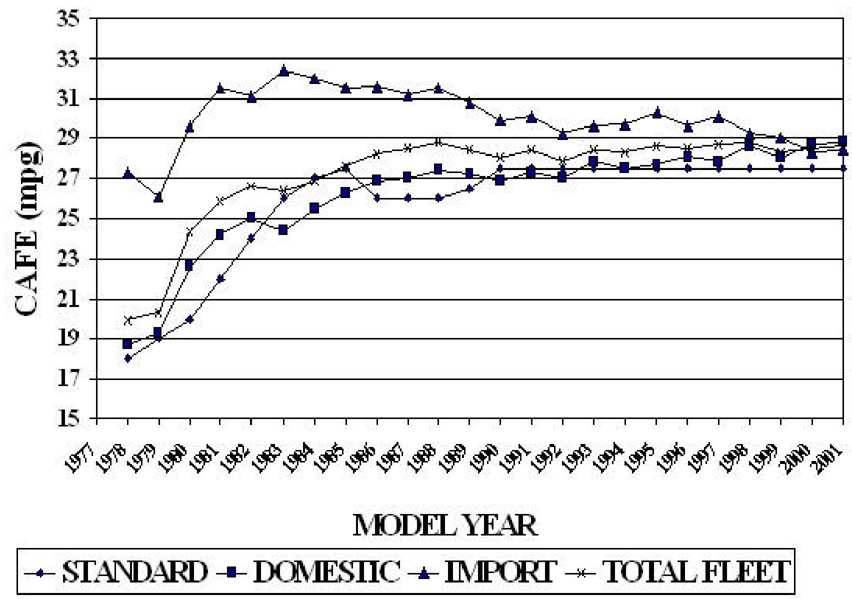
at least 14.5, but less than 15.5 mpg $4500

at least 13.5, but less than 14.5 mpg $5400

at least 12.5, but less than 13.5 mpg $6400

less than 12.5 mpg $7700

Reference: http://www.epa.gov/otaq/cert/factshts/fefact01.pdf



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Reference: U.S. Department of Transportation, National Highway Traffic Safety Administration, “Automotive Fuel Economy Program. Annual Update Calendar Year 2001,” Report DOT HS 809 512, September 2002, available on web at http://www.nhtsa.dot.gov/cars/problems/studies/fuelecon/

2000-2001 CAFE Data (Cars)

- Average domestic manufacturer increased from 28.7 mpg in 2000 to 28.8 mpg in 2001
- Average import manufacturer increased from 28.3 mpg in 2000 to 28.4 mpg in 2001
- Fleet average increased from 28.5 mpg in 2000 to 28.6 in 2001

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DOMESTIC	2000	2001	IMPORT	2000	2001
DaimlerChrysler*	27.9	27.7	BMW	24.8	25.1
Ford*	28.3	27.5	Daewoo	28.6	29.7
General Motors*	27.9	28.1	DaimlerChrysler	25.3	27.1
Honda	31.4	36.3	Fiat	13.6	13.7
Nissan	28.1	27.7	Ford	27.4	27.8
Toyota	33.3	34.2	General Motors	25.4	26.5
Average	28.7	28.8	Honda	29.3	29.3
			Hyundai	30.7	31.4
			Kia	30	30.4
			Lotus	20.7	20.6
			Mitsubishi	29.4	...
			Nissan	28.3	28.3
			Porsche	24.3	24.2
			Subaru	28	27.8
			Suzuki	35	35.2
			Toyota	28.9	28.9
			Volkswagen	28.8	28.1
			Average)	28.3	28.4

Reference: U.S. Department of Transportation, National Highway Traffic Safety Administration, "Automotive Fuel Economy Program. Annual Update Calendar Year 2001," Report DOT HS 809 512, September 2002, available on web at http://www.nhtsa.dot.gov/cars/problems/studies/fuelecon/

2000-2001 CAFE Data (Truck)

- No separate data for domestic and imported
- Fleet average decreased from 21.3 mpg in 2000 to 20.9 in 2001
- Standard is 20.7 mpg until 2003

