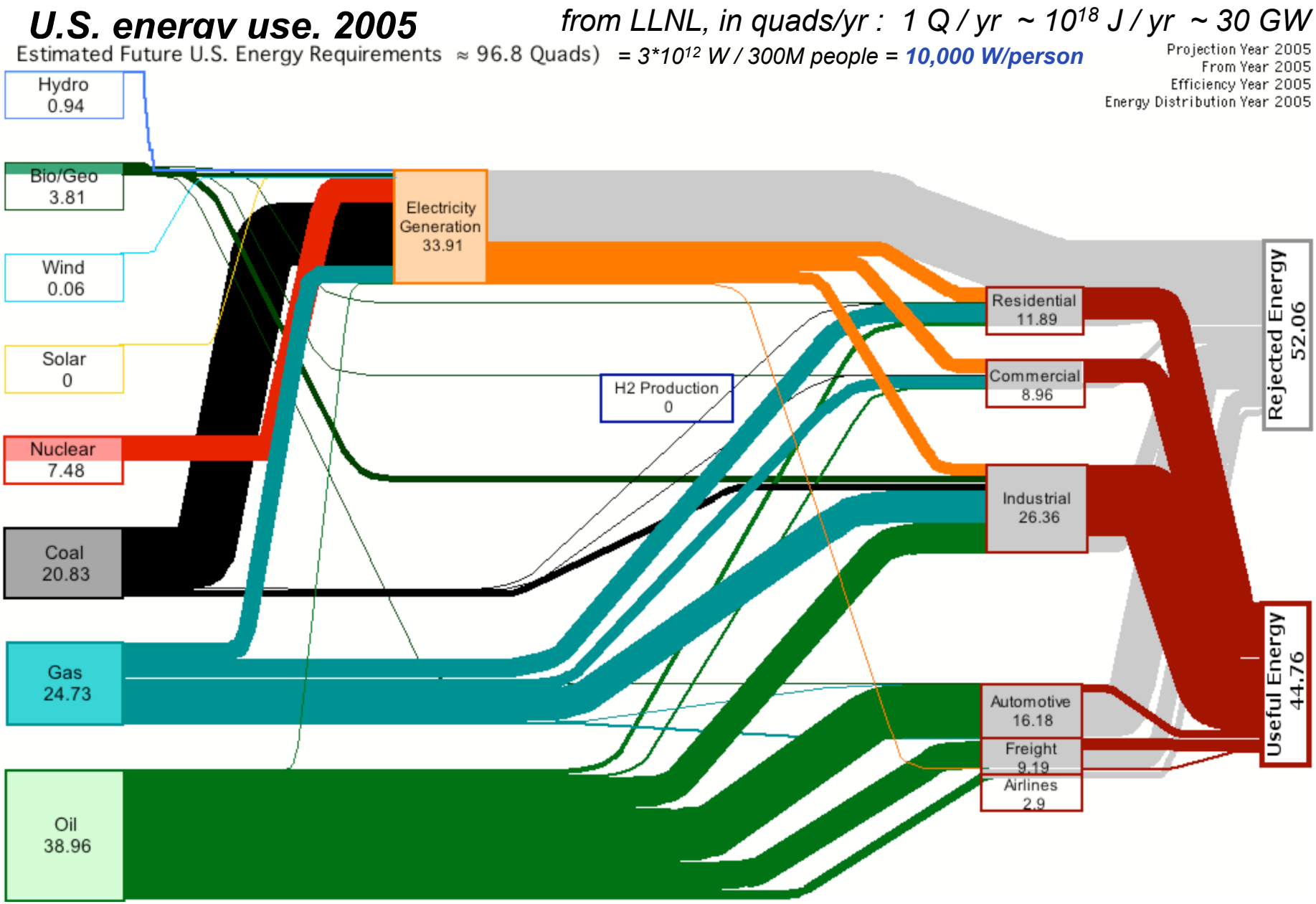
GEOS 24705 / ENST 24705
Lecture 15: the internal combustion engine and transportation

Oil is now 1/3 of U.S. primary energy use



Why are liquid fuels so important?

….they are primary transportation fuel

1. Allow **internal combustion engine** which is intrinsically lighter than external combustion engine (W/kg)
   determines how fast you go

2. Fuel has high **mass energy density** so range is high (J/kg)
   determines how far you go

3. Fuel has high **volume energy density** so again, easy to bring enough to get high range (J/m^3)

Reciprocating internal combustion engines

…. Power nearly everything that runs on liquid fuel

…. Consume nearly all oil used

…. Make up 1/3 of U.S. primary energy consumption

Automobiles and trucks
Motorcycles
Locomotives
Boat engines
Propeller airplanes
Diesel generators
Riding lawnmowers
Outboard motors
Chainsaws (the non-electric kind)
Weed-whackers

Uses: things that need to be mobile, where power-to-mass matters

Transportation: early attempts with steam

Nicolas Cugnot, steam-powered automobile

First car (1769), military tractor for carrying artillery, 2.5 mph

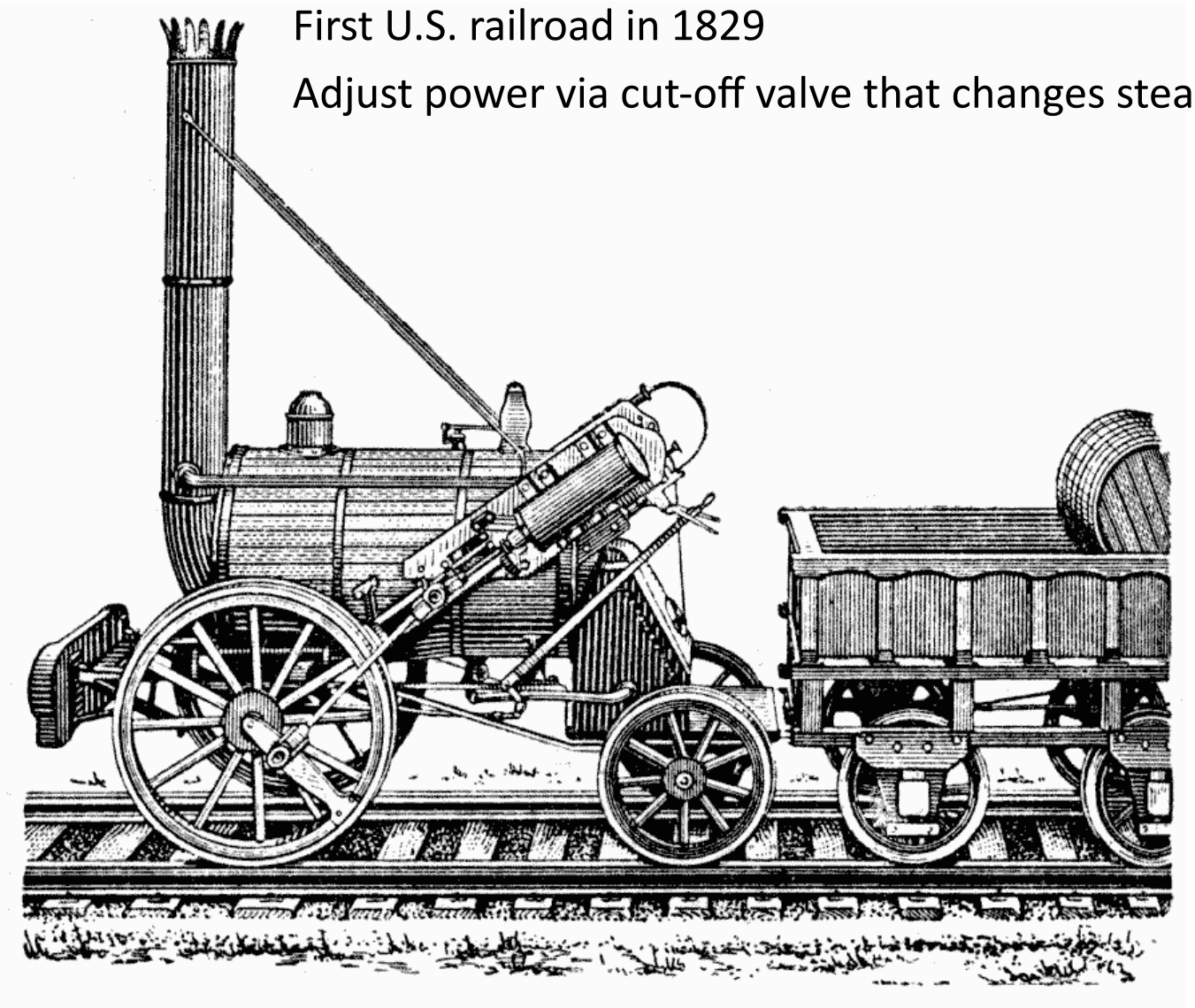
First car accident (1771)

