TRANSPORTATION

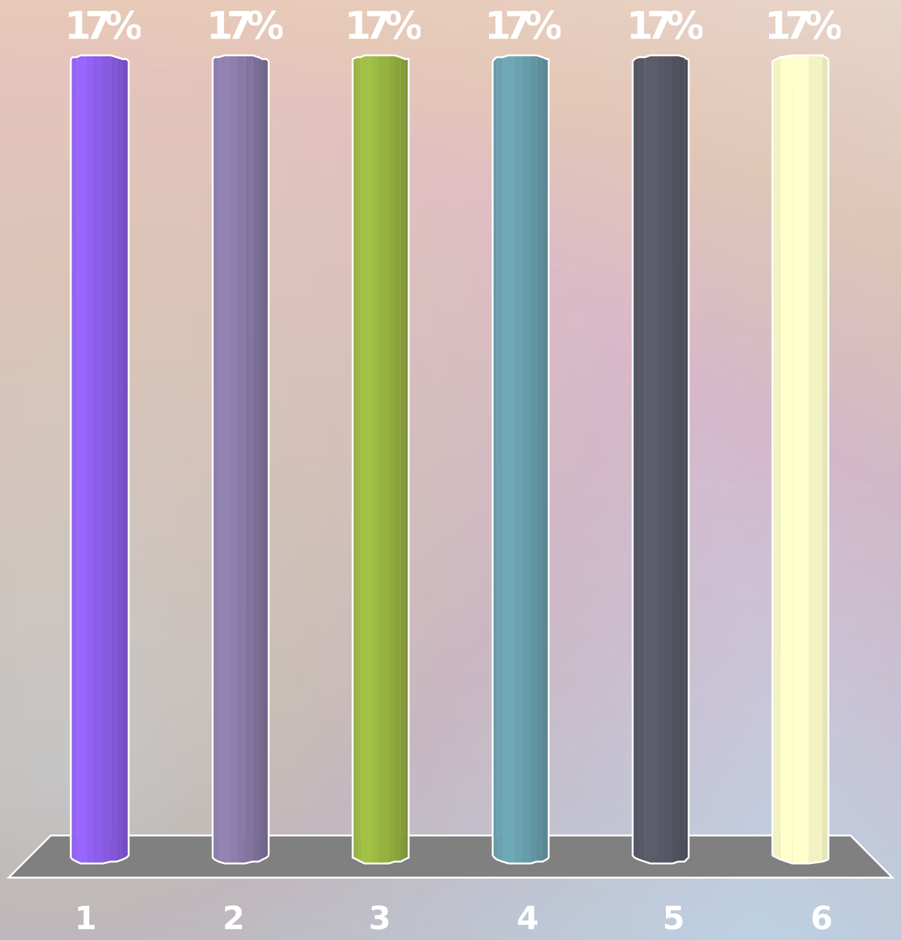
Original slided provided by Dr. Daniel Holland

- One of the three basic energy use sectors.
- Important not just for people, but also for goods.
- Changes in transportation costs can affect the cost of just about everything.

Audio Link

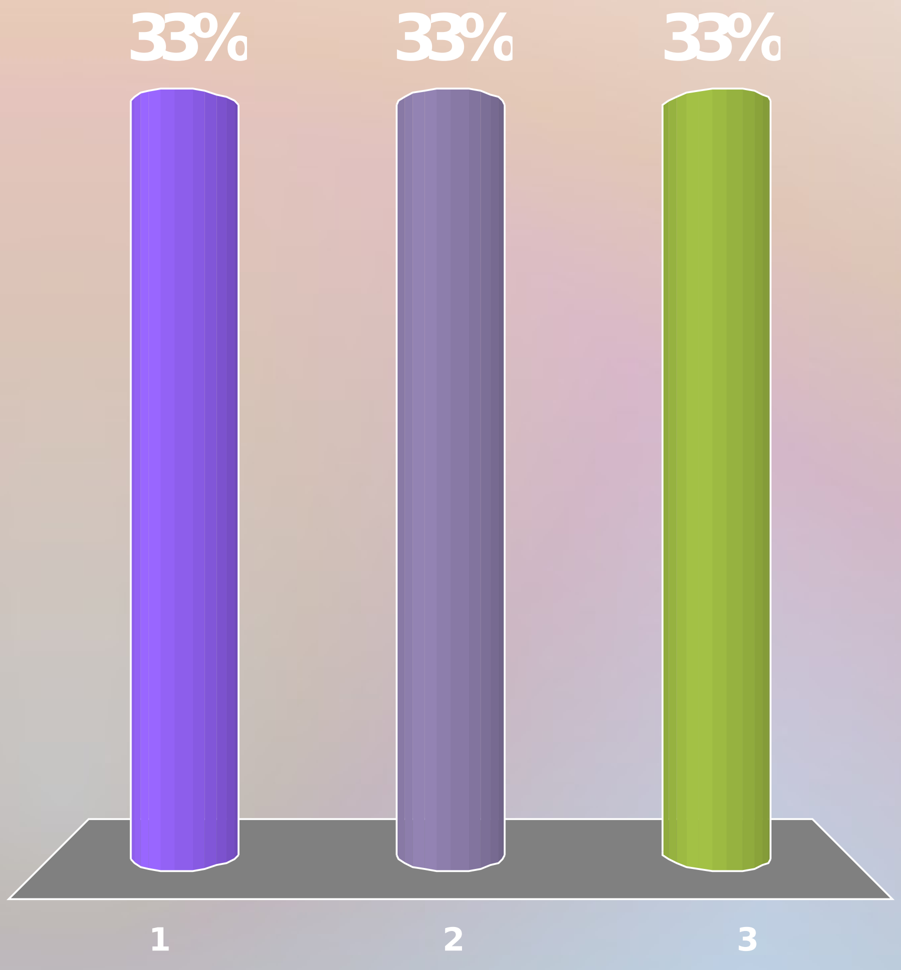
How many cars does your family own?

1. 0
2. 1
3. 2
4. 3
5. 4
6. More than 4



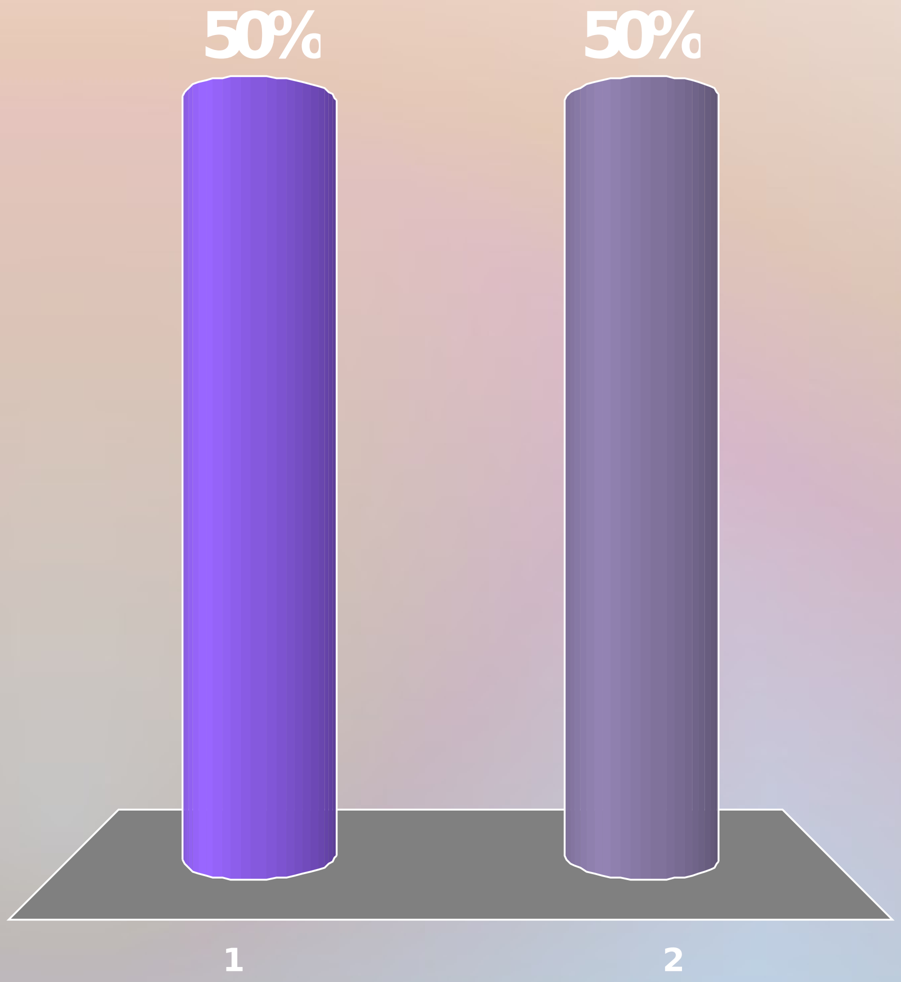
Do you use the free bus service provided by ISU?