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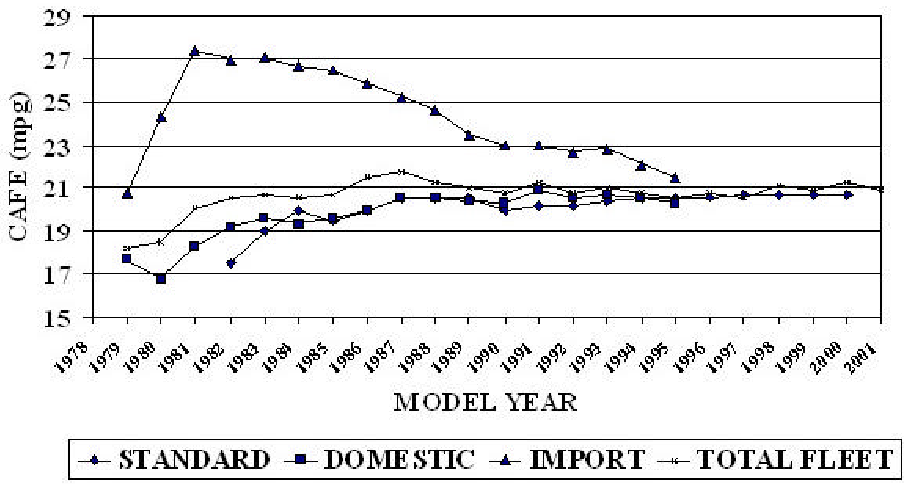
Combined domestic and imported truck fuel economy data

Year	2000	2001
BMW	17.5	19.2
DaimlerChrysler	21.4	20.7
Ford	21.0	20.5
General Motors	21.0	20.5
Honda	25.4	24.9
Hyundai	...	25.2
Isuzu	20.9	21.1
Kia	23.5	22.9
Land Rover	16.8	...
Mitsubishi	21.5	...
Nissan	20.8	20.7
Suzuki	23.0	22.0
Toyota	21.8	22.1
Volkswagen	18.9	20.5
Average	21.3	20.9

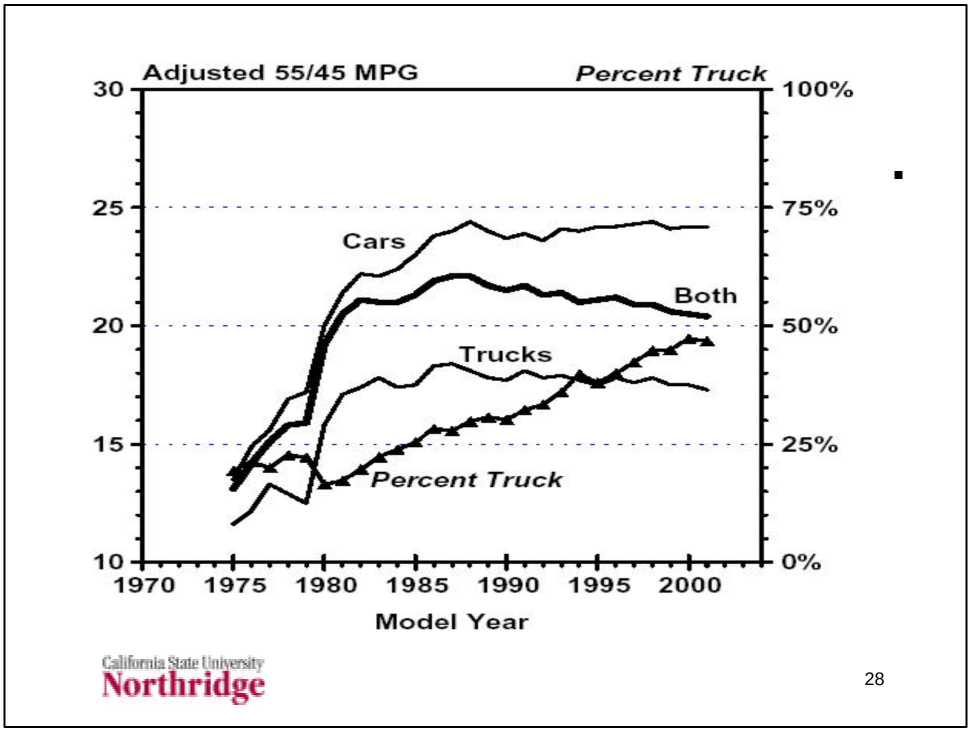
Hyundai did not market trucks in the US in 2000; Land Rover was acquired by Ford in May 2000 and DaimlerChrysler obtained a controlling 34% interest in Mitsubishi in April 2000. Land Rover and Mitsubishi truck data for 2001 are shown under Ford and DaimlerChrysler, respectively.