Transportation: steam used mainly for locomotives

First full-scale steam rail locomotive in Britain in 1804

First U.S. railroad in 1829

Adjust power via cut-off valve that changes steam intake to piston



Stephenson's Rocket, 1829, winner of Rainhill Trials race between Liverpool and Manchester..

Desire to get away from steam and external combustion

But what fuel to use? What is available?

* Gunpowder
* Coal gas (made by heating and gasifying coal)
* Hydrogen (made chemically)

.. and only later…

* Liquid petroleum distillates

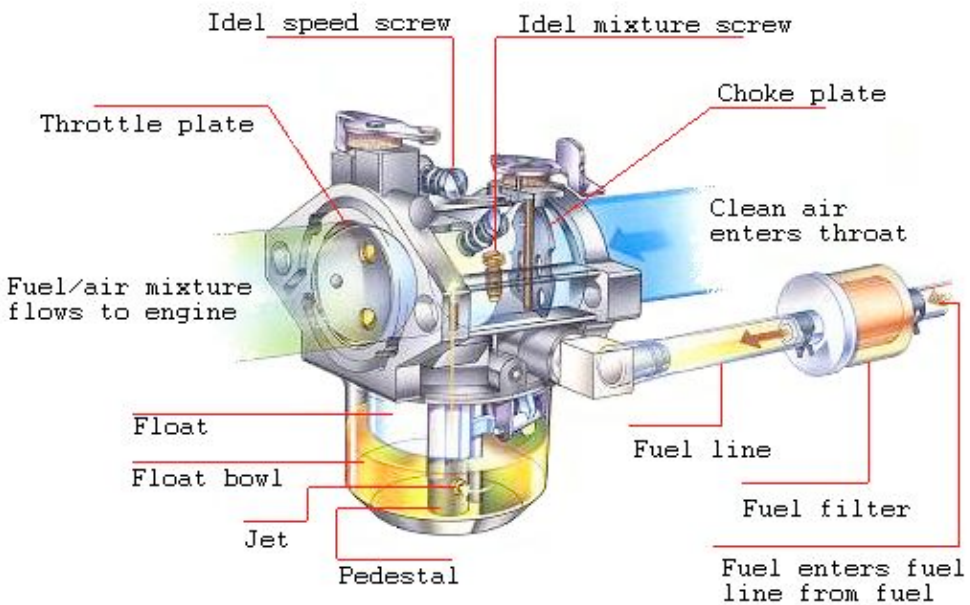
Obstacles to liquid fuel

- Availability

  (little petroleum refining before mid-1800s, even by 1888 petrol purchasable only in drugstores as medicine)

- Mixing liquid fuel into gaseous air

  (required invention of carburetor)



Carburetor and Fuel System

Internal combustion engine history: early history in France

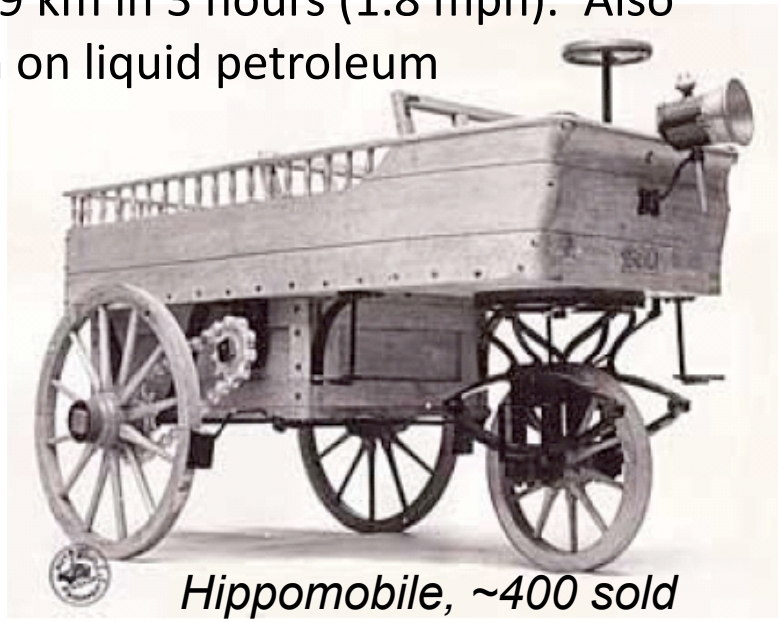
1680: Christian Huygens (Holland) designs *(but doesn't build)* an internal combustion engine driven by gunpowder

1690: Denis Papin designs *(but doesn't build)* an internal combustion engine driven by gunpowder. Gives up an invents steam engine instead (design later built by Newcomen).

Early-mid 1800's: experiments with modifying steam engines to run on coal gas (i.e. natural gas)

1858: Jean Joseph Étienne Lenoir patents spark-ignition ICE running on coal gas. In 1863 drives hydrogen-powered vehicle 9 km in 3 hours (1.8 mph). Also drives vehicle with engine modified to run on liquid petroleum 7 miles at 4.5 mph.

1862: Alphonse Eugène Beau de Rochas, French engineer, designs and patents *(but doesn't build)* the first four-stroke engine with compression cycle



Hippomobile, ~400 sold

The birthplace of the internal combustion engine was not France

Internal combustion engine

President Obama, State of the Union speech, Feb. 2009, on bailing out Detroit automakers:

"The nation that invented the automobile cannot walk away from it."

Internal combustion engine

Edmunds *Inside Line*:

"In what will surely be seen as a provocative move by the new administration, President Barack Obama announced last night in a televised address to the U.S. Congress that all inventions of note from at least the last 200 years will now be credited to Americans.

The president revealed last evening that credit for the invention of the automobile will be transferred from one Karl Benz of Germany to an unspecified American."

Internal combustion engine history:
development in German-speaking countries

1876: Nicolaus Otto builds workable, commercial version of 4-stroke gas *(not gasoline!)* engine, patents it (again). Now known as "Otto cycle".

1879: Karl Benz gets patent on 2-stroke version of gas-fueled Otto engine.