1. Frequently
2. Occasionally
3. Not at all



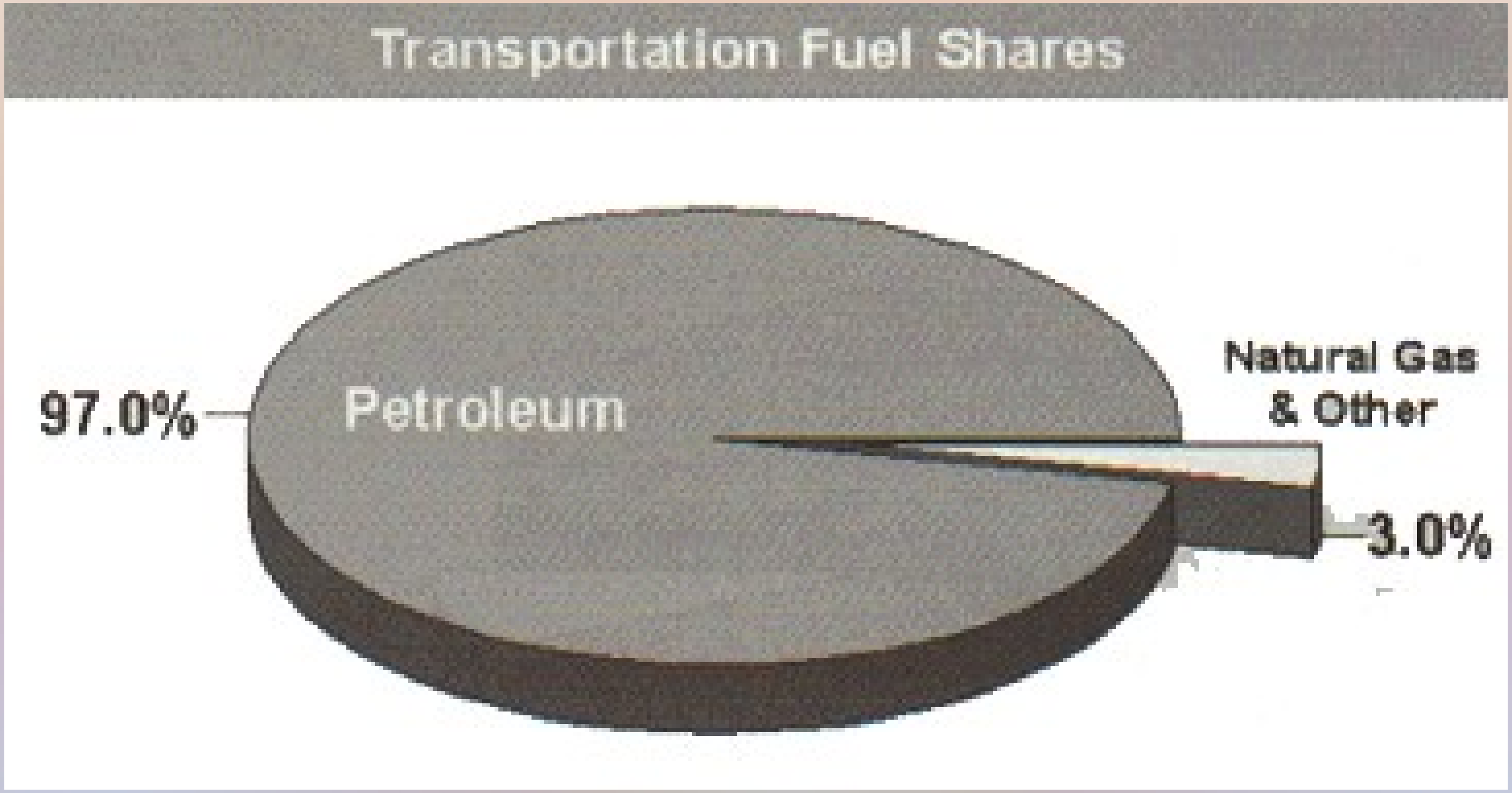
Do you have a car at ISU?

1. Yes
2. No



- There are approximately 200,000,000 cars trucks and busses in the US.
- Each one has a parking space at each end of a trip
- Taken together, roads and parking account for approximately 1% of the land surface of the US. This is an area approximately equal to Indiana.
- Transportation use almost 70% of the total petroleum used in the US.

Fuel Source for Transportation



Energy Density of Various Fuels

Storage Type	Energy Density (MJ/kg)
Gasoline	46.4
Natural Gas	53.6
NiMH battery	0.25
Lead Acid Battery	0.14
Li Ion Battery	0.46 to 0.72
Hydrogen	143
Antimatter	89,876,000,000