Reference: U.S. Department of Transportation, National Highway Traffic Safety Administration, "Automotive Fuel Economy Program. Annual Update Calendar Year 2001," Report DOT HS 809 512, September 2002, available on web at http://www.nhtsa.dot.gov/cars/problems/studies/fuelecon/

CAFE History - Trucks



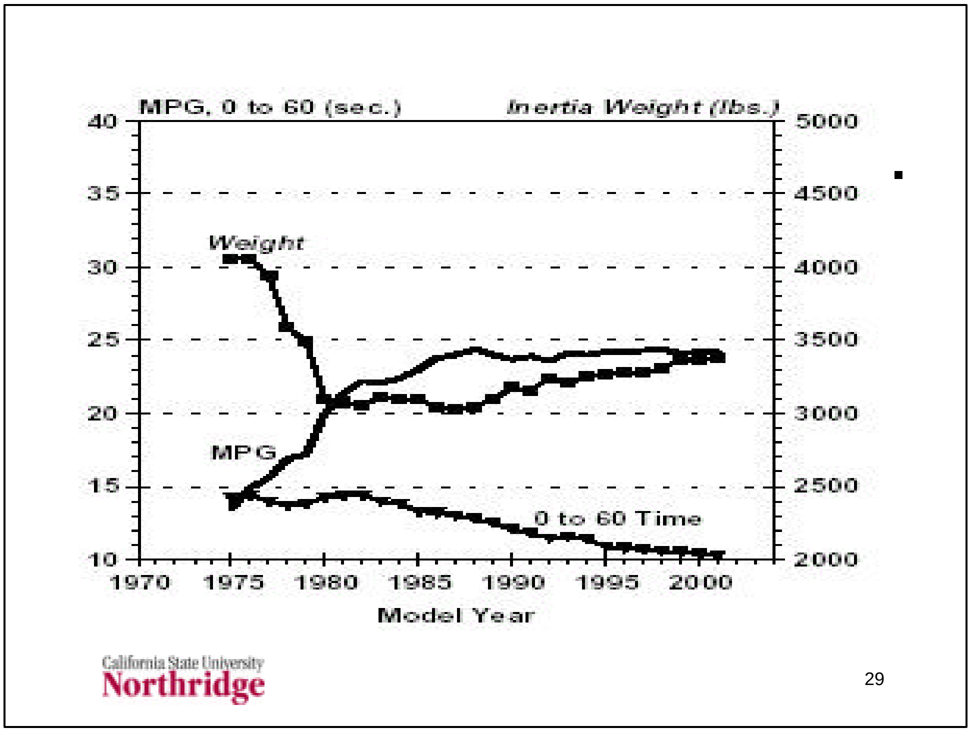
Reference: U.S. Department of Transportation, National Highway Traffic Safety Administration, “Automotive Fuel Economy Program. Annual Update Calendar Year 2001,” Report DOT HS 809 512, September 2002, available on web at http://www.nhtsa.dot.gov/cars/problems/studies/fuelecon/



Reference: United States Environmental Protection Agency, “Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This report uses the adjusted values for fuel economy. These will be about 15% lower than the measured values used to determine compliance with the CAFE standards.

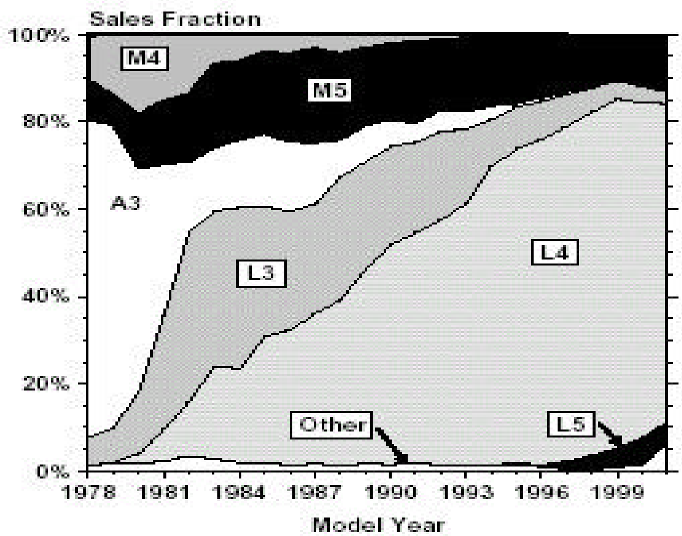
“New light-vehicle fuel economy improved fleet-wide from the middle 1970s through the late 1980s, but it has been consistently falling since then. Viewed separately, the average fuel economy for new cars has been essentially flat over the last 16 years, varying only from 23.6 mpg to 24.4 mpg. Similarly, the average fuel economy for new light trucks has been largely unchanged for the past 20 years, ranging from 17.3 mpg to 18.4 mpg. The increasing market share of light trucks, which have lower average fuel economy than cars, accounts for much of the decline in fuel economy of the overall new light vehicle fleet.”