1885: Daimler & Maybach, having quit Otto's company, invents prototype of modern engine fueled by liquid petroleum with carburetor

1885: Karl Benz builds 3-wheeled automobile with flex-fueled engine
later patents: spark ignition, sparkplug, carburetor, clutch, gear shift, radiator

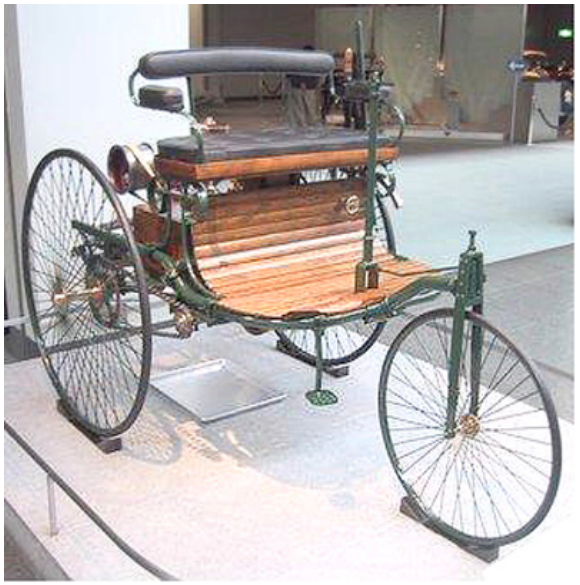
1886-1889: Daimler/Maybach automobiles:
4 wheels, 4-cylinder engine, 10 mph top spd,
first sale in 1892 (Benz has > 500 by 1899)

1893: First auto manufacturing in U.S.
(Duryea company, MA)

1896: Henry Ford starts auto company in Detroit

1908: Mass production of Ford Model Ts

Benz, 1885 – gas or petrol use



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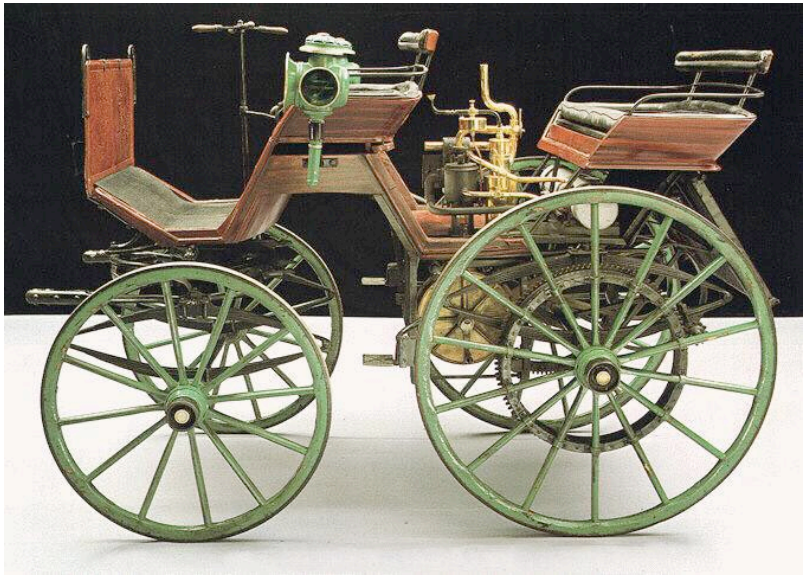
Daimler-Maybach, 1886. (VintageWeb)



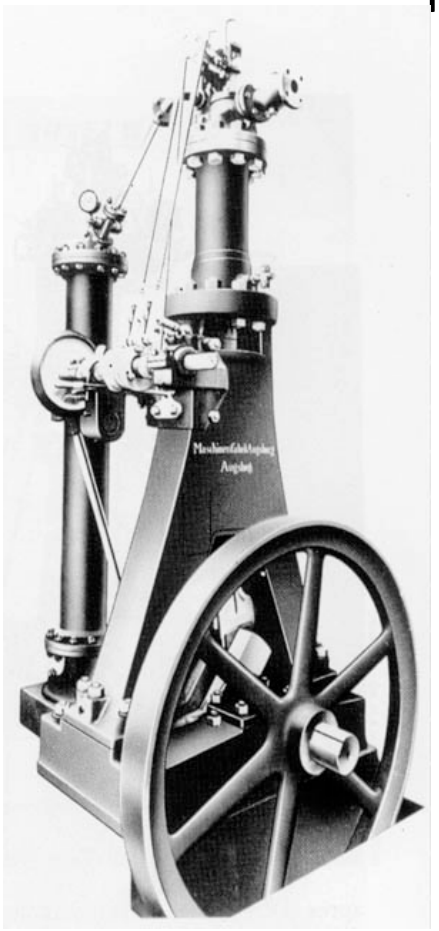
Internal combustion engine history:

2 other famous German-speaking auto inventors: who were they?

Both exhibited at the 1900 Paris Exposition

One *(former electric shop worker)* won the speed competition with an **all-electric car** carrying a 900-pound battery with a 38 mile range & top speed of 36 mph.

The other *(former steam engine designer)* won the Grand Prix of the whole Exposition for a new **biofueled engine** running on peanut oil, operating on a new thermodynamic cycle he'd invented from 1st principles



Diesel engine, invented 1893, 17% efficient. Designer: Rudolf Diesel, German-trained

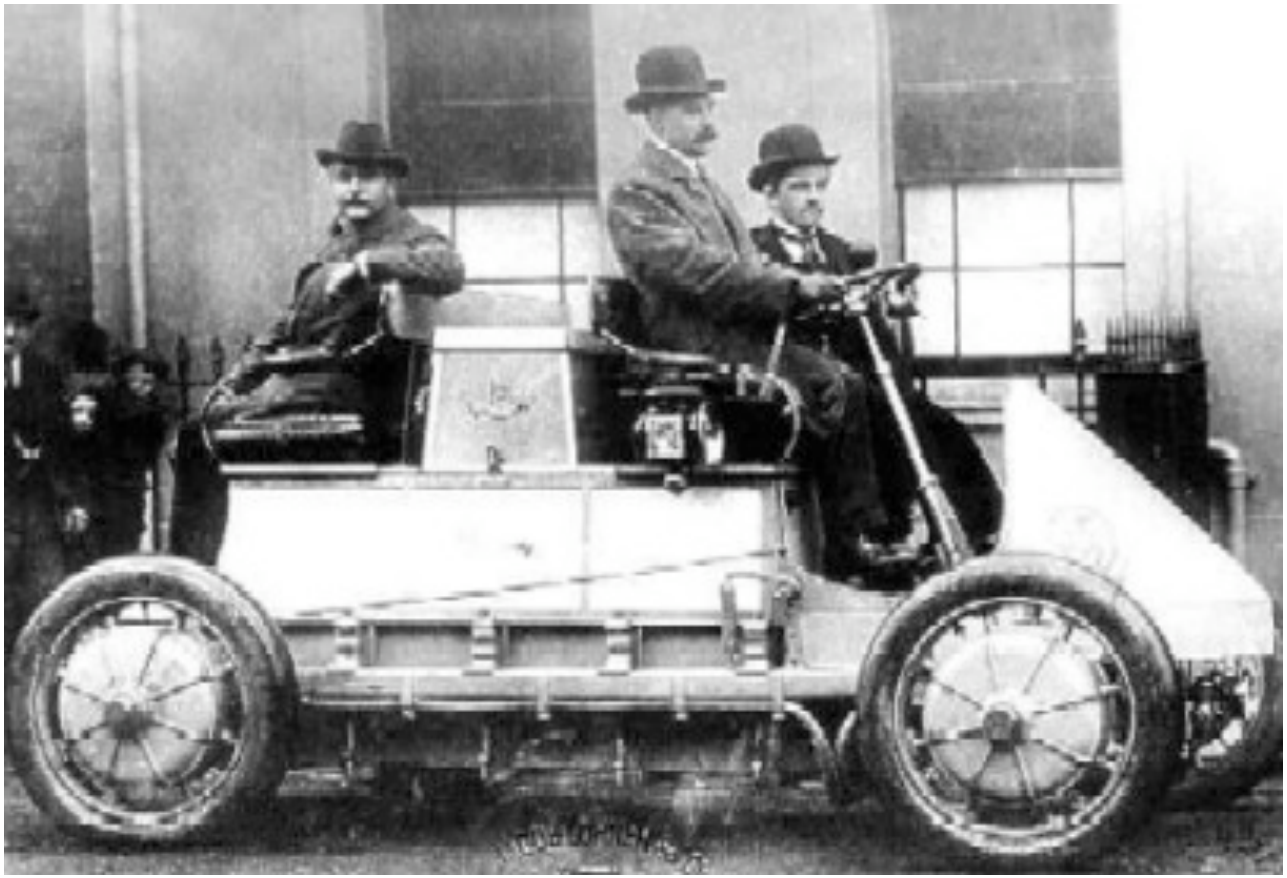
Lohner-Porsche Elektromobil, designer: Ferdinand Porsche, Austrian, age 24. Note electric motors in front wheels.