Percentage of Energy for Different Transport Modes

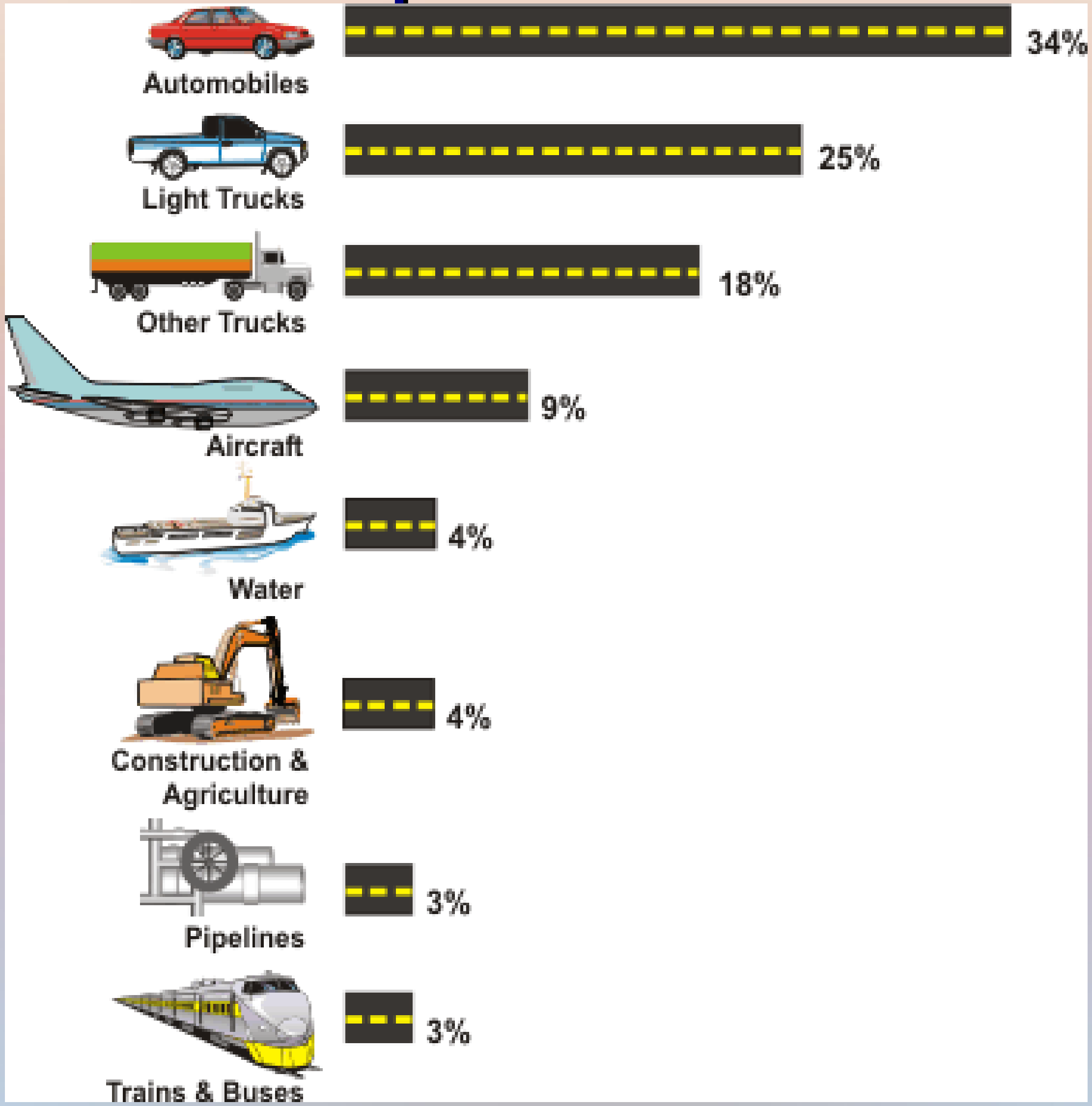


Table 28.1 Energy efficiency of various transportation modes [adapted from RIS99]

Passenger Transportation	Passenger km/GJ
Bicycle	5400
Walking	3210
Bus	1010
Train	641
Car	321
Aircraft	236
Freight Transportation	**Tonnage km/GJ**
Pipelines	3710
Waterways	3210
Railroads	2530
Trucks	675
Aircraft	45.6

Forces on a Moving Vehicle

$$1)\ \text{Acceleration:}$$

$$F_a = ma$$

$$2)\ \text{Hill Climbing}$$

$$F_h = mgs$$

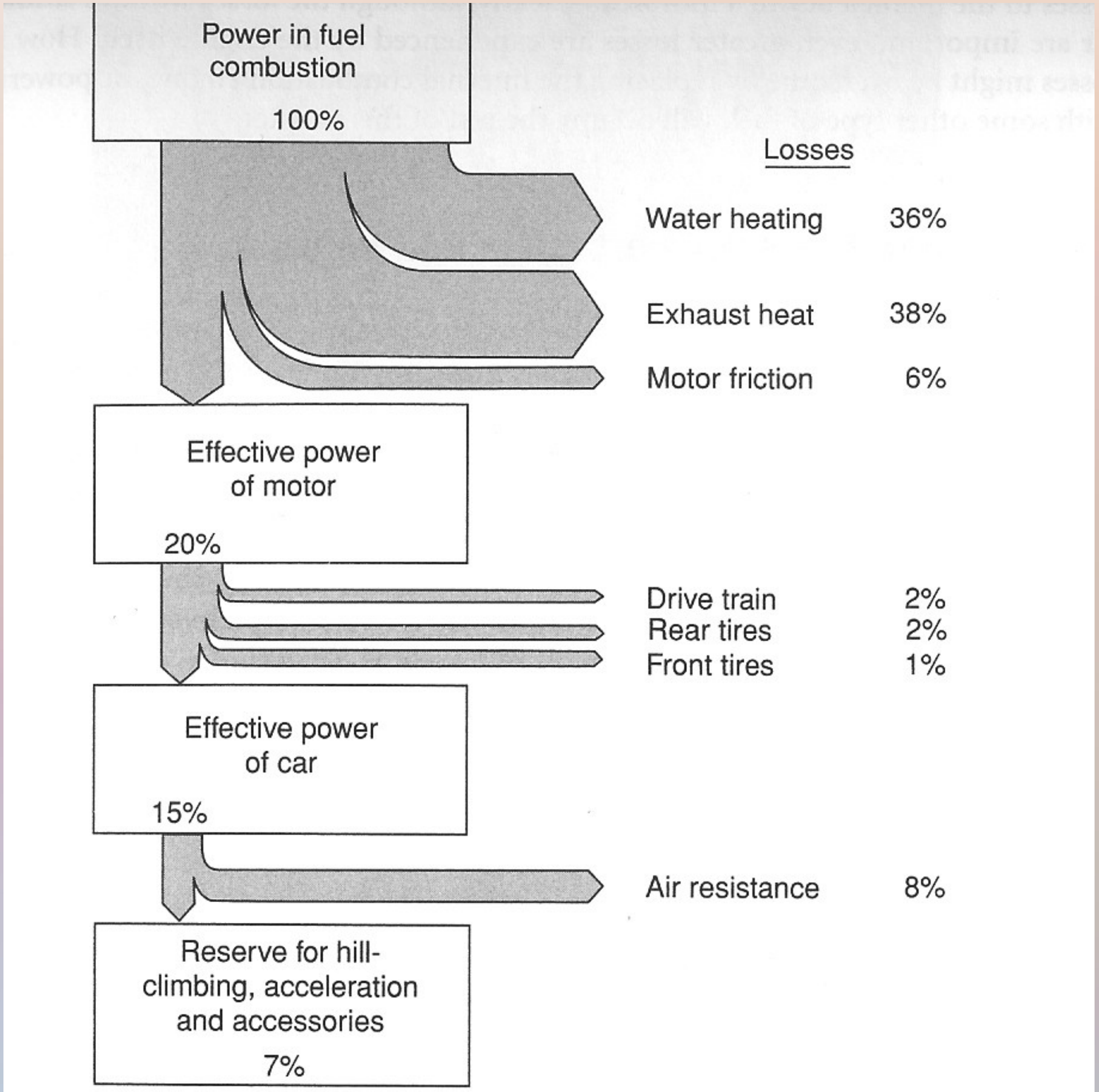
$$3)\ \text{Rolling Friction}$$

$$F_r = C_r mv$$

$$4)\ \text{Areodynamic Drag}$$

$$F_{ad} = \frac{1}{370} C_D A_f v^2$$

Energy usage in a typical car



28.2 Relative contribution of losses to the inefficiency of a motorcar being operated unde

Heat losses in water and exhaust are due to 2nd Law (Carnot efficiencies)

How Can We Reduce Forces

- $F_{tot}=F_a + F_h + F_r + F_{ad}$
- Don’t go up hills. (Works around here.)
- Go at constant speeds.
- Improve engineering (reduce C_r and C_D.)
- Reduce mass.

Power

$$Work = Fd$$

$$Power = W/t = Fd/t = Fv$$

Note the Power requirement goes up the faster we go not just because forces increase .

Areodynamic Drag

$$F_{ad} = \frac{1}{370} C_D A_f v^2$$

$$P_{ad} = \frac{1}{370} C_D A_f v^3$$

Note that since $P_{ad} \propto v^3$ if we double the speed it take 8 times as much power .