Reference: United States Environmental Protection Agency, “Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This chart shows an increase in weight and power-to-weight ratio (measured as the time to accelerate from a standing start to 60 mph) over the last several years. These factors should decrease fuel economy. Other design changes have been used to keep the fuel economy constant in face of these changes.

These data are for cars only.



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Reference: United States Environmental Protection Agency, “Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This chart shows the change in transmission types. Newer transmission designs that produce more efficient drivetrains and have a greater number of gears that allow the engine to operate closer to its optimum point have been increasing in application. (Of course, the more efficient manual transmissions have been disappearing.

These data are for cars only.

Transmission types:

A3 3-speed automatic, no lockup

L3 3-speed automatic with lockup in one or more gears

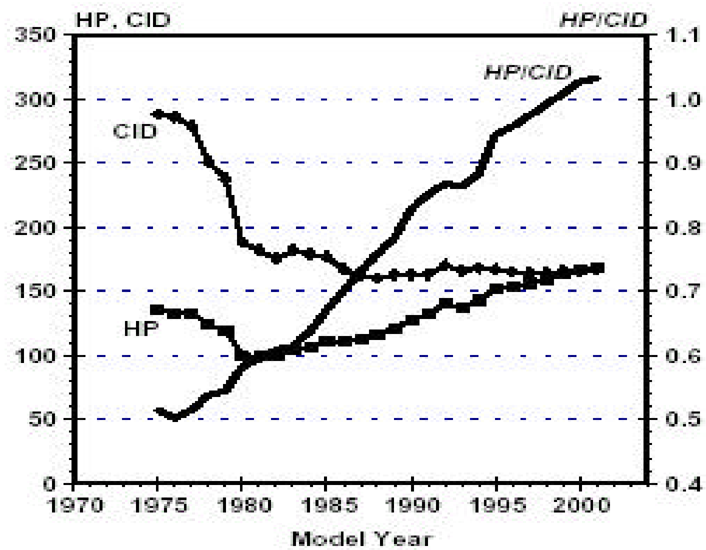
L4 4-speed automatic with lockup in one or more gears

L5 5-speed automatic with lockup in one or more gears

M4 4-speed manual transmission

M5 5-speed manual transmission

The lockup provides a direct connection between the input and output shafts of the automatic transmission and bypasses the fluid coupling in the torque converter. This improves the efficiency of the transmission.



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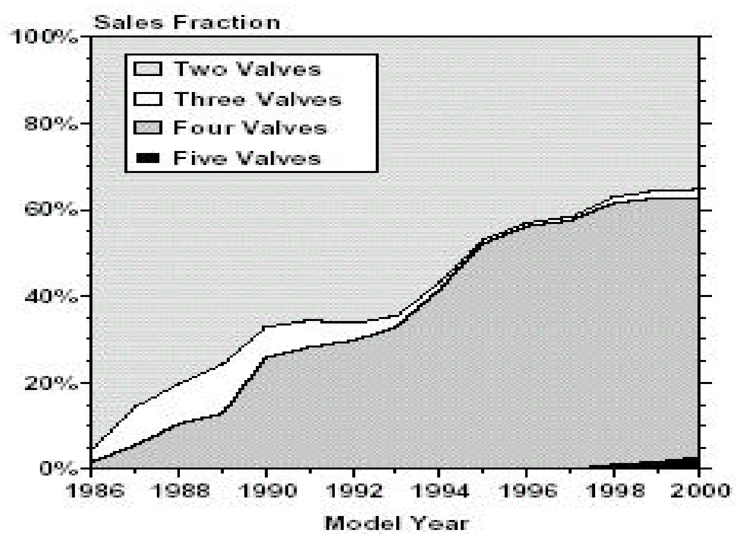
Reference: United States Environmental Protection Agency, “Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This chart shows the changes in maximum rated power (in HP) and engine displacement in cubic inches (CID).