Transportation: hybrid electric motor-driven cars not new

First hybrid 1901: to extend range, gasoline engine added to charge battery

Lohner-Porsche, hybrid “Mixte”, top speed 35 mph. In-wheel motors on all four wheels – first four-wheel drive vehicle. 83% efficient at conversion of electrical-mechanical energy.

Figure: jalopnik.com



Transportation: hybrid technology used for large vehicles

Hybrid technology in “land trains”: gasoline engine in lead car drives generator; electricity carried to each car to drive separate electric motors

Porsche “Landwehr”, post-1905 (while Porsche employed by Daimler), used by Emperor Joseph’s military to bring supplies to troops..

Figure: hybrid-vehicle.org

Transportation: steam and electric both viable in personal vehicles

Stanley Steamer: biggest selling U.S. car by 1899 (200 sold) in production til 1927, typically

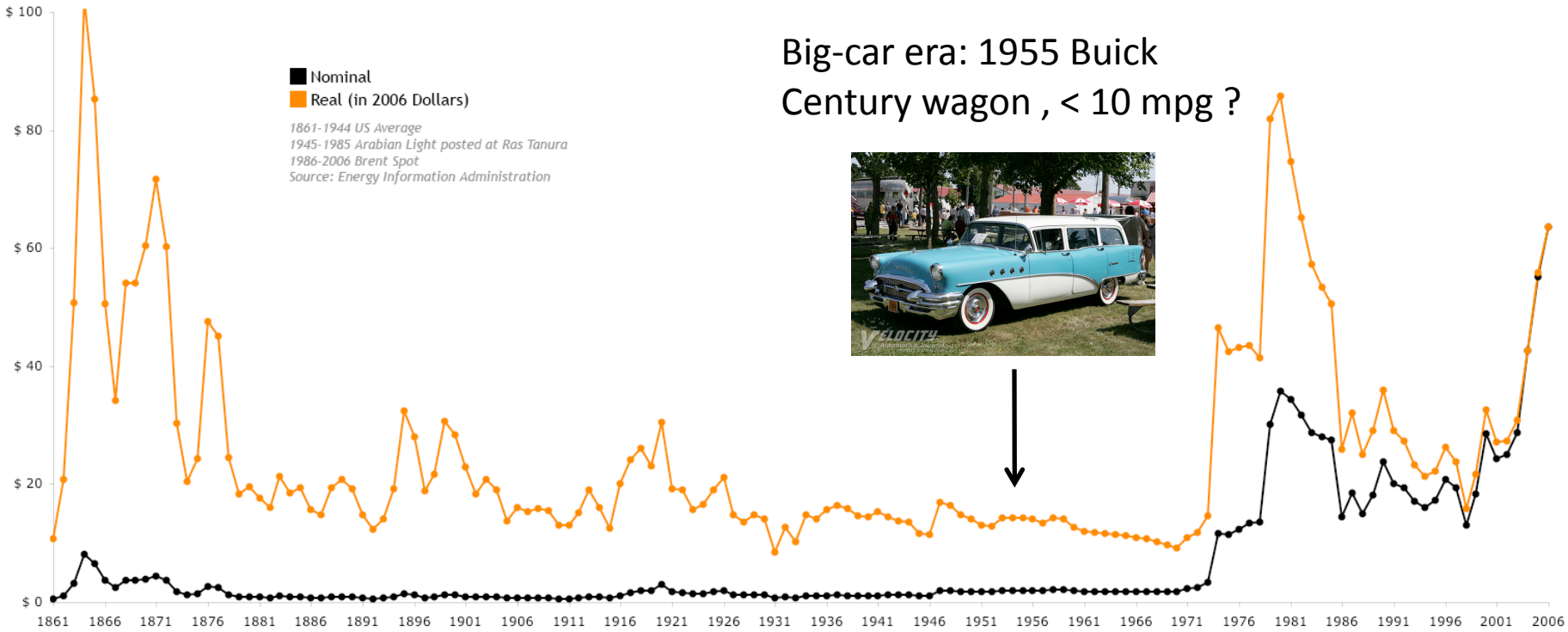
Set world speed record in 1906 (128 mph)

Burned gasoline or kerosene externally & made steam in vertical-tube boiler

1911 Model 72 20 hp Roadster, Stanley Corp. (Photo: Ken Hand)

Why did the internal combustion engine win out?

In part, because fuel became cheap…



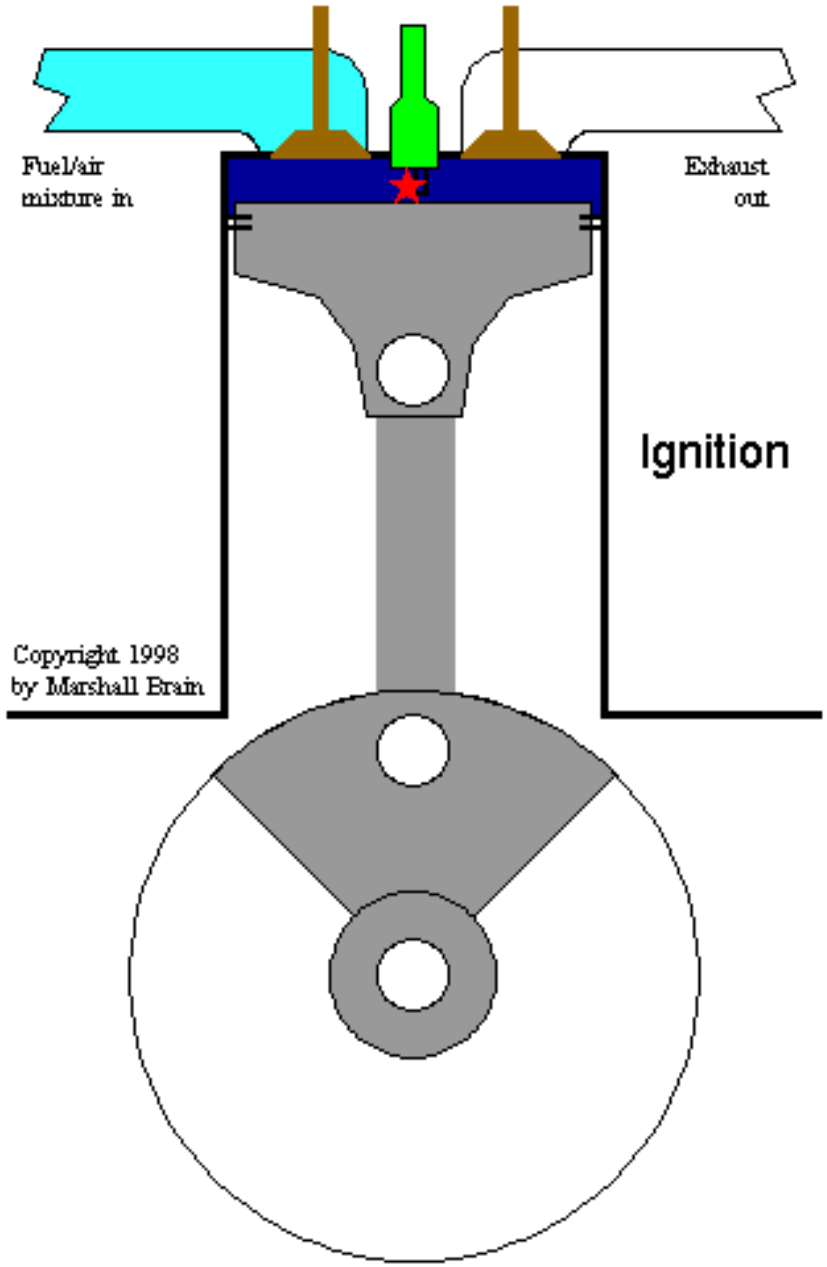
Big-car era: 1955 Buick Century wagon , < 10 mpg ?

Production of Model T Fords begins 1908

Oops! Compact cars are nice after all

Figure from: Wikimedia Commons

Four-stroke engine: Otto cycle
driver of most transportation



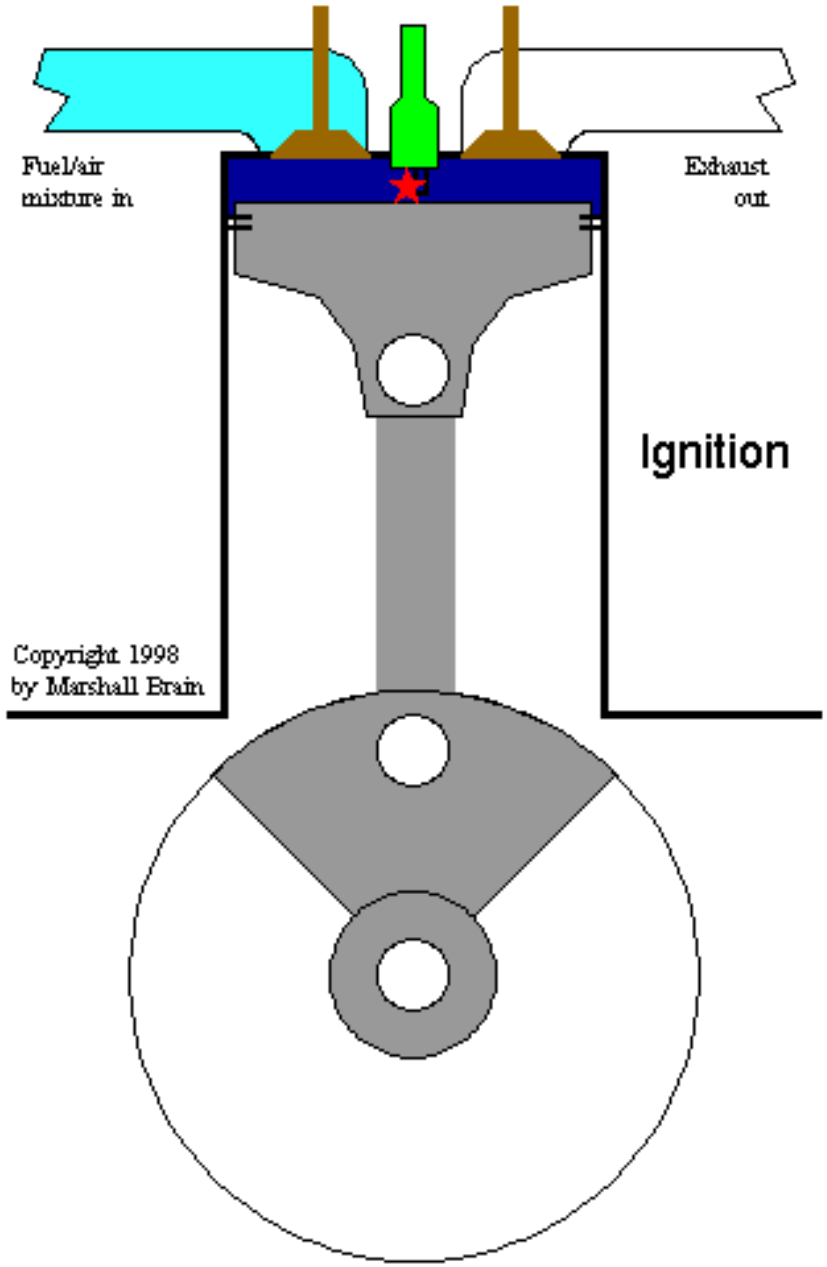
One preparation cycle and one power cycle

1. Intake
2. Compression
3. Combustion
4. Expansion

Note need for spark plug to set off combustion

Note means of converting linear motion to rotational – looks similar to “sun and planet” gearing from Watt’s steam engine

Four-stroke engine: Otto cycle
driver of most transportation



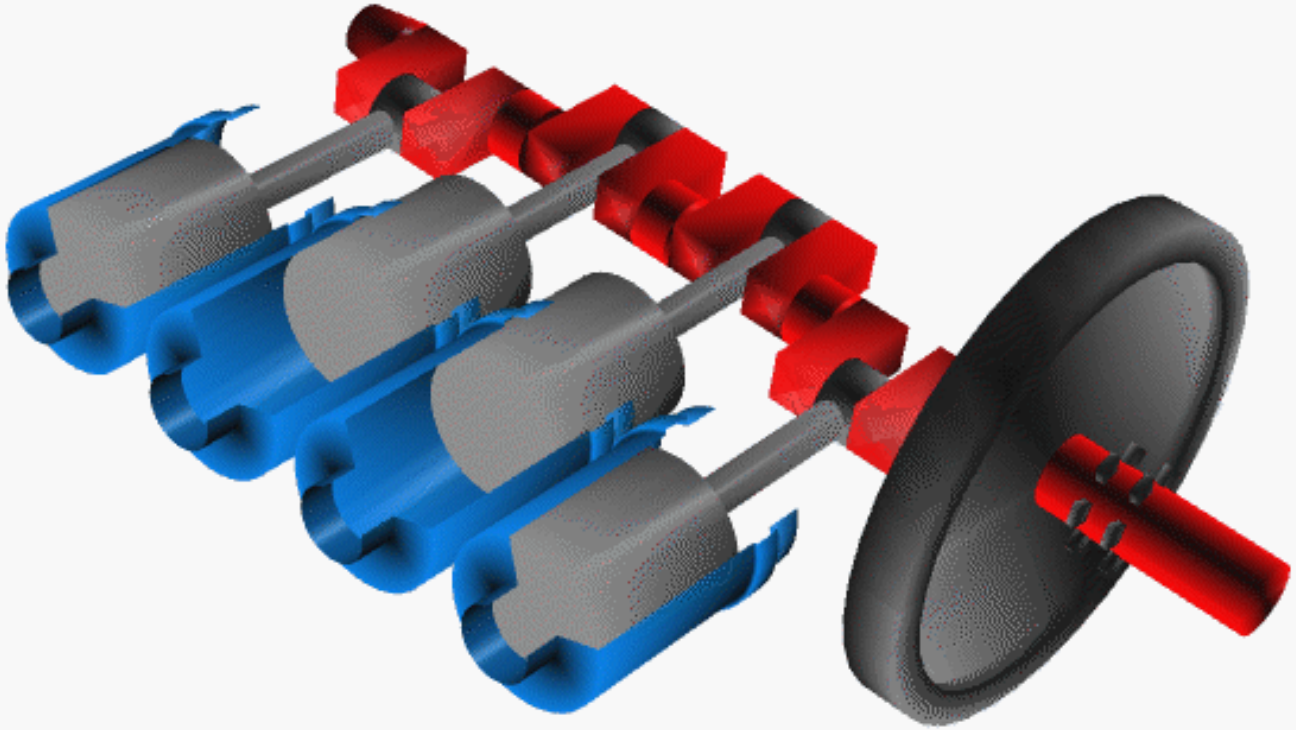
Advantages:
Produces heated, compressed, very dense fuel/air mixture

Disadvantages:
"off" half the time – half the power-to-mass ratio that it might have

Generally have at least two cylinders, so that when one is "off" the other can provide the push to keep rotating the shaft

Four-stroke engines: generally have pairs of cylinders

Gasoline engines for automobiles typically have 4-8 cylinders
Out-of-phase cylinders provide force to drive pistons through compression phase and yield balanced power



Note central crankshaft allowing pistons to turn linear motion into rotational motion and to put work into the same shaft

Four-stroke engines: generally have pairs of cylinders

Some high-power automobile engines have 8 cylinders, hence “V8”

BMW M3 V8 Engine: 4.0-litres

Two-stroke engine

Simpler, cheaper

Advantages:

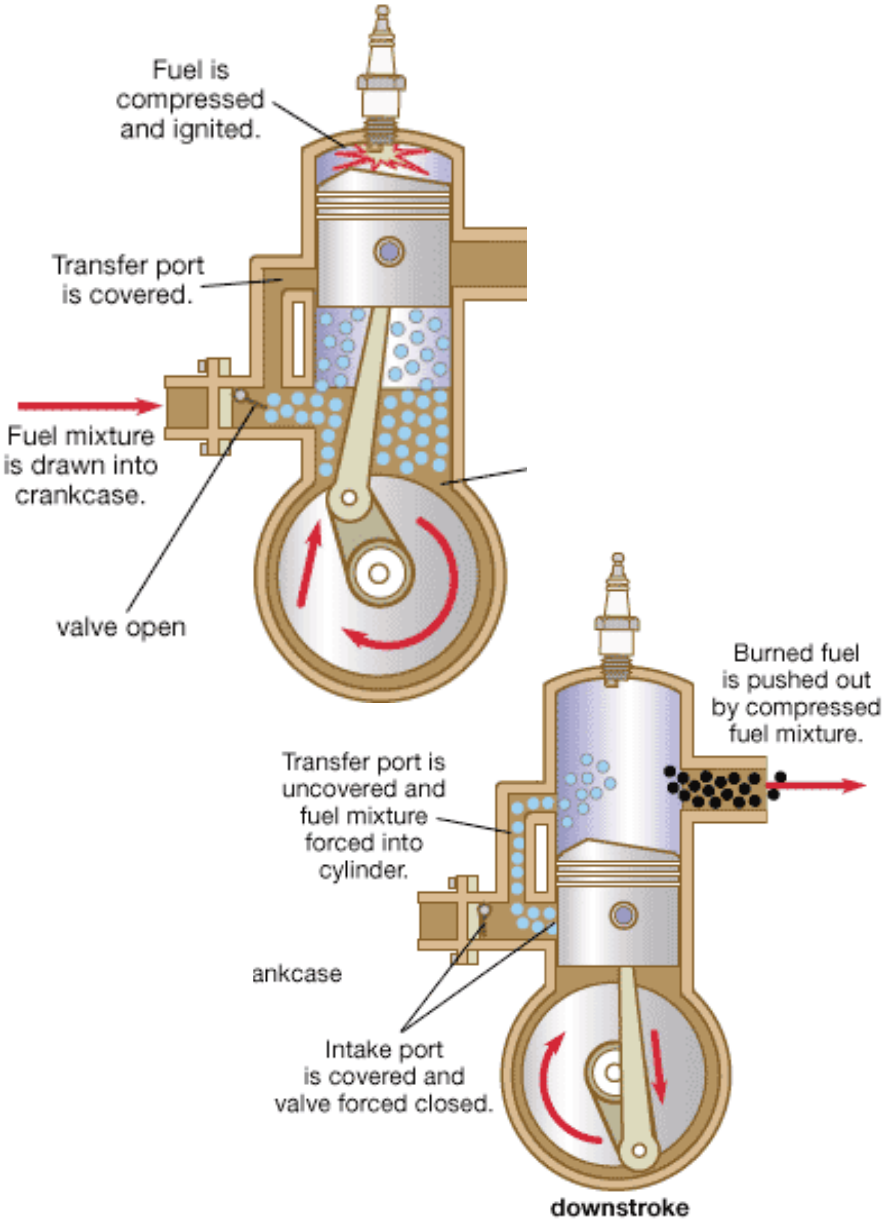
Higher power-to-mass since is never "off" – each stroke is power stroke. Smoother power in one-cylinder engine

Therefore: engine of choice for cheap or hand-carried applications

Disadvantages:

Some unburned fuel escapes – very polluting

Since fuel fills crankcase, lubricating oil must be mixed into fuel mixture – *even more polluting*



Two-stroke and four-stroke engine comparison

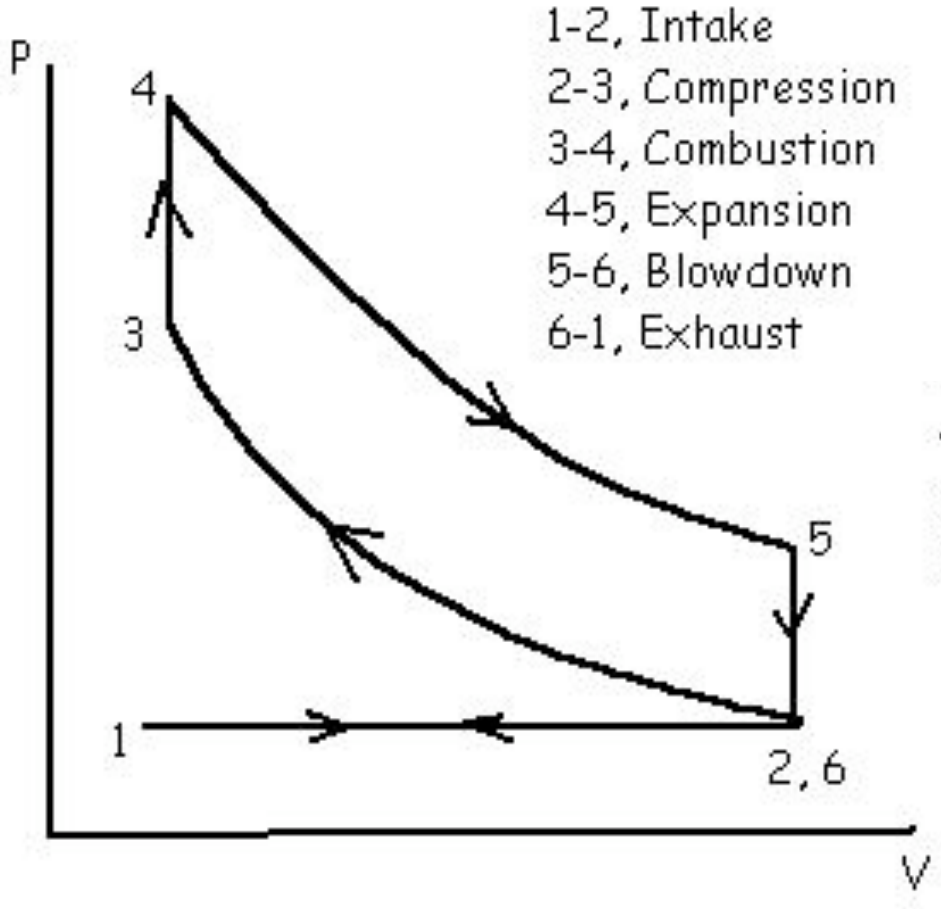
Four Stroke Engine Animation

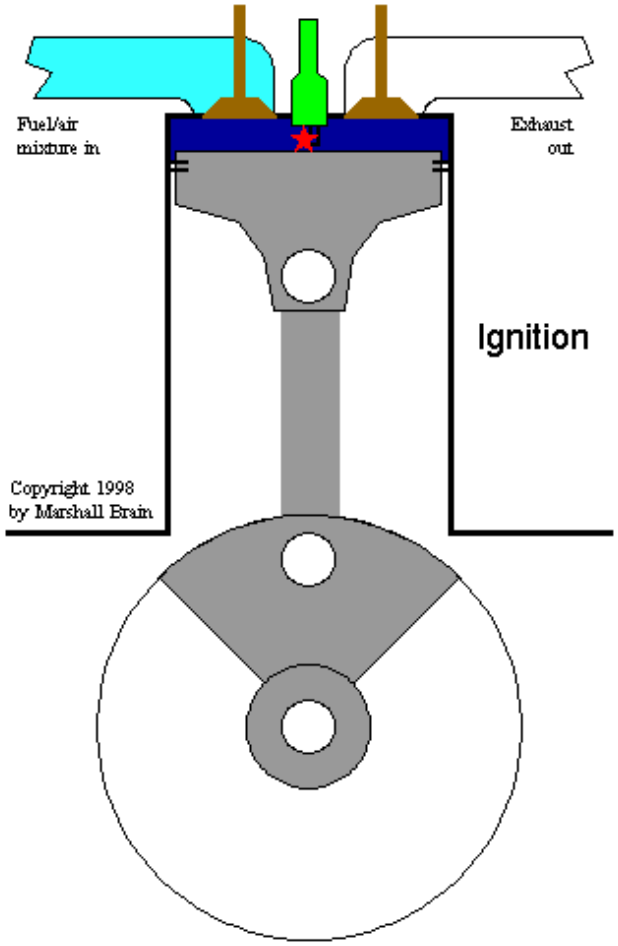
Two Stroke Engine Animation

See: www.animatedengines.com

Thermodynamic cycles: Otto cycle

Fast combustion + valve opening =
2 constant-volume legs. Sparkplug
to ignite quickly and completely.





Efficiency = $1 - 1/r_k^{\gamma-1}$ where = r_k = compression ratio V_1/V_2

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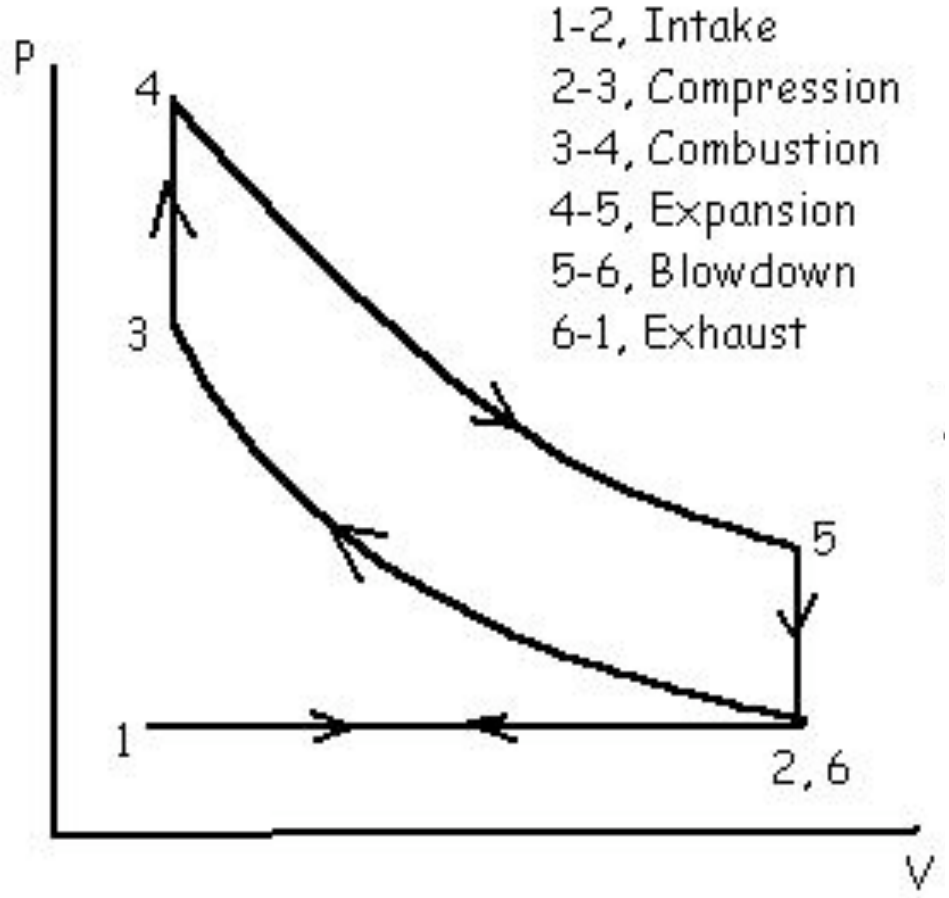
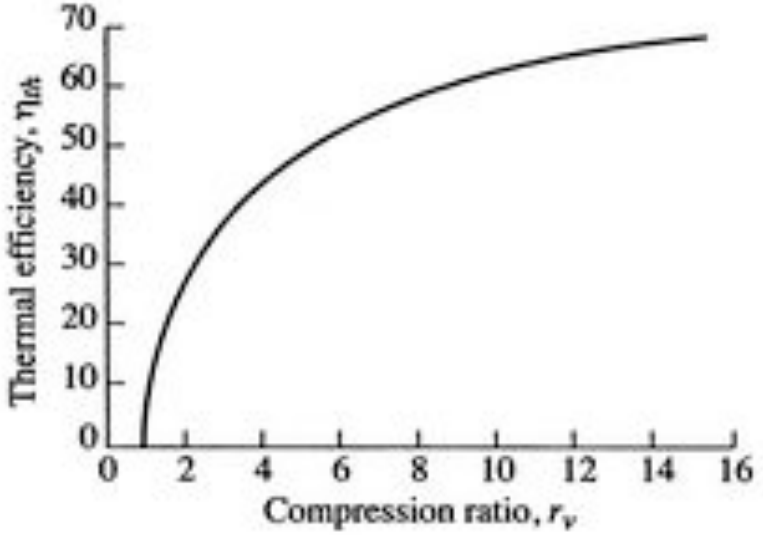


Since efficiency is a function of compression ratio, engineer for high ratios, typ. ~ 10:1 in cars

Figure: web.mit.edu



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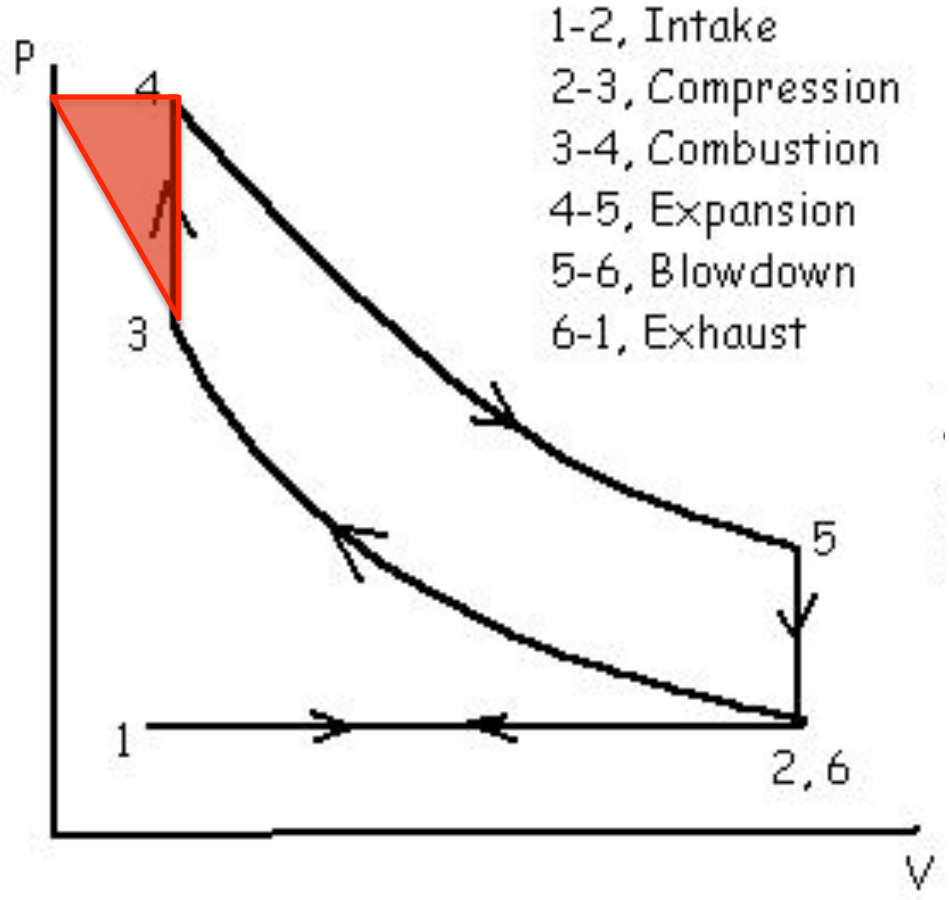
Thermodynamic cycles: Otto cycle

But do you need a constant-volume leg on combustion? More power if can compress gas even more



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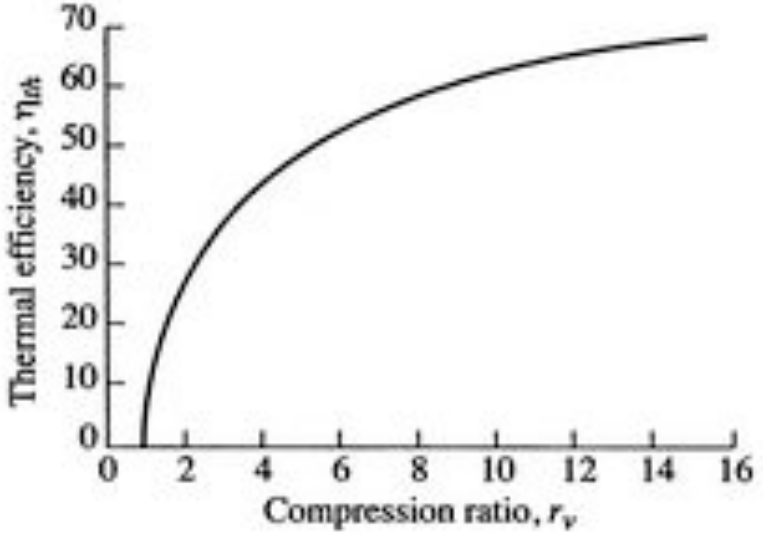
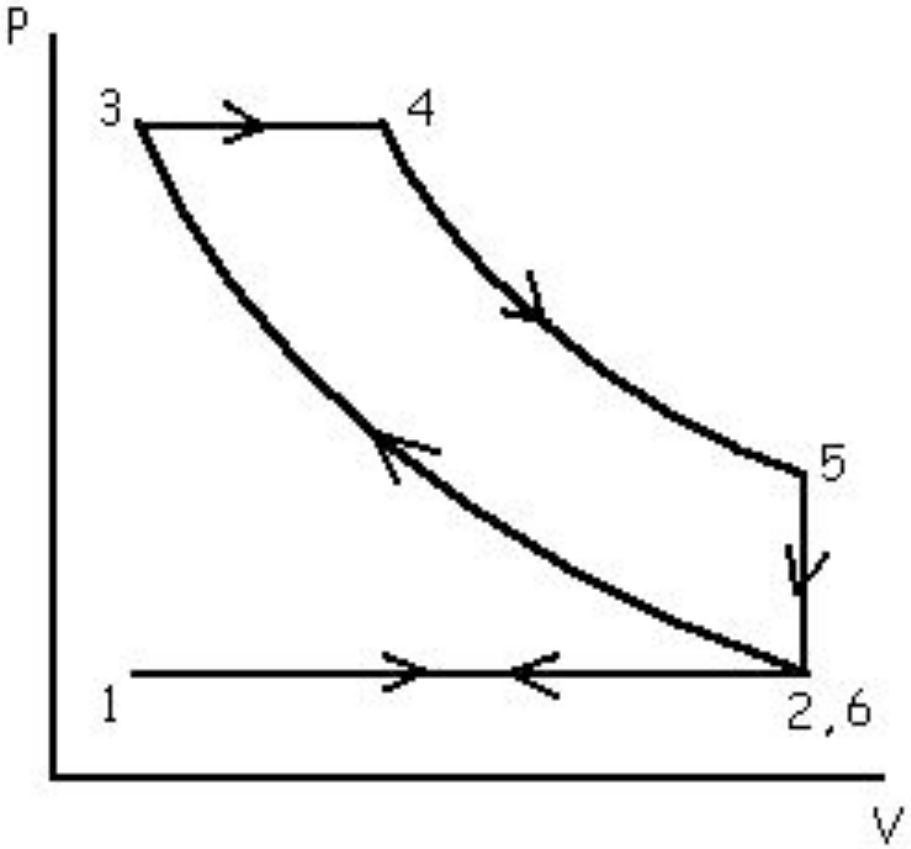


Efficiency = $1 - 1/r_k^{\gamma-1}$ where = r_k = compression ratio V_1/V_2

Thermodynamic cycles: Diesel cycle

Cycle designed for higher efficiencies, achievable only if fuel can withstand higher pressures. Fuel must be sprayed in to compressed air to control ignition.



Efficiency = $[1 - 1/(r_k^{\gamma-1})]*(\alpha^{\gamma} - 1)/(\gamma(\alpha - 1))$,
where α is the "cutoff ratio" V_4/V_3

What we call Diesel fuel is a petroleum-based fuel designed for the Diesel cycle. Peanut oil worked perfectly well at first!

Diesel fuel less volatile, ignites on compression but only at very high P

Compression ratios always > 14, can be > 22