Drag Coefficients

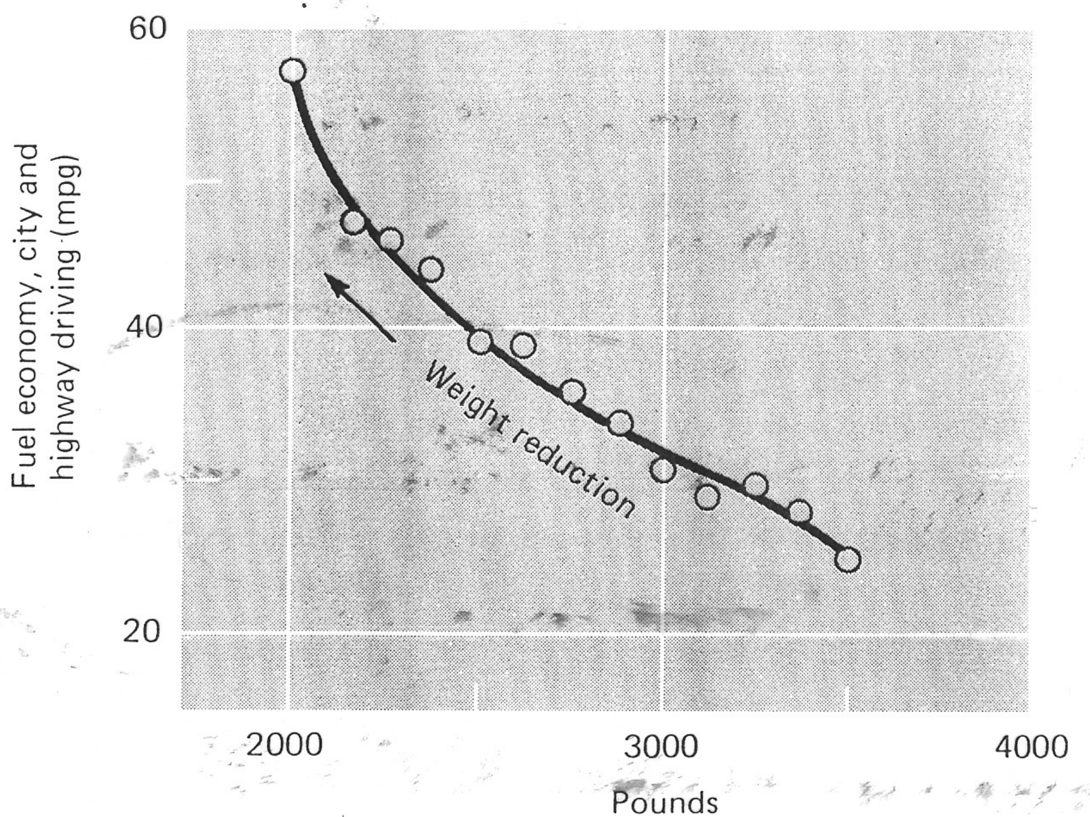
2.1 - a smooth brick
0.9 - a typical bicycle plus cyclist
0.57 - Hummer H2, 2003
0.51 - Citroën 2CV
0.42 - Lamborghini Countach, 1974
0.36 - Ferrari Testarossa, 1986
0.34 - Chevrolet Caprice, 1994-1996
0.34 - Chevrolet Corvette Z06, 2006
0.338 - Chevrolet Camaro, 1995
0.33 - Audi A3, 2006
0.29 - Subaru XT, 1985
0.29 - BMW 8-Series, 1989
0.29 - Porsche Boxster, 2005
0.29 - Chevrolet Corvette, 2005
0.29 - Mercedes-Benz W203 C-Class Coupe, 2001 - 2007
0.28 - Toyota Camry and sister model Lexus ES, 2005
0.28 - Porsche 997, 2004
0.27 - Toyota Camry Hybrid, 2007
0.26 - Toyota Prius, 2004
0.25 - Honda Insight, 1999
0.24 - Audi A2 1.2 TDI, 2001
0.195 - General Motors EV1, 1996
0.137 - Ford Probe V prototype, 1985
Automobile_drag_coefficient

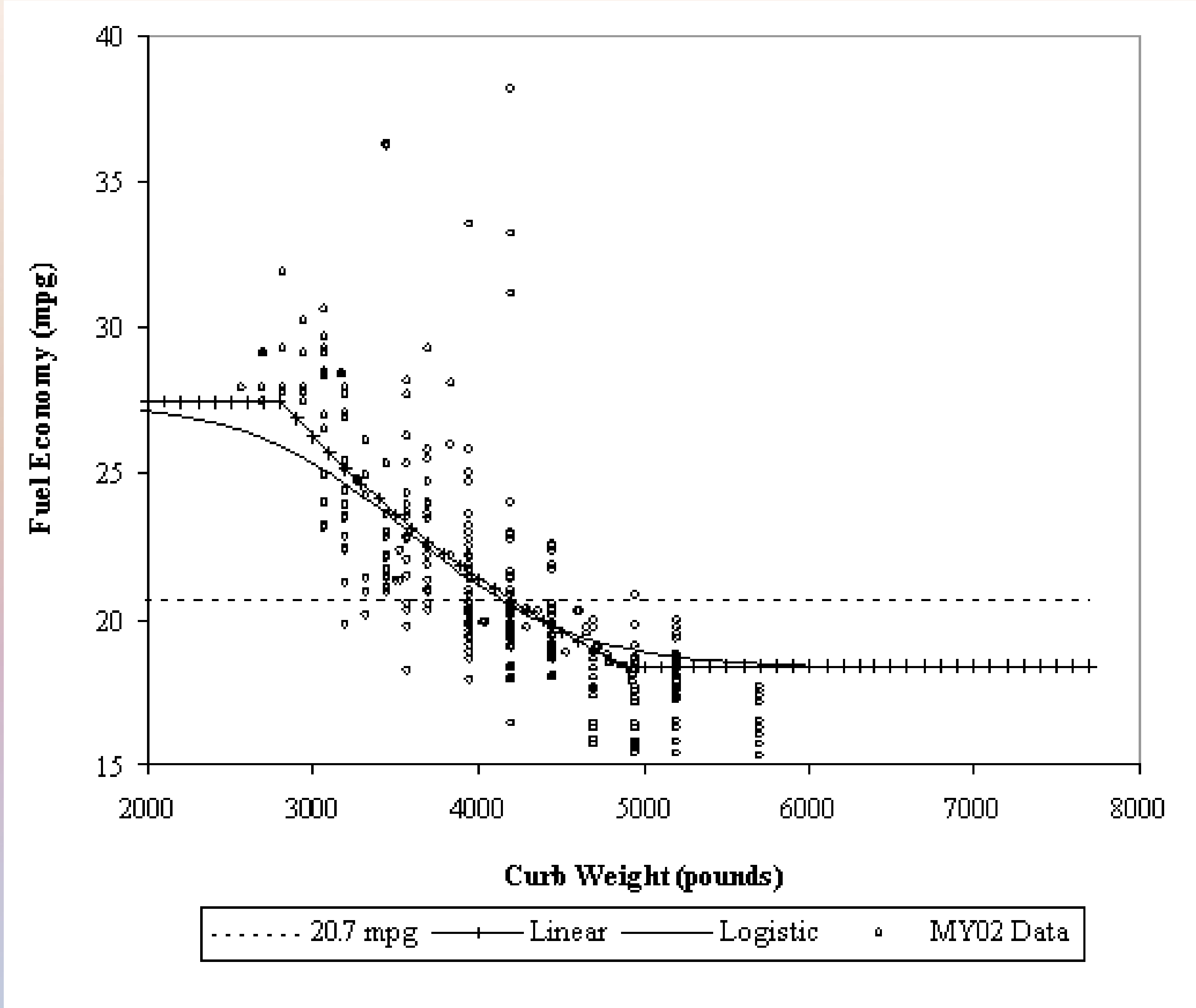
Audio Link

All other forces depend on mass

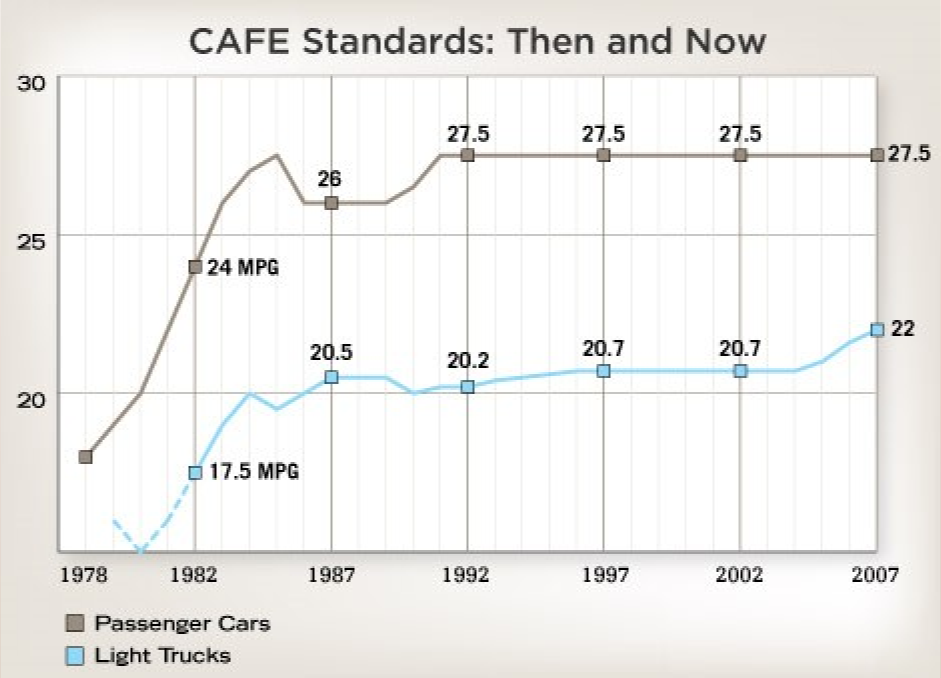
FIGURE 16.5

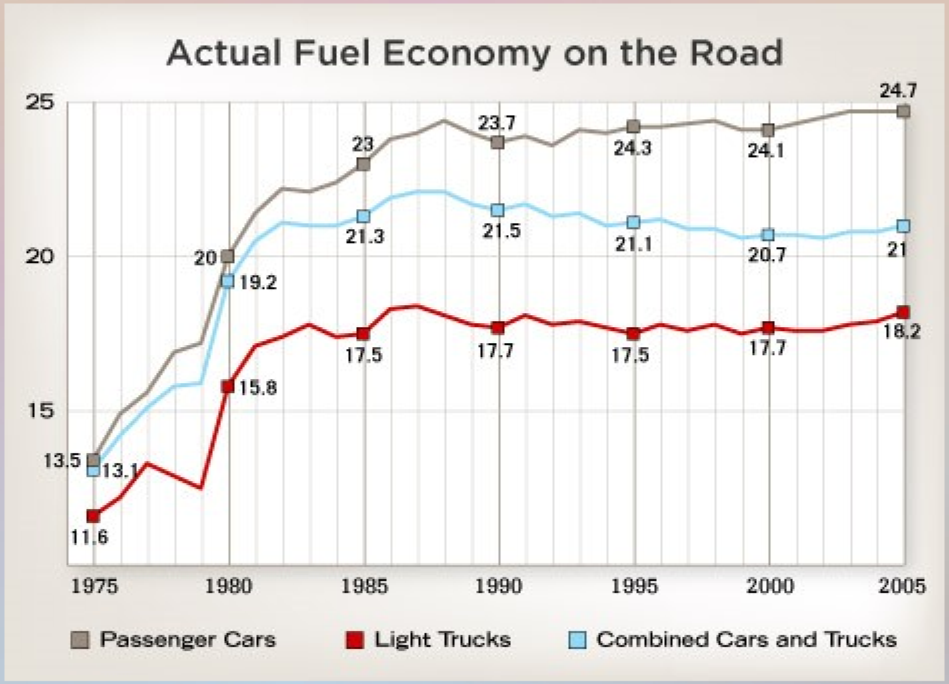
The data for fuel economy and vehicle weight presented here were compiled in 1983 for the most fuel-efficient vehicle in a given weight class. As expected from basic physics considerations, the fuel economy increases as the vehicle weight decreases. Adapted from Figure 1 in "Technological Trends in Automobiles," Emmett J. Horton and W. Dale Compton, *Science* **225**, 587 (10 August 1984).





40
35
30
25
20
15
2000
3000
4000
5000
6000
7000
8000
Fuel Economy (mpg)
Curb Weight (pounds)
20.7 mpg
Linear
Logistic
MY02 Data





Corporate Average Fuel Economy

First enacted by Congress in 1975, the purpose of CAFE is to reduce energy consumption by increasing the fuel economy of cars and light trucks.

CAFE TESTING

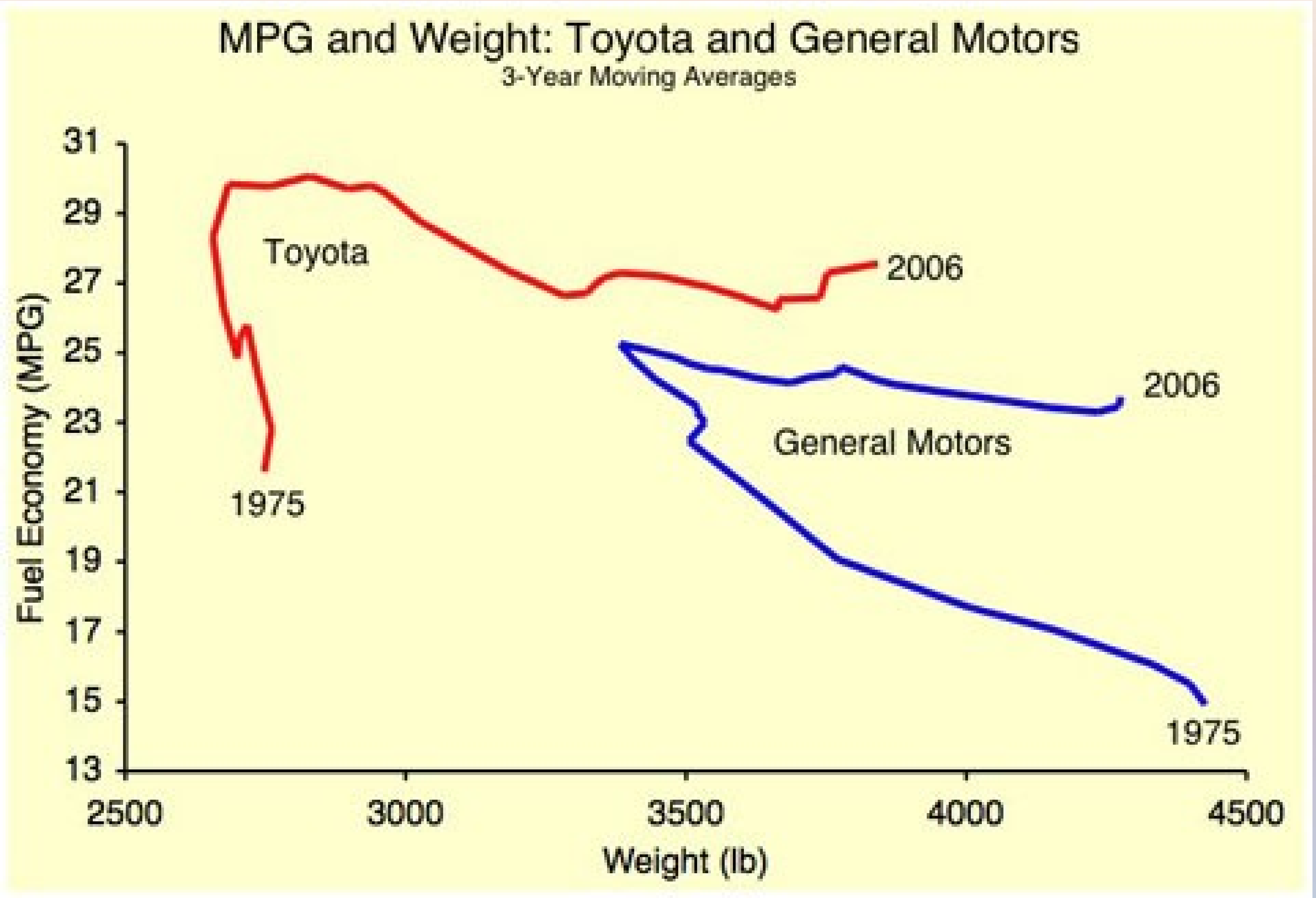
The city and highway tests are currently performed under mild climate conditions (75 degrees F) and include acceleration rates and driving speeds that EPA believes are generally lower than those used by drivers in the real world. Neither test is run while using accessories, such as air conditioning. The highway test has a top speed of 60 miles per hour, and an average speed of only 48 miles per hour.

Table 1. Average Required Fuel Economy (mpg) under Proposed Standards

	2012	2013	2014	2015	2016
Passenger Cars	33.6	34.4	35.2	36.4	38.0
Light Trucks	25.0	25.6	26.2	27.1	28.3
Combined	29.8	30.6	31.4	32.6	34.1

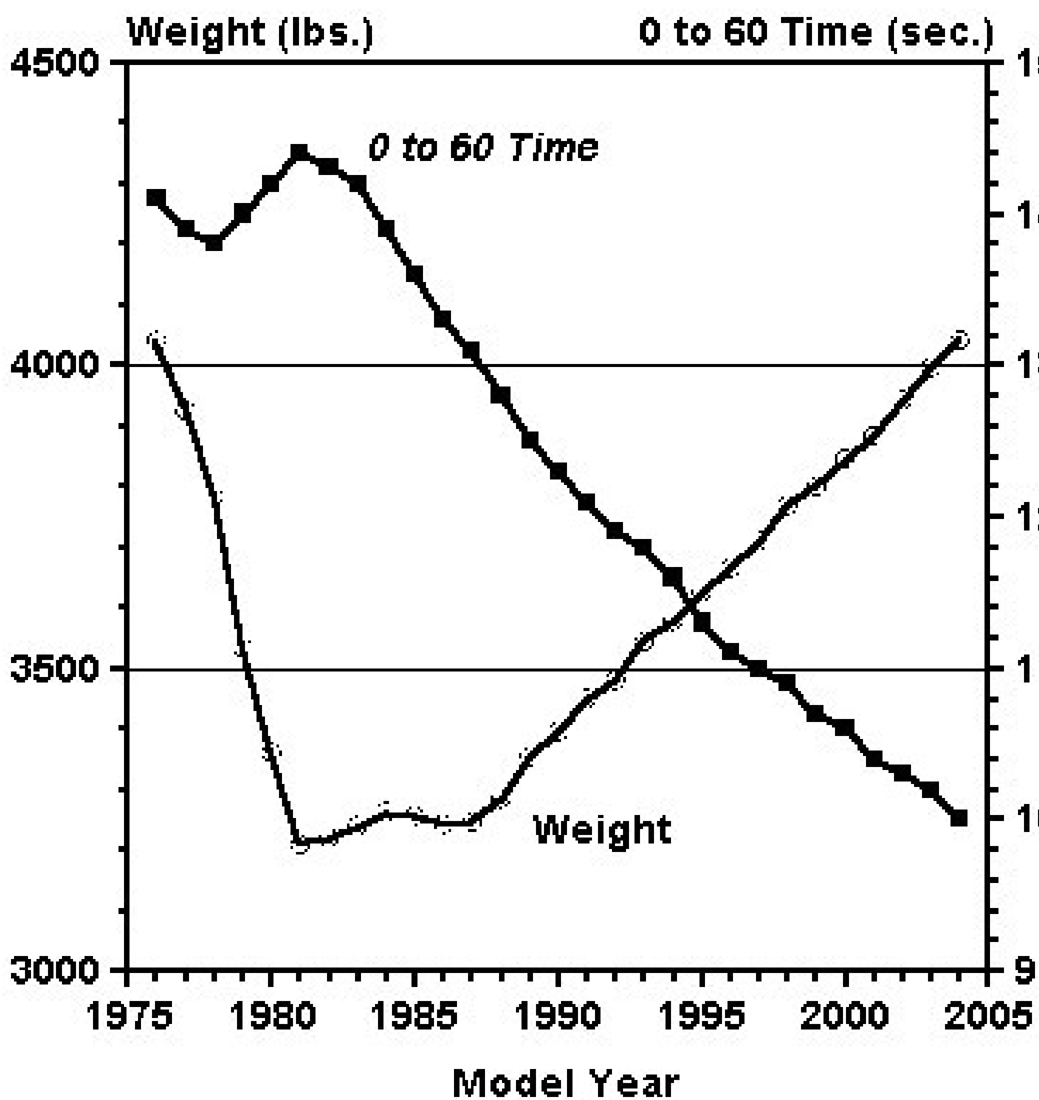
For the reader's reference, these estimated required mpg levels would be equivalent to the following in gallons per 100 miles for passenger cars and light trucks:

Table 2. Gallon/100 miles Equivalent to Average Required mpg


MPG and Weight: Toyota and General Motors
3-Year Moving Averages
Fuel Economy (MPG)
31
29
27
25
23
21
19
17
15
13
2500
3000
3500
4000
4500
Weight (lb)
Toyota
2006
1975
General Motors
2006
1975

Weight and Performance

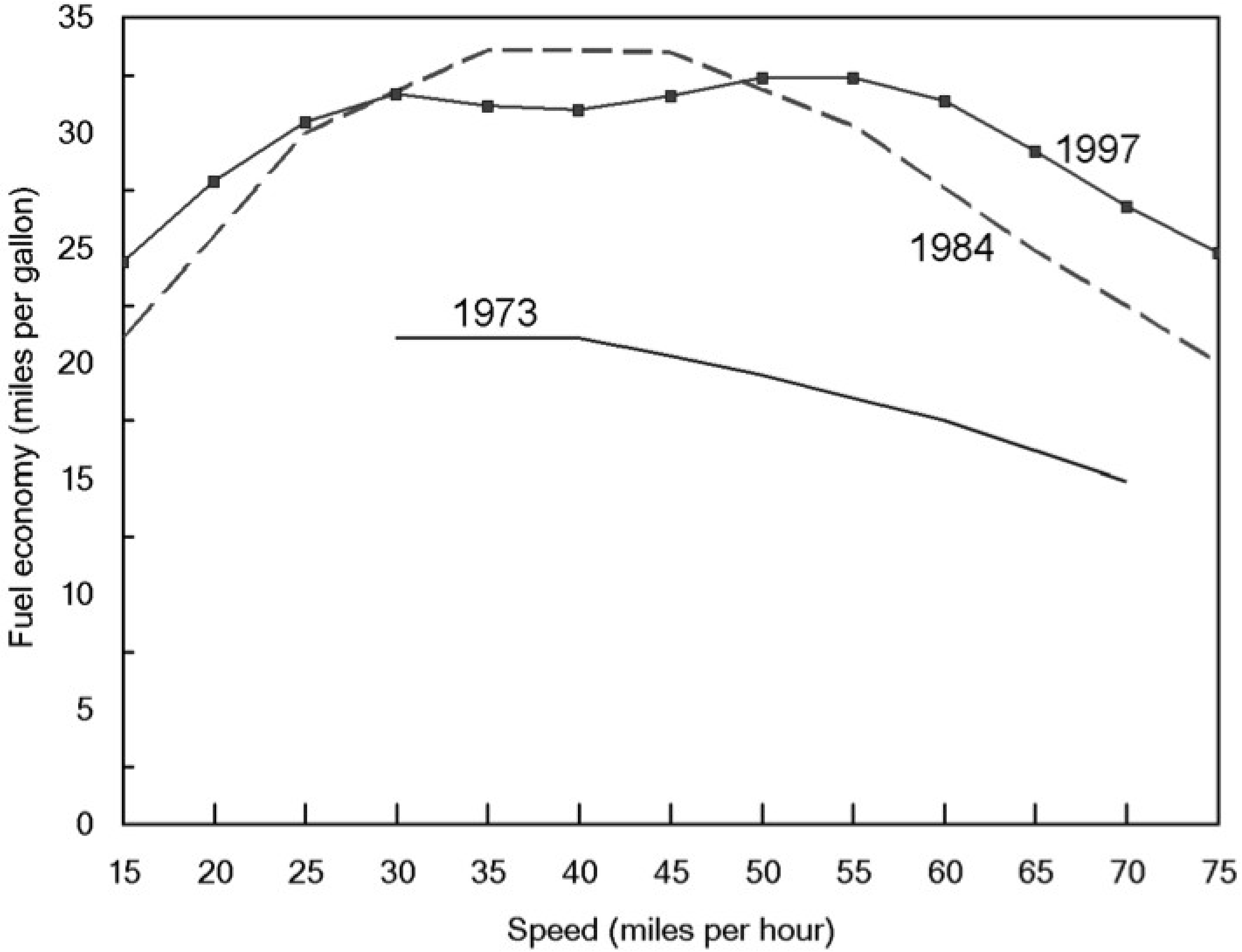
(Three Year Moving Average)

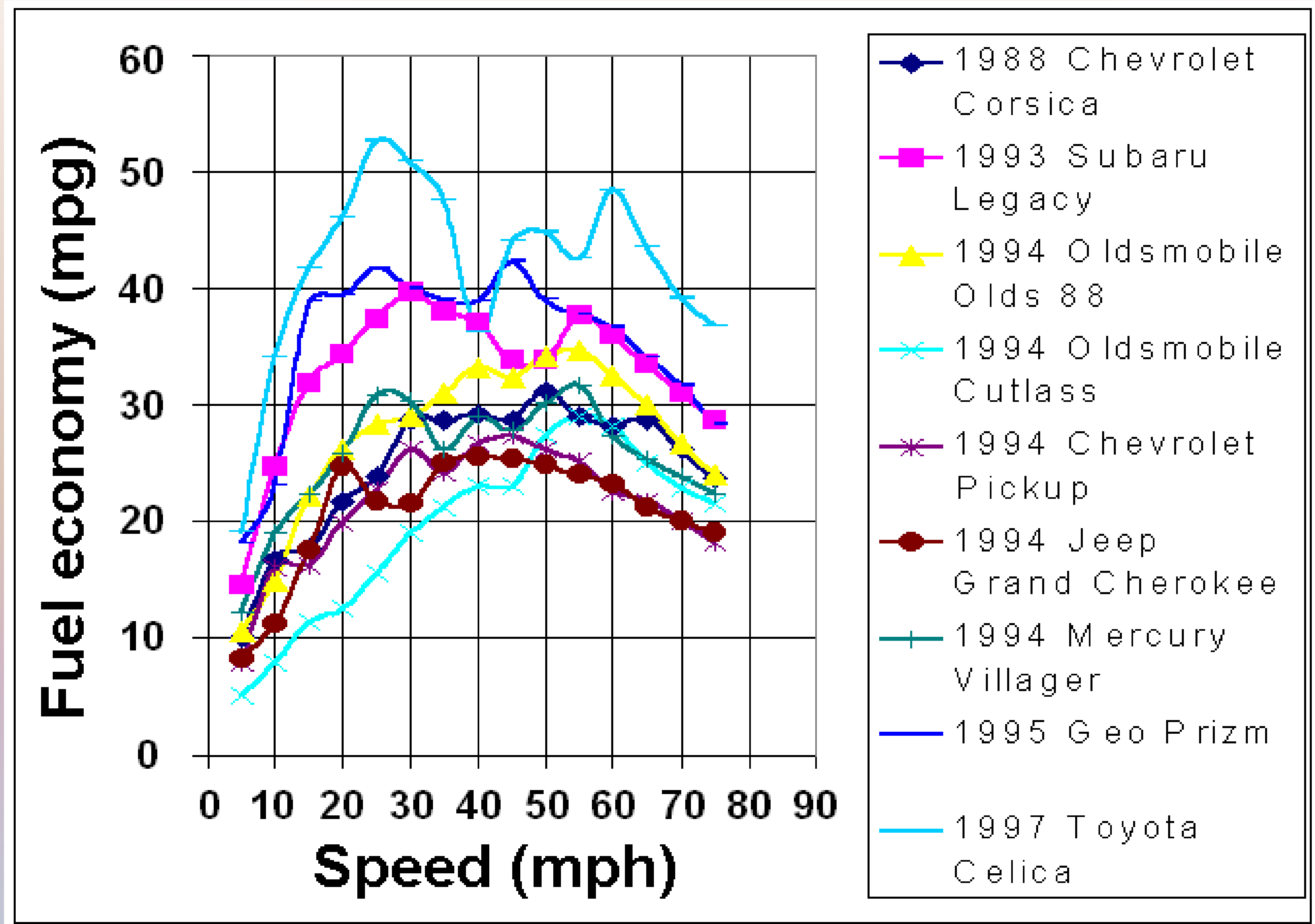


Characteristics of Light Duty Vehicles for Four Model Years

	1975	1987	1998	2009
Adjusted Fuel Economy (mpg)	13.1	22.0	20.1	21.1
Weight (lbs.)	4060	3220	3744	4108
Horsepower	137	118	171	225
0 to 60 Time (sec.)	14.1	13.1	10.9	9.5
Percent Truck Sales	19%	28%	45%	49%
Percent Front-Wheel Drive	5%	58%	56%	55%
Percent Four-Wheel Drive	3%	10%	20%	27%
Percent Multi-Valve Engine	-	-	40%	79%
Percent Variable Valve Timing	-	-	-	65%
Percent Cylinder Deactivation	-	-	-	9%
Gasoline-Direct Injection	-	-	-	3.5%
Percent Turbocharger	-	-	1.4%	3.1%
Percent Manual Trans	23%	29%	13%	6%
Percent Continuously Variable Trar	-	-	-	8%
Percent Hybrid	-	-	-	1.8%
Percent Diesel	0.2%	0.2%	0.1%	0.5%

Figure 4.2. Fuel Economy by Speed, 1973, 1984, and 1997 Studies

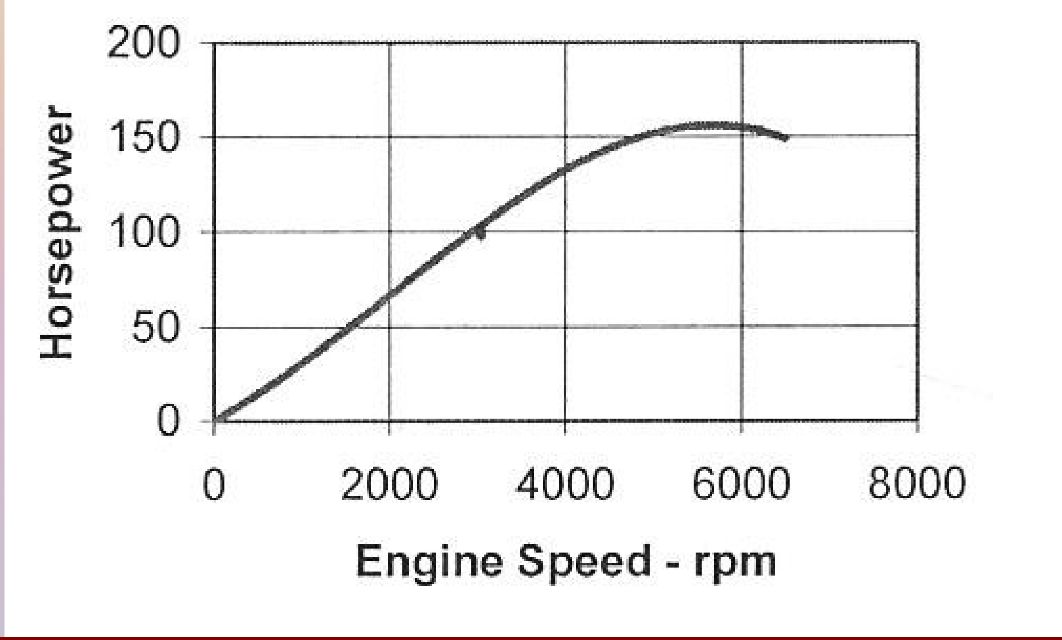




Fuel economy (mpg)
60
50
40
30
20
10
0
0 10 20 30 40 50 60 70 80 90
Speed (mph)
1988 Chevrolet Corsica
1993 Subaru Legacy
1994 Oldsmobile Olds 88
1994 Oldsmobile Cutlass
1994 Chevrolet Pickup
1994 Jeep Grand Cherokee
1994 Mercury Villager
1995 Geo Prizm
1997 Toyota Celica

Maximum Load

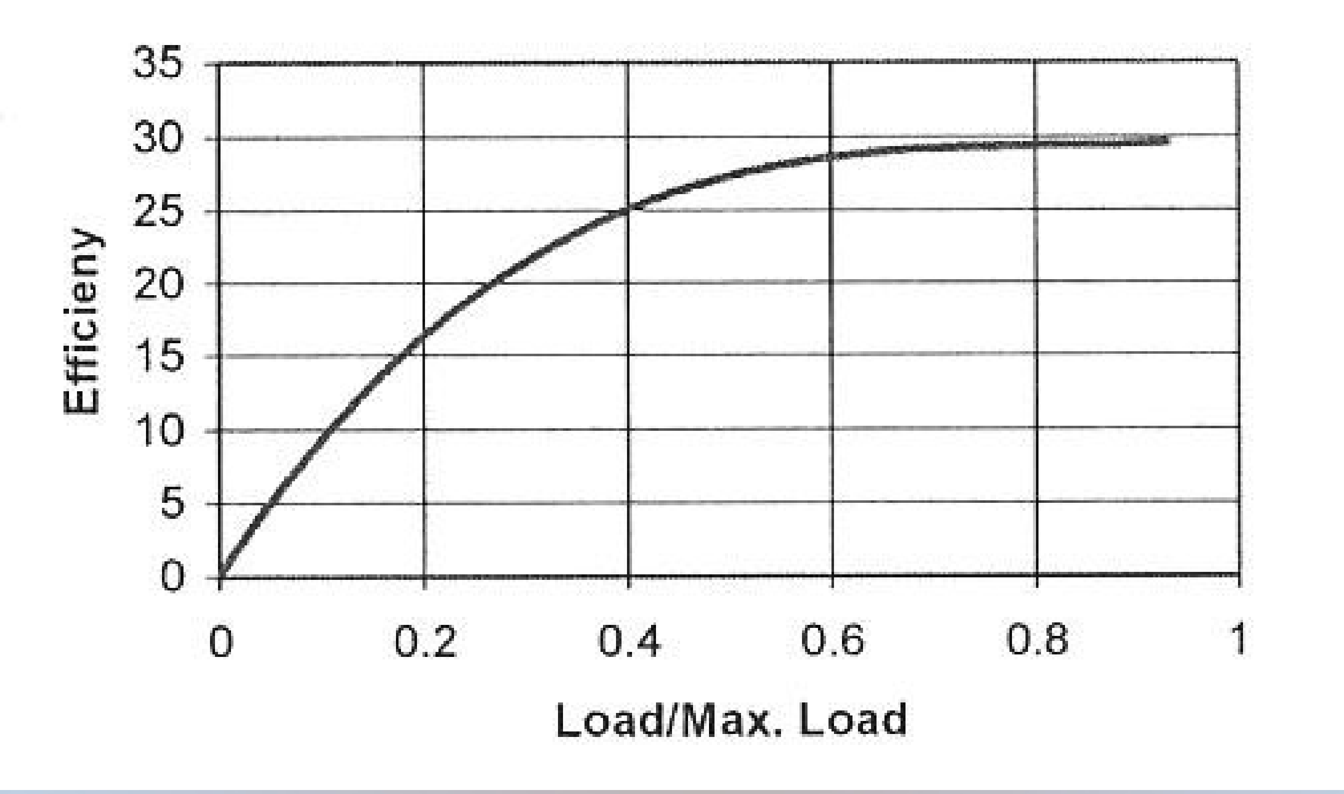
- The power that an engine can provide depends on the engine rpm.



The maximum load is the maximum power that the engine can generate at a given speed: e.g. at 3000 rpm, the max load is 100 hp.

Efficiency vs. Max Load

- Engine are most efficient when they are running near max load.



Example of the effects of an overpowered car

- Previous slides are for a typical 3500 lb car.
- At 70mph the power required is 25hp and the engine is running at 3000 rpm.
- The max load at 3000 rpm is 100hp thus we have a partial load of only 0.25 and thus our efficiency is only 19%.
- If we use a smaller engine our partial load increases and we get better efficiency
- If we use a more powerful engine, the partial load decreases and we get worse efficiency.

Techniques to improve efficiency

- Only use some of the cylinders when cruising. Others engage when you need more power.
- Use two engines: example Hybrid cars that combine gas and electric motors.,

Characteristics of the worst case car

- Very Heavy (increases forces due to rolling friction, acceleration, and hill climbing.)
- Boxy (increases aerodynamic drag)
- Overpowered (decreases partial load efficiency)

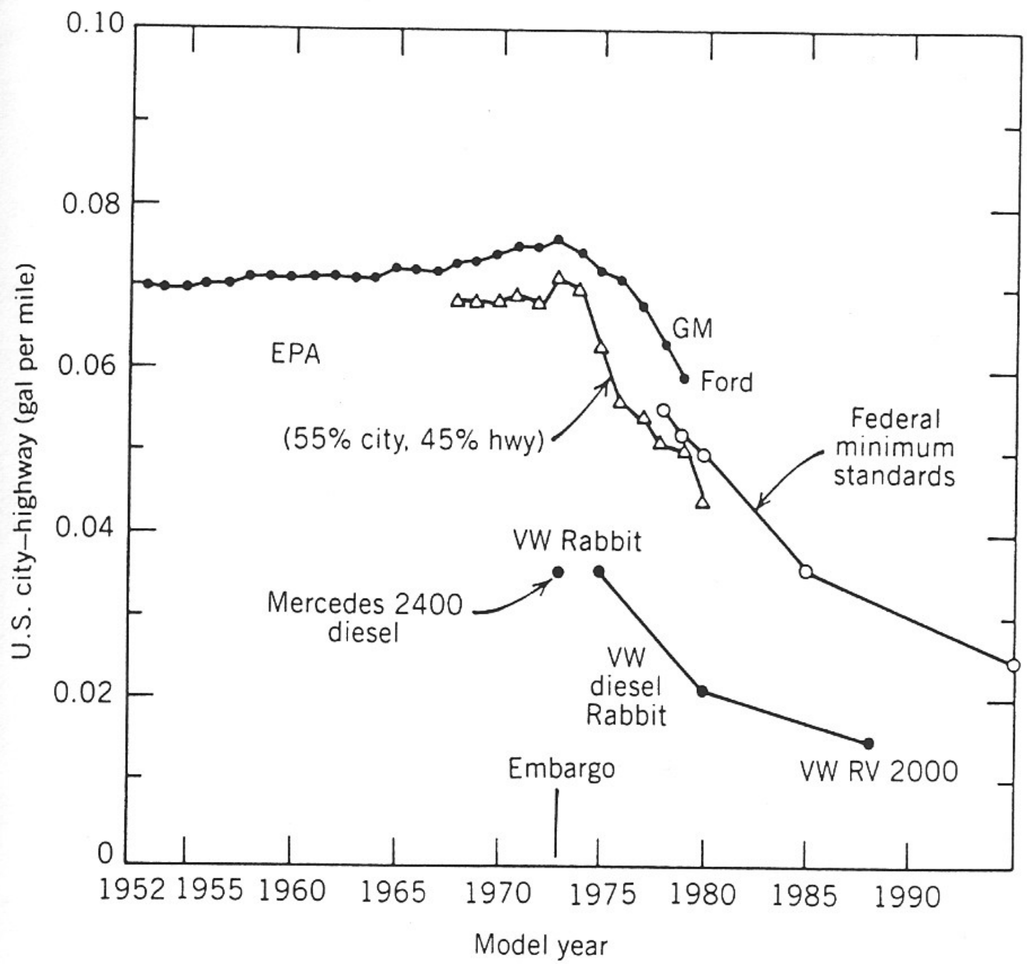


Figure 9–7.
Some measurements, standards, and projections of auto fuel consumption in the United States during the period 1952 to 1995. (Source: Lawrence Berkeley Laboratory Report LBL-11990.)

Figure 3
Comparison of Auto Fuel Economy Standards Among Countries, Normalized to U.S. Test Procedures