These data are for cars only



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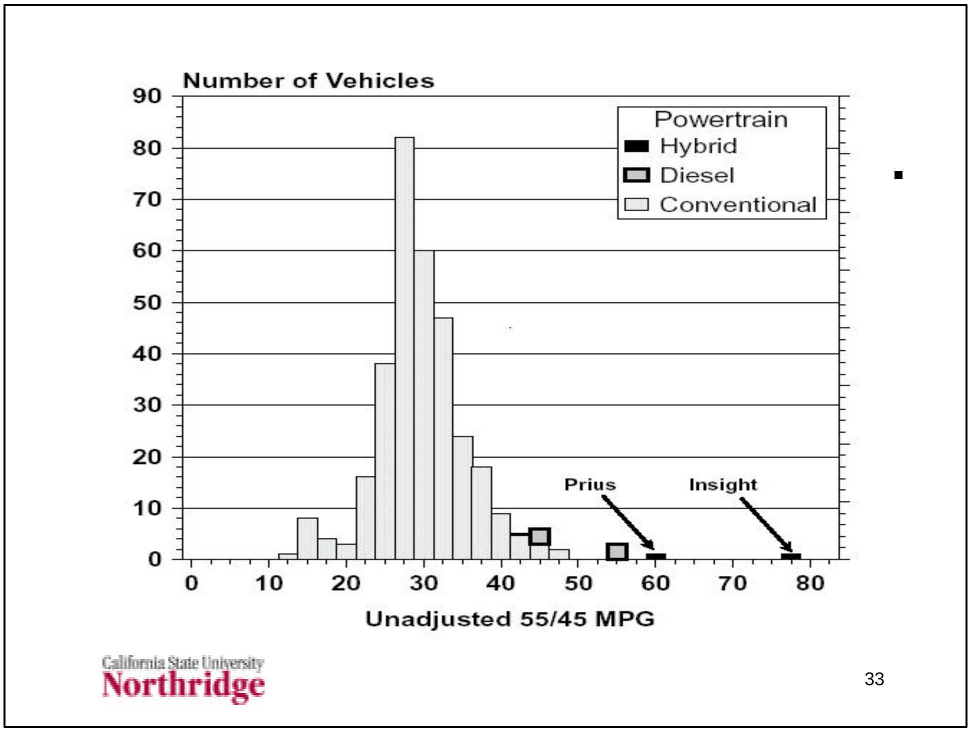
Reference: United States Environmental Protection Agency, “Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This chart shows the increase in sales of multivalve engines. Over half the cars manufactured in 2000 had four-valve engines. As noted earlier, these engines are able to produce higher output for a given displacement. This allows smaller displacement engines to be used in cars to improve efficiency or it can be used to produce more power without degrading fuel economy.

These data are for cars only

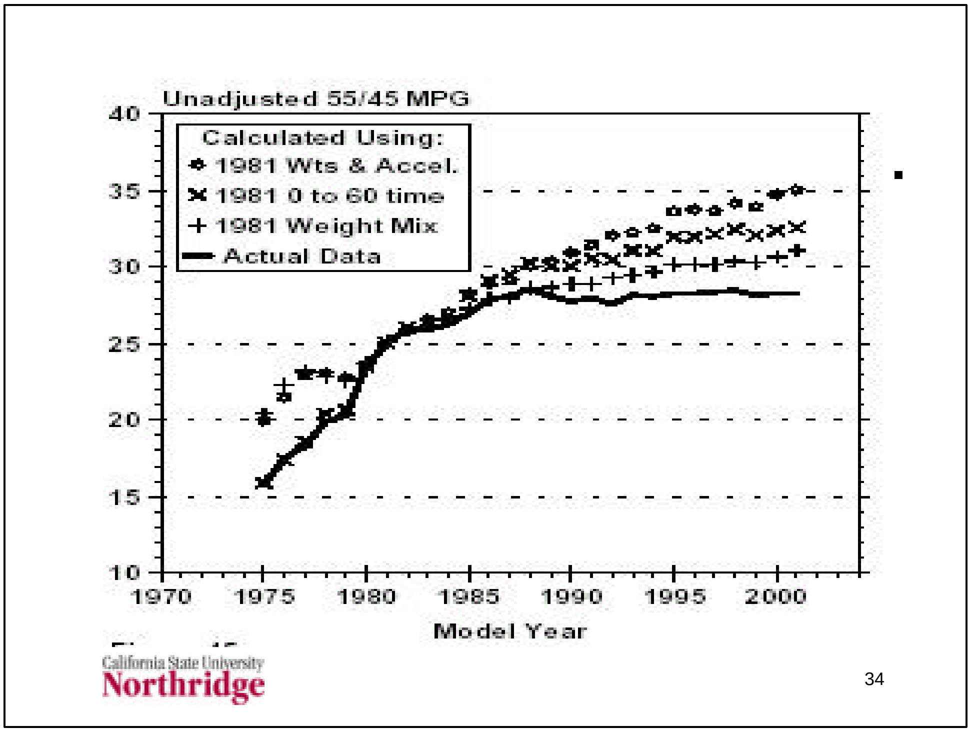


Reference: United States Environmental Protection Agency, “Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This chart shows the distribution of mileage for the small car class maintained in the fuel economy guide. This class is not well defined in terms of marketing. It has some small, high-performance sports cars which have very poor fuel economy. It also has subcompact cars with high fuel economy. There are approximately 350 fuel-economy models in this class. (Includes cars with different engine/transmission configurations.)

Unadjusted (higher) values of fuel economy are used on this chart.

The hybrid drive provides great flexibility in the power output of the engine. A much smaller engine can be used to operate nearer the peak bmep. When smaller amounts of power are required, the extra output of the engine is used to charge a battery. When extra power is required, the battery is discharged and the power of an electric motor is added to the output power of the engine.

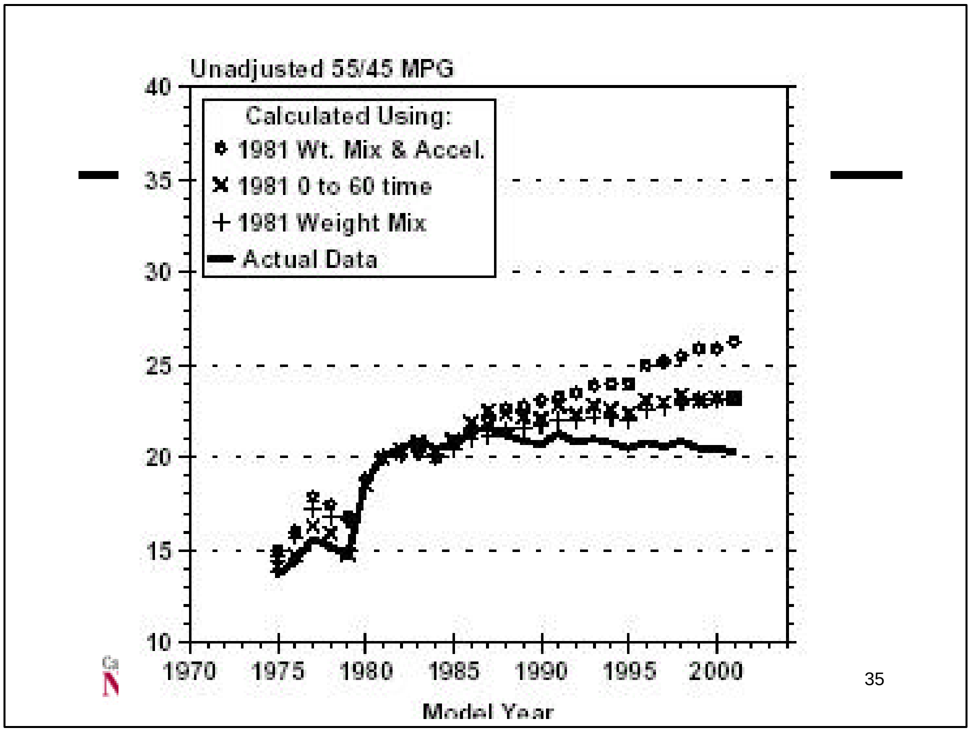


Reference: United States Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site. The material below was copied from this report and edited slightly.

EPA estimated the MPG/performance interdependence was using a regression analysis performed on the EPA databases. This yielded sensitivity coefficients on the order of 0.4, i.e., a 10% increase in 0-to-60 time corresponds to a 4% increase in fuel economy. Using these sensitivities, average MPG data at one 0-to-60 level can be adjusted to what it would have at a different one.

Similarly, by normalizing either the weight or size distribution, a comparison can be made of what the fuel economy of each year's fleet would have been if it had the same weight or size distribution as in a given base year. This year's cars get better fuel economy than their counterparts from both baseline years but are significantly heavier and have faster 0-to-60 acceleration time. This year's trucks get about the same fuel economy as the base line years and are also heavier and have faster 0-to-60 times.

This figure for cars (and the next figure for trucks) provide estimates of what the MPG of the car and truck fleet would have been each model year if (1) the weight mix had been kept the same as in each of the two base years, (2) the average acceleration time was kept at the base year's acceleration time, and (3) both the weight distribution and average acceleration time were the same as in the base year.



Reference: United States Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends 1975 Through 2001 Office of Air and Radiation Report EPA420-R-01-008, September 2001. Available at EPA web site.

This figure for trucks is prepared in the same way as the previous figure for cars. The baseline 1981 data for both cars and trucks is compared to more recent data inthe table below. The original EPA report also examined changes using a 1991 baseline.

Unadjusted Fuel Economy, Inertia Weight, and 0-to-60 Time For Three Model Years

Vehicle Type	Model Year	55/45 MPG	Inertia Weight (pounds)	0 to 60 Time (seconds)
Cars	1981	25.1	3076	14.4
	1991	28.0	3154	11.8
	2001	28.3	3380	10.3
Trucks	1981	20.1	3806	14.6
	1991	21.3	3948	12.6
	2001	20.3	4511	10.6

NAS/NRC 2002 Report

- Safety Concerns
- Technology exists to further improve fuel economy
- External costs $0.30/gallon of gasoline for markets and greenhouse gases
- Do new engine technologies (diesel, lean burn) conflict with emissions?

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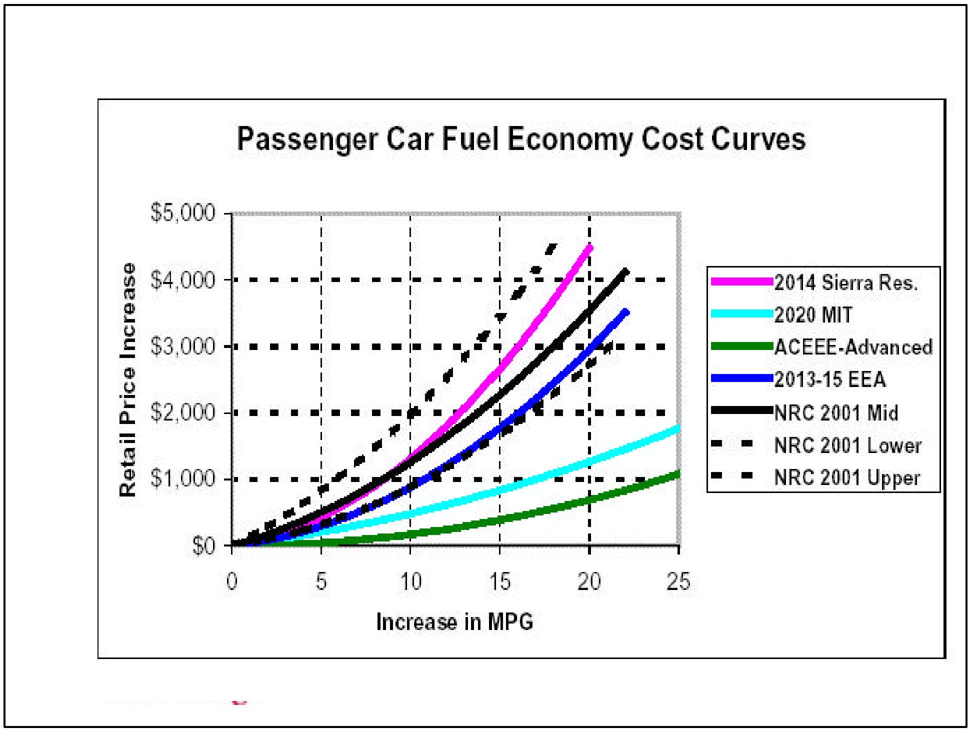
Committee on Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, "EFFECTIVENESS AND IMPACT OF CORPORATE AVERAGE FUEL ECONOMY (CAFE) STANDARDS (PREPUB-LICATION — UNEDITED PROOF)" Division on Engineering and Physical Sciences, Board on Energy and Environmental Systems, Transportation Research Board , National Research Council, NATIONAL ACADEMY PRESS, Washington, D.C., 2002.
http://books.nap.edu/html/cafe/ch4.pdf

Finding 5. Technologies exist that, if applied to passenger cars and light-duty trucks, would significantly reduce fuel consumption within 15 years. Auto manufacturers are already offering or introducing many of these technologies in other markets (Europe and Japan, for example) where much higher fuel prices ($4-5/gal) have justified their development. However, economic, regulatory, safety and consumer preference-related issues will influence the extent to which these technologies will be applied in the United States.

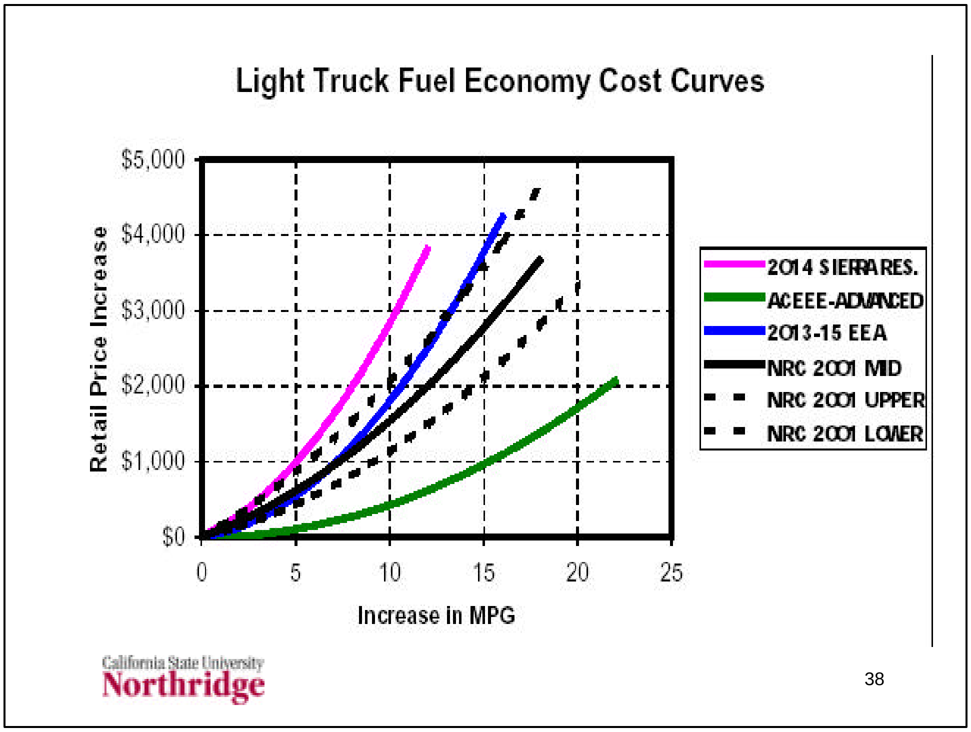
Finding 7. There is a marked inconsistency between pressing automotive manufacturers for improved fuel economy from new vehicles on the one hand and insisting on low real gasoline prices on the other. Higher real prices for gasoline—for instance, through increased gasoline taxes—would create both a demand for fuel-efficient new vehicles and an incentive for owners of existing vehicles to drive them less.

Finding 8. The committee identified externalities of about $0.30 per gallon of gasoline, associated with the combined impacts of fuel consumption on greenhouse gas emissions and on world oil market conditions. These externalities are not necessarily taken into account when consumers purchase new vehicles. Other analysts might produce lower or higher estimates of externalities.



Committee on Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, "EFFECTIVENESS AND IMPACT OF CORPORATE AVERAGE FUEL ECONOMY (CAFE) STANDARDS (PREPUB-LICATION — UNEDITED PROOF)" Division on Engineering and Physical Sciences, Board on Energy and Environmental Systems, Transportation Research Board , National Research Council, NATIONAL ACADEMY PRESS, Washington, D.C., 2002.
http://books.nap.edu/html/cafe/ch4.pdf

This is the projected costs that the NAS committee computed compared with other studies. This chart is for cars.



Committee on Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards, "EFFECTIVENESS AND IMPACT OF CORPORATE AVERAGE FUEL ECONOMY (CAFE) STANDARDS (PREPUB-LICATION — UNEDITED PROOF)" Division on Engineering and Physical Sciences, Board on Energy and Environmental Systems, Transportation Research Board , National Research Council, NATIONAL ACADEMY PRESS, Washington, D.C., 2002.
http://books.nap.edu/html/cafe/ch4.pdf

This is the projected costs that the NAS committee computed compared with other studies. This chart is for trucks..