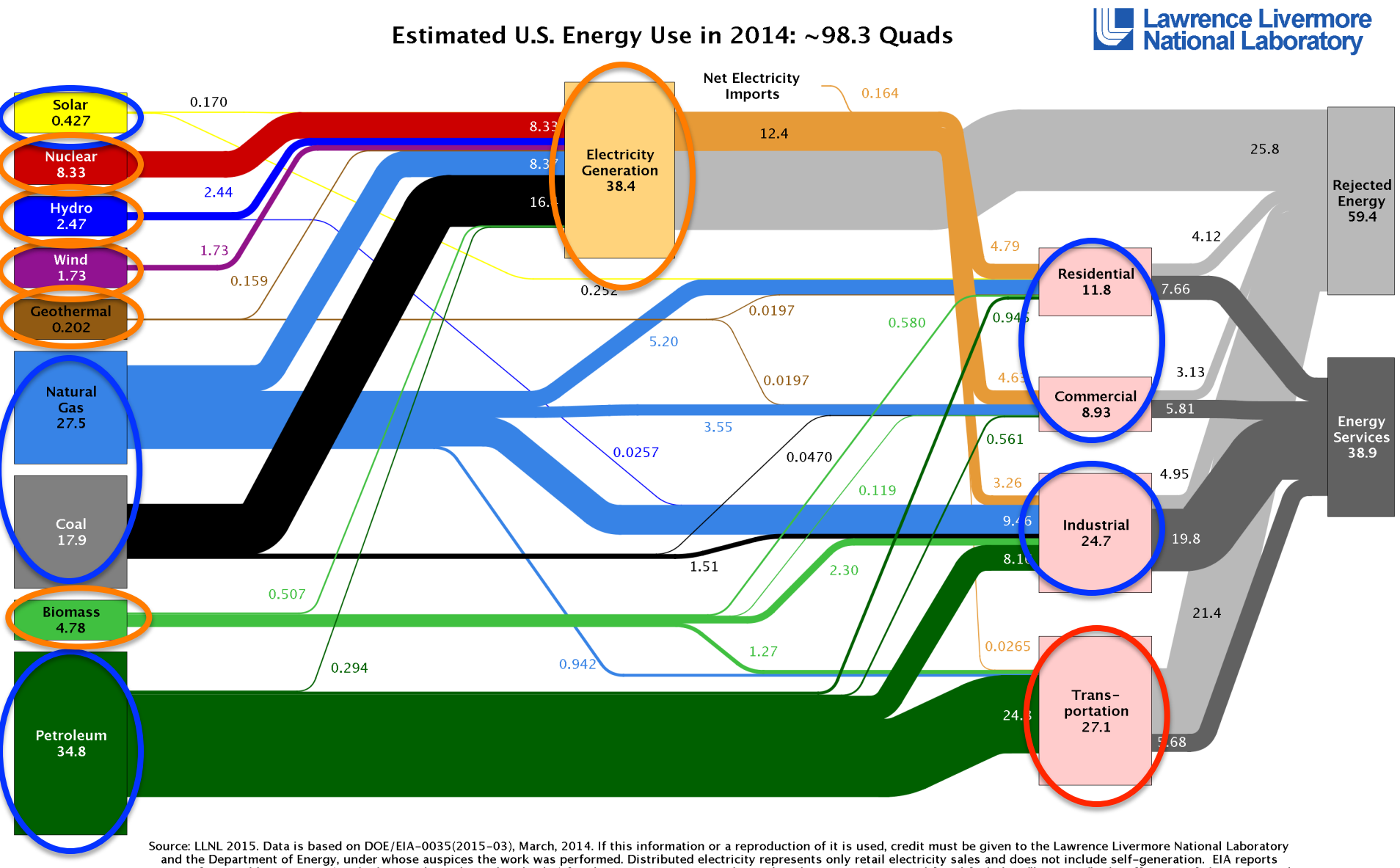
GEOS 24705 / ENST 24705 / ENSC 21100

Lecture 17

End of wind, transportation & engines

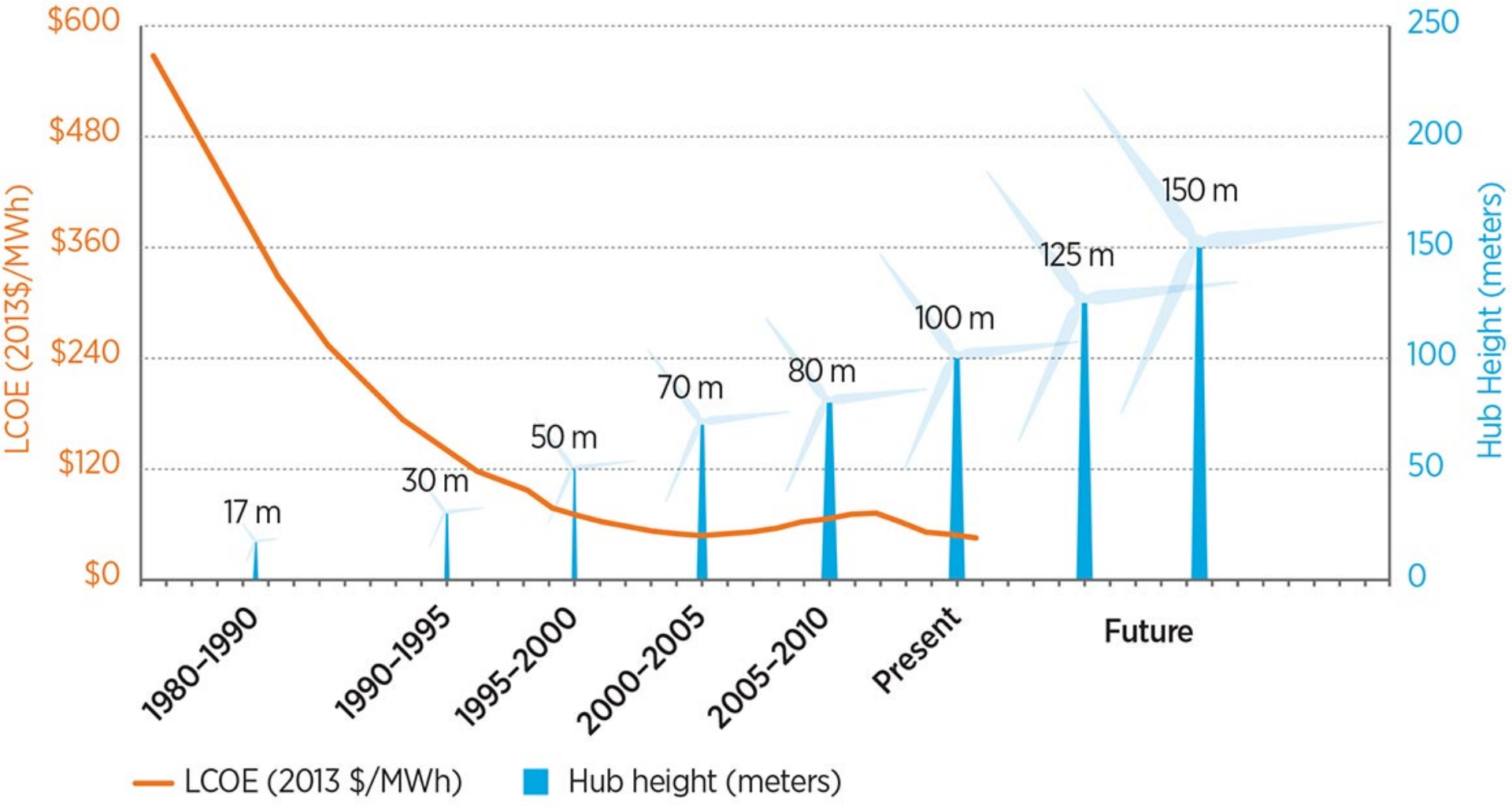
Many topics left to cover

from LLNL, in quads/yr : 1 Q / yr ~ 10^{18} J / yr ~ 30 GW



Source: LLNL 2015. Data is based on DOE/EIA-0035(2015-03), March, 2014. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Wind is increasing now because prices are competitive



What about offshore wind? Why so much in Europe?



Horns Rev, Denmark, 2002

Copenhagen, Denmark



GE Renewable Energy

Integrated Solutions For Offshore Wind Farms



Onshore DC/AC Converter Station & AC Substation
For far offshore wind farms DC often provides the best techno-economic solution for transmission to the shore. Leader in HVDC with over 30,000 MW of installed capacity worldwide, GE has developed efficient grid connections.

Offshore AC Substation
To connect the offshore wind farm to the onshore electricity network or to an AC/DC converter station, GE supplies several types of offshore wind substations, such as selffloating and self installing solutions.

Offshore AC/DC Converter Station
To convert the power generated by the wind turbines in alternating current (AC) to direct current (DC) for transmission to shore, GE offers the HVDC MaxSine* VSC technology for sustainable grid connections.

Haliade* 150-6MW
Built upon GE's Pure Torque* technology for reliability, the turbine features a 6 MW direct-drive permanent magnet generator and is suitable for all offshore conditions.

From wind turbine installation to grid connection

- A reliable, efficient and high yield offshore wind turbine
- An innovative AC platform and efficient transmission over long distances with HVDC technology

Non proportional scale image. *Trademark of General Electric Company

Technology constraints from high turbines

- More power per tower: big turbines
- Minimal maintenance, so very simple generators – minimize chance of **breakage**
  - No electrical connection to rotor
    - **Induction generators** – no brushes on rotor

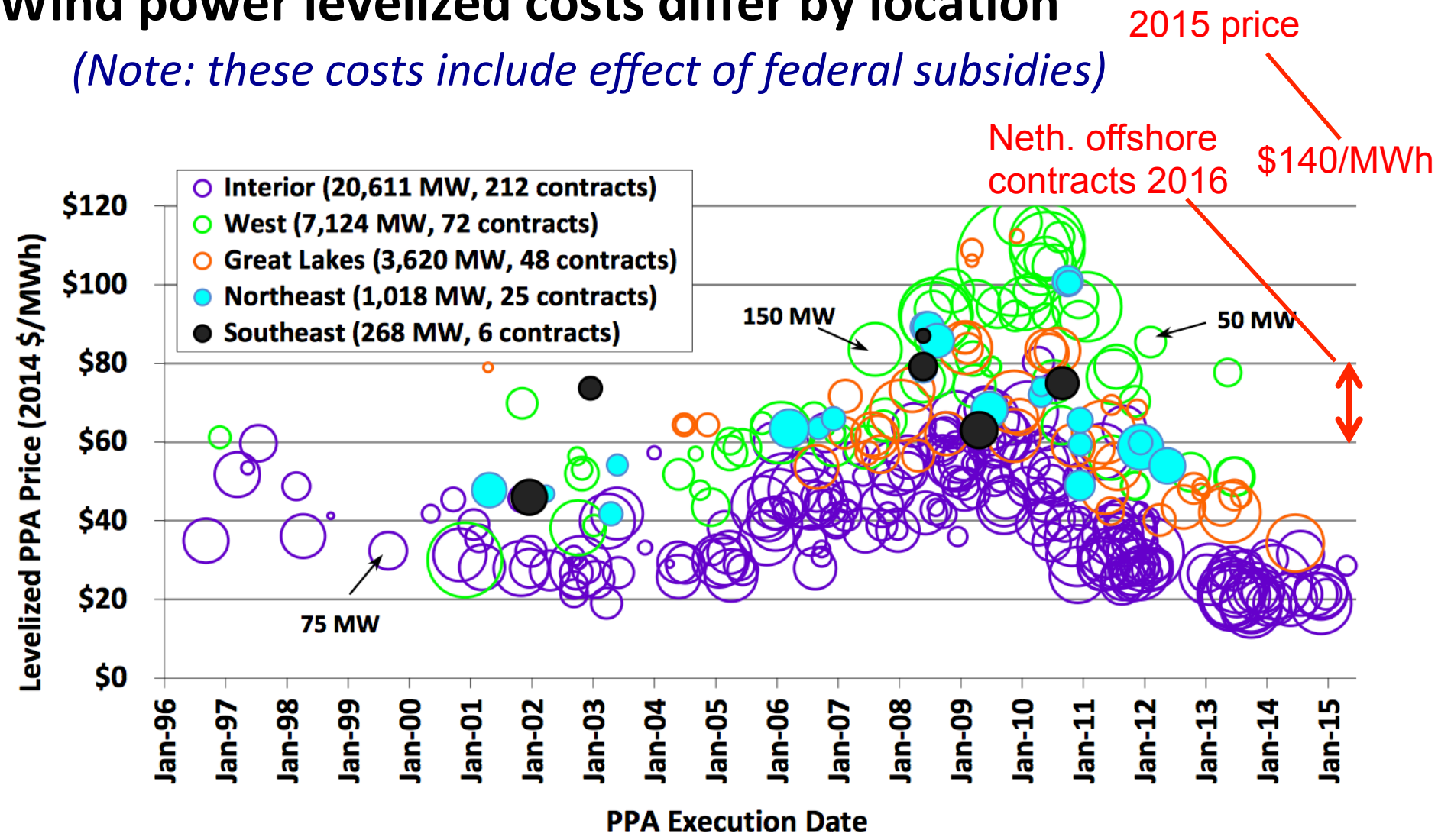
      Drawback – asynchronous (power is out of phase)
    - **Permanent magnet generators** – must use neodynium

      Drawbacks – heavy, + exacerbates shortage of rare earth elements.
  - No gearbox
    - New trend toward **direct-drive generators.**

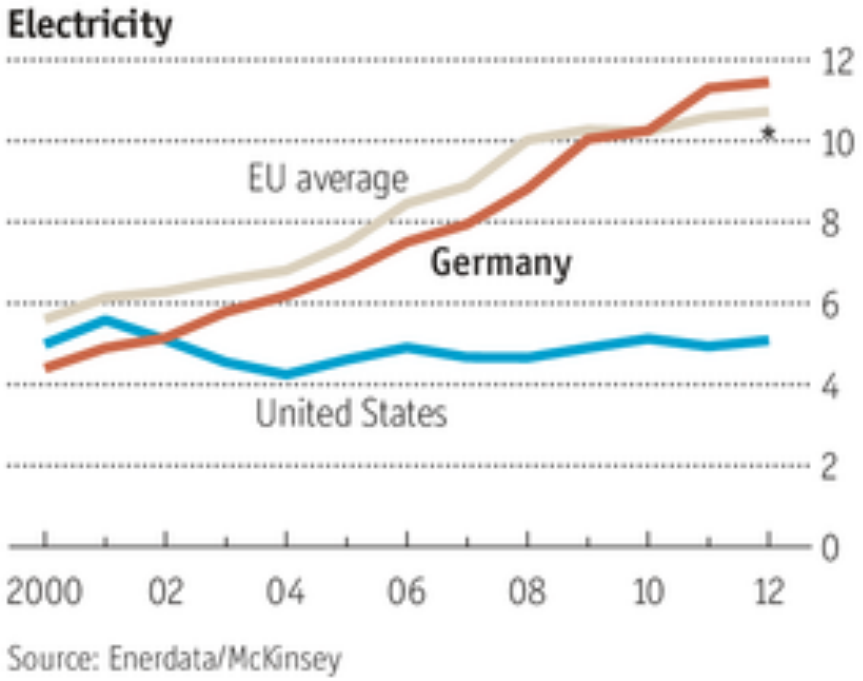
      Drawback – generators must be even bigger (ca. 4 m diameter), so nacelle is even heavier.

Wind power levelized costs differ by location

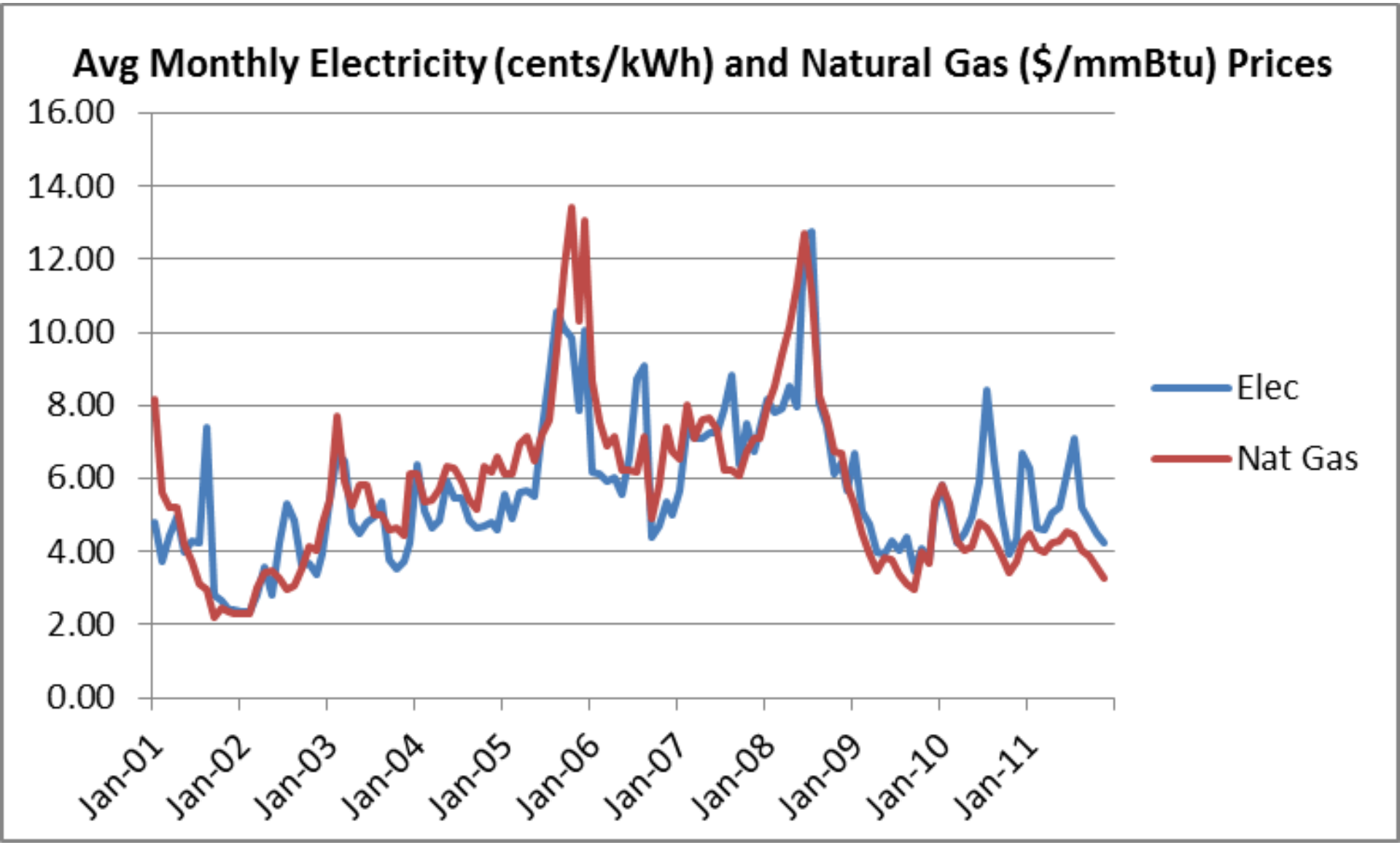
(Note: these costs include effect of federal subsidies)



Economics of renewables are different in Europe



U.S. electricity price follows natural gas



Transportation

Why are liquid fuels so important?

Why are they the primary transportation fuel ?

1. Allow **internal combustion engine** which is intrinsically lighter than external combustion engine (W/kg)

2. Fuel has high **mass energy density** so range is high (J/kg)

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

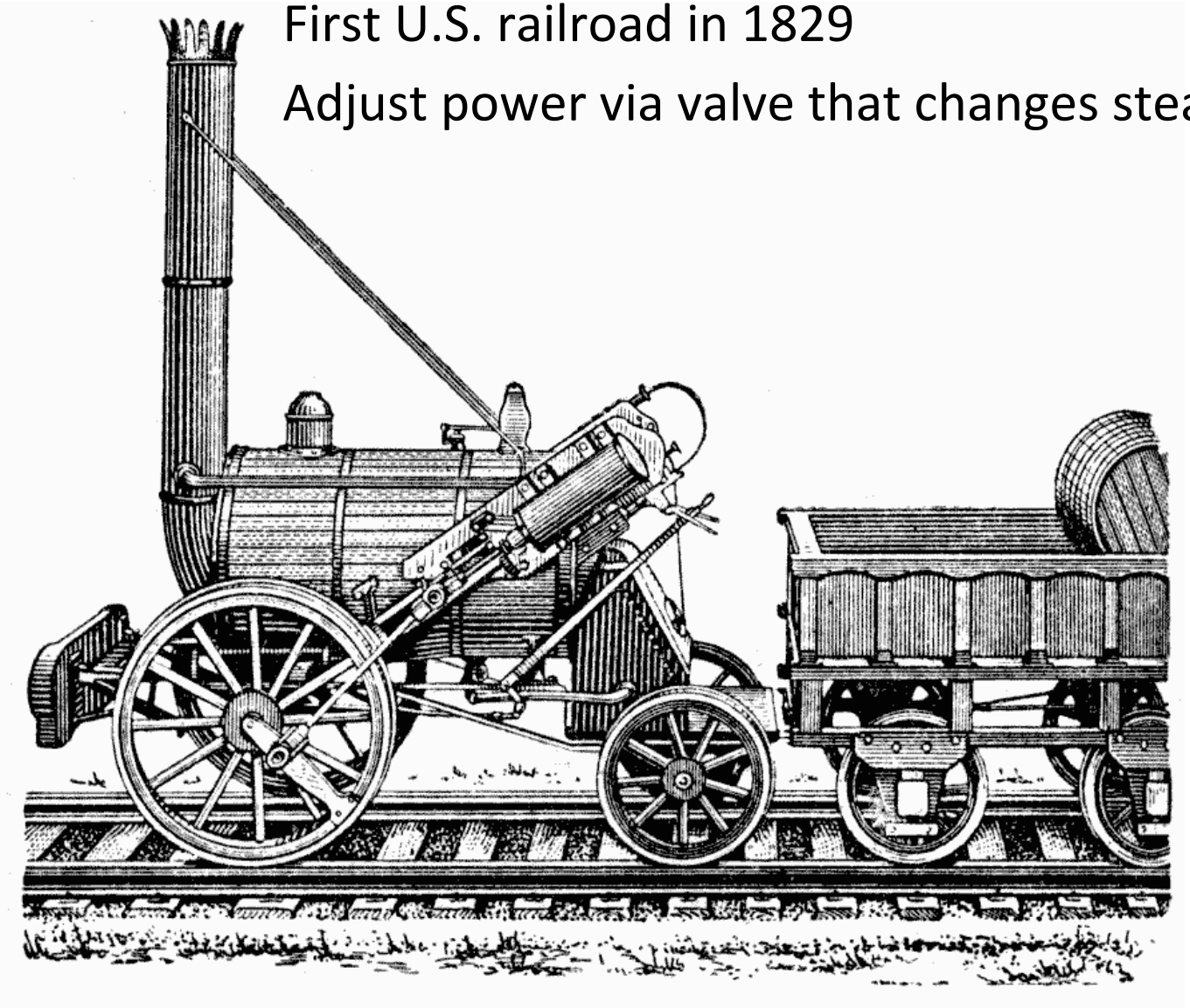
Uses: things that need to be mobile, where power-to-mass matters

19th century: steam used for locomotives

First full-scale steam rail locomotive in Britain in 1804

First U.S. railroad in 1829

Adjust power via valve that changes steam intake to piston



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

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)

(W. Parsons, U.K: steam car, first fatal accident 1869, driven by his sons)



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

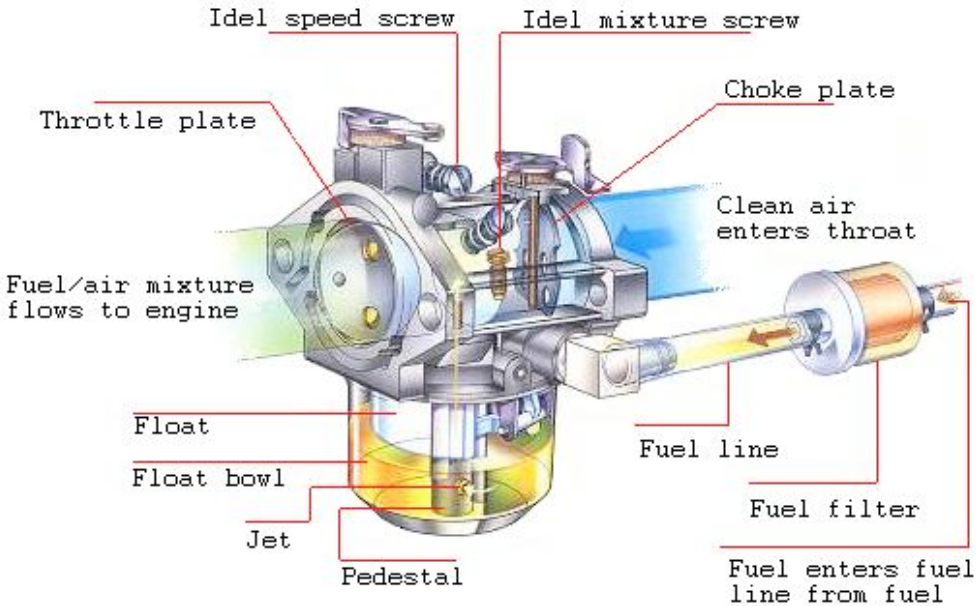
Obstacles to liquid fuel

- 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, later fuel injection)



Carburetor and Fuel System

Internal combustion engine history: early history

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

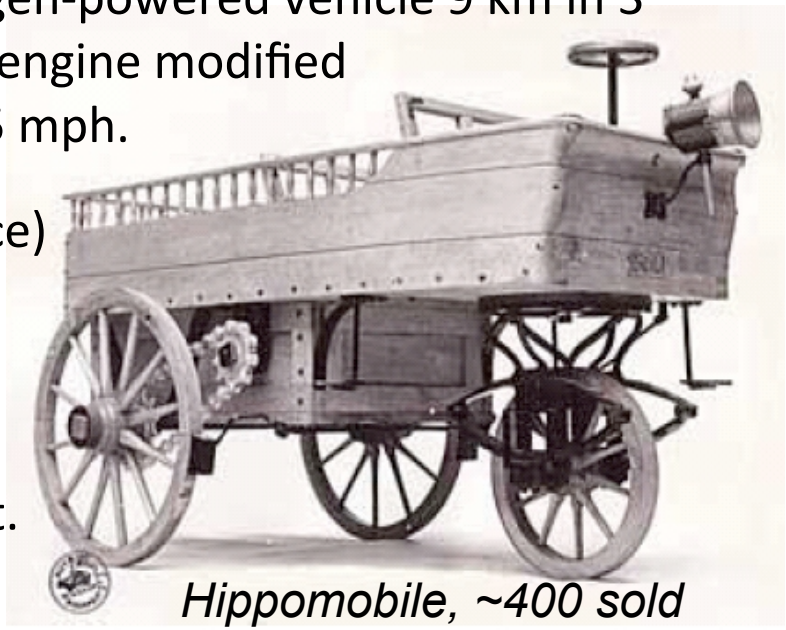
1690: Denis Papin (France) designs *(but doesn't build)* an internal combustion engine driven by gunpowder. Gives up and invents steam engine instead *(against design but no build, later built by Newcomen).*

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

1858: Jean Joseph Étienne Lenoir (France) patents spark-ignition 2-stroke 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 (France) designs and patents *(but doesn't build)* a four-stroke engine with compression cycle

1872: George Brayton (U.S.) develops 2-stroke gas/kerosene engine, ct. pressure combust.



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, 2009*:

"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."

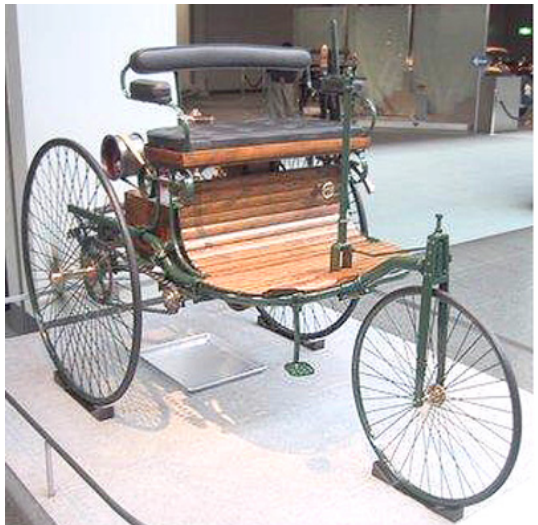
Internal combustion engine history:
development in German-speaking countries

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: Karl Benz builds 3-wheeled automobile with 4-stroke engine, 2/3 hp
patent 1886. also patents: spark ignition, sparkplug, carburetor, clutch, gear shift, radiator

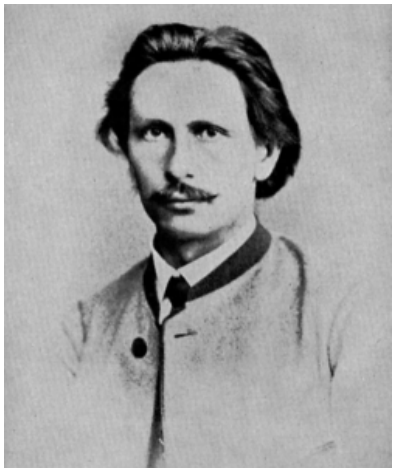
Benz Patent Motorwagen 1885 – gas or petrol use



Bertha Benz. 1888 first test drive, 65 miles Mannheim-Pforzheim and back



Karl Benz



Internal combustion engine history:

Bertha Benz's bold drive

`Bertha was a wife, but also an investor, and a shrewd marketer. She understood that in order for this to be a success, people had to actually *see* the cars run and drive, and she knew her husband would never attempt anything more than the short test runs he'd been driving. Bertha knew something more dramatic was needed.

And so, one of history's greatest "f--- it, I'm doing this" moments was born.

Bertha took the three-wheeler to see her mom. This doesn't sound like a big deal now, but then it was like saying "I'm gonna go visit my mom who lives on an orbiting platform, and to get there I'm going to take this experimental anti-gravity pod that runs on niobium, which I'll just figure out how to find along the way. See ya!" '

----- *Jason Torchinsky, Jalopnik*



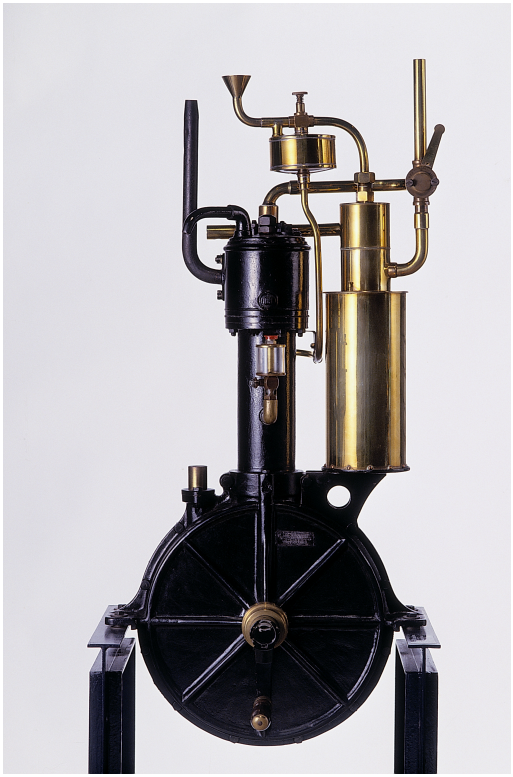
Image: Bertha Benz on the Patent Motorwagen, date unknown. On the actual ride she took her 14- and 15-year old sons. *Image from Ca. Automotive Museum.*

Internal combustion engine history:

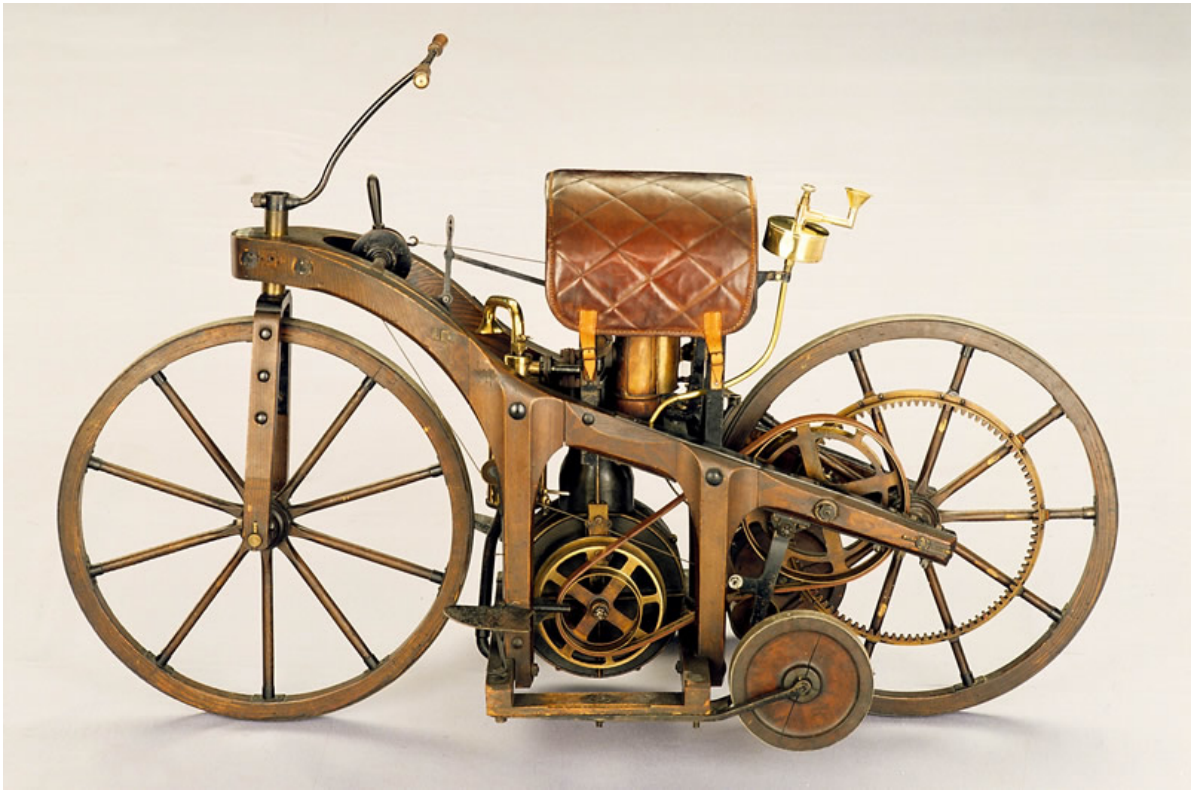
multiple developments in German-speaking countries

1885: Daimler & Maybach (having quit Otto's company) develop advanced 4-stroke engine, attach it to motorcycle

Daimler-Maybach grandfather-clock engine
(1885, horizontal cylinder. Image: Daimler.com)



Daimler-Maybach motorcycle, 1885
(replica. Image: Daimler.com)

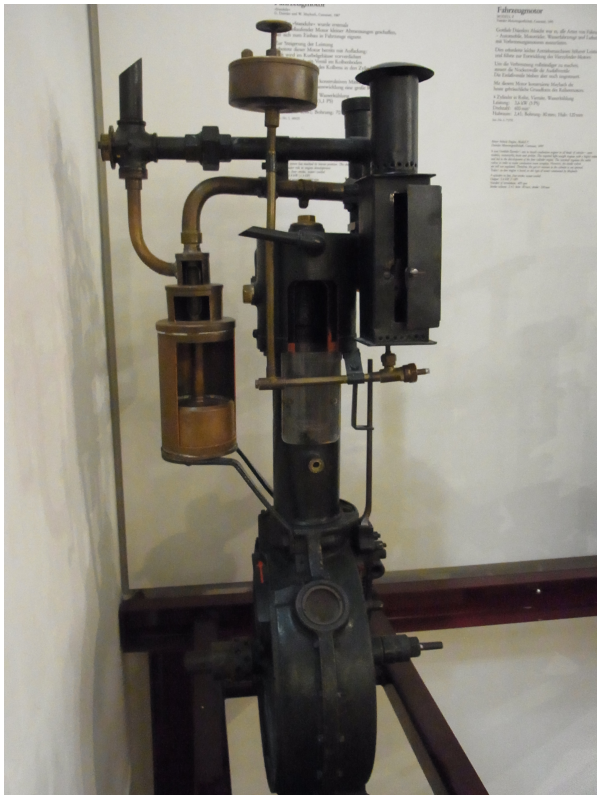


Internal combustion engine history:
multiple developments in German-speaking countries

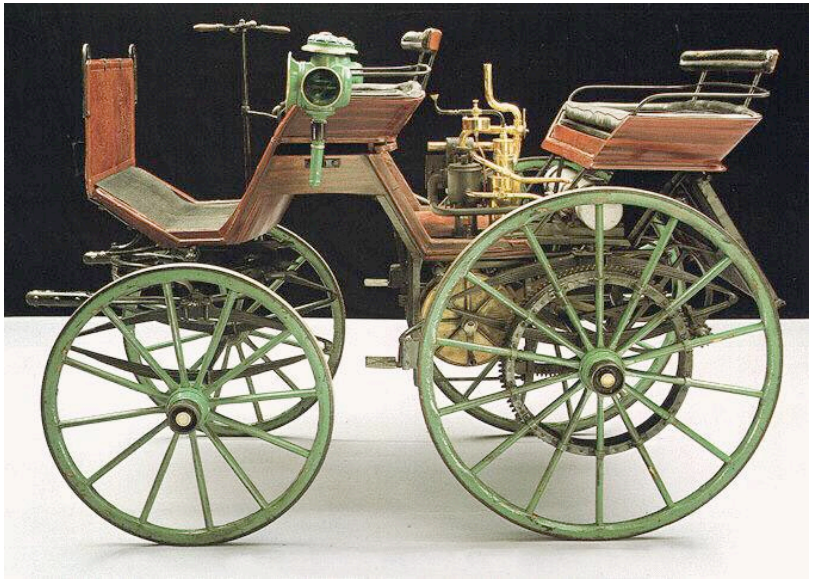
1885: Daimler & Maybach develop advanced 4-stroke engine, attach it to motorcycle

1886-1889: Daimler & Maybach makes 4-wheeled automobile
4-cylinder engine, 10 mph top spd, first sale in 1892

Daimler-Maybach engine, 1887
(at Deutsches Museum)



Daimler-Maybach automobile, 1886 (VintageWeb)



Internal combustion engine history:
multiple developments in German-speaking countries

1891: Benz forms Benz & Cie co.

1899: 430 workers, 572 cars sold world's largest auto company, but production is not fast

1885: Daimler & Maybach develop advanced 4-stroke engine, attach it to motorcycle

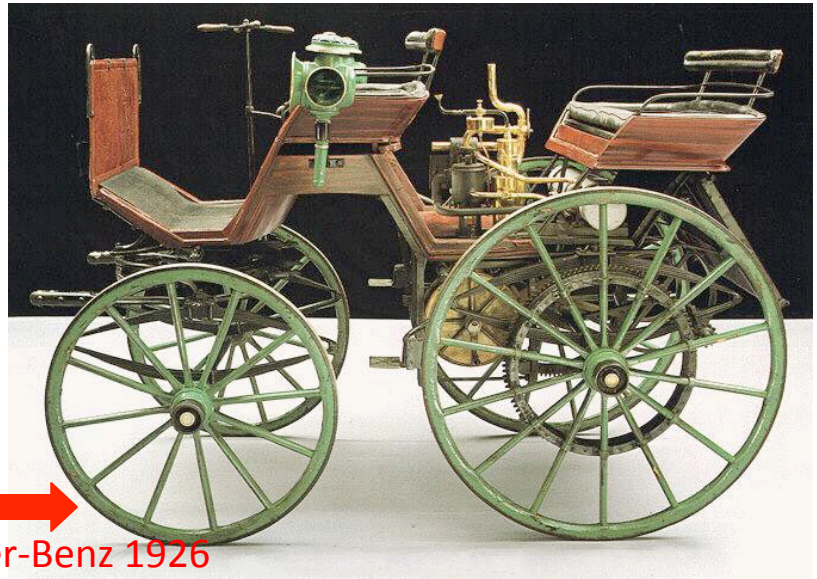
1886-1889: Daimler & Maybach makes 4-wheeled automobile

4-cylinder engine, 10 mph top spd, first sale in 1892

Benz & Cie Vikoria automobile, 1894
(Karl and Bertha onboard, image: Wikipedia)



Daimler-Maybach automobile, 1886 (VintageWeb)



Merger to Daimler-Benz 1926

Internal combustion engine history:

--> production improvements in U.S.

1893: First auto manufacturing in U.S. (Duryea Co., MA), flowering of many small companies

1896: Henry Ford starts company, Detroit

1908: Mass production of Ford Model Ts

Ford Model T assembly line, 1924.



Ford Model T, 1908. *(repainted, howstuffworks.com)*



Two-stroke engine

Simple, cheap

First stroke:

Piston rises, compresses fuel/air mix

Meanwhile, unburnt fuel is drawn into crankcase

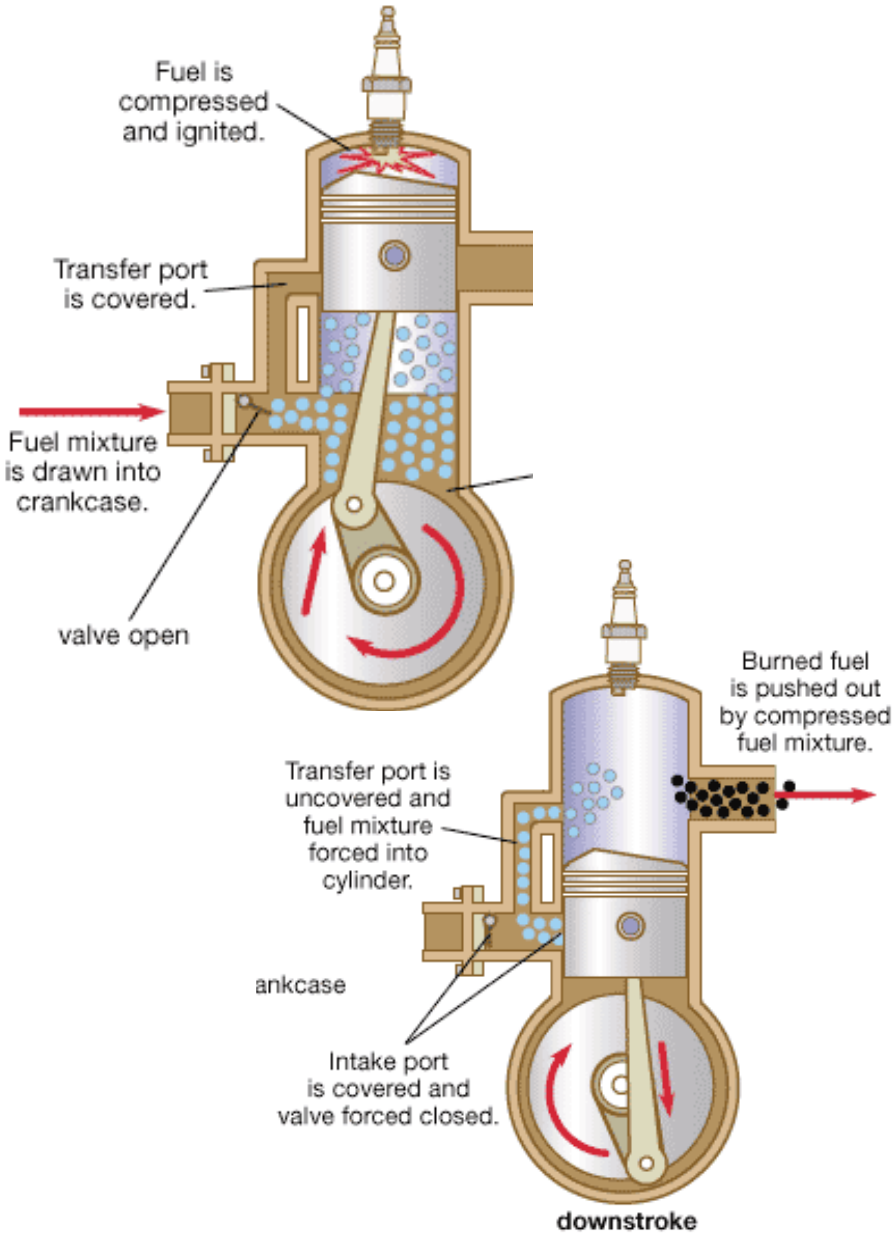
Second stroke:

Fuel/air is ignited

Piston driven down

Exhaust gas leaves cylinder

Fuel/air mixture enters cylinder

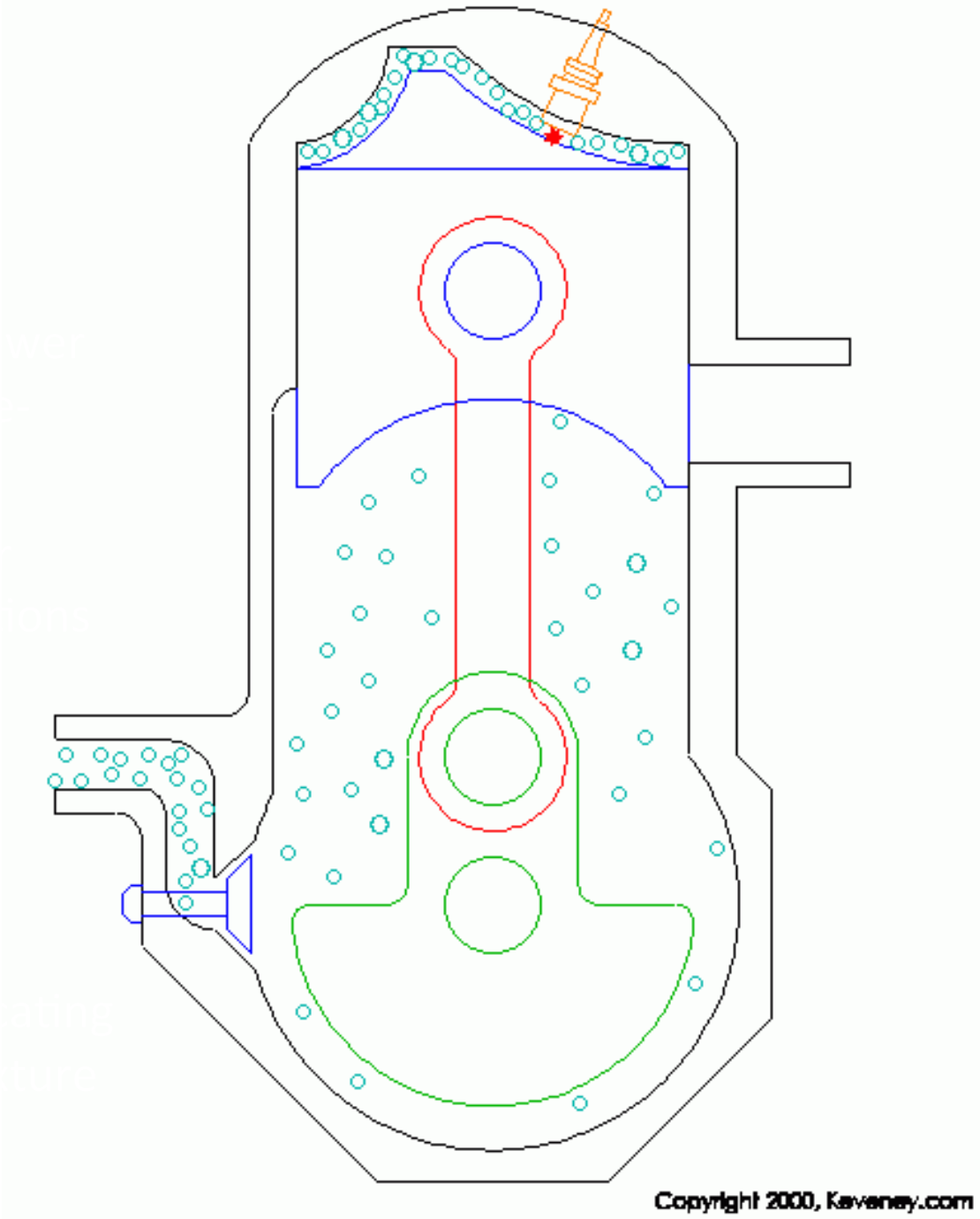


Two-stroke engine

Simple, cheap

Advantages:

Disadvantages:



Two-stroke engine

Simple, cheap

Advantages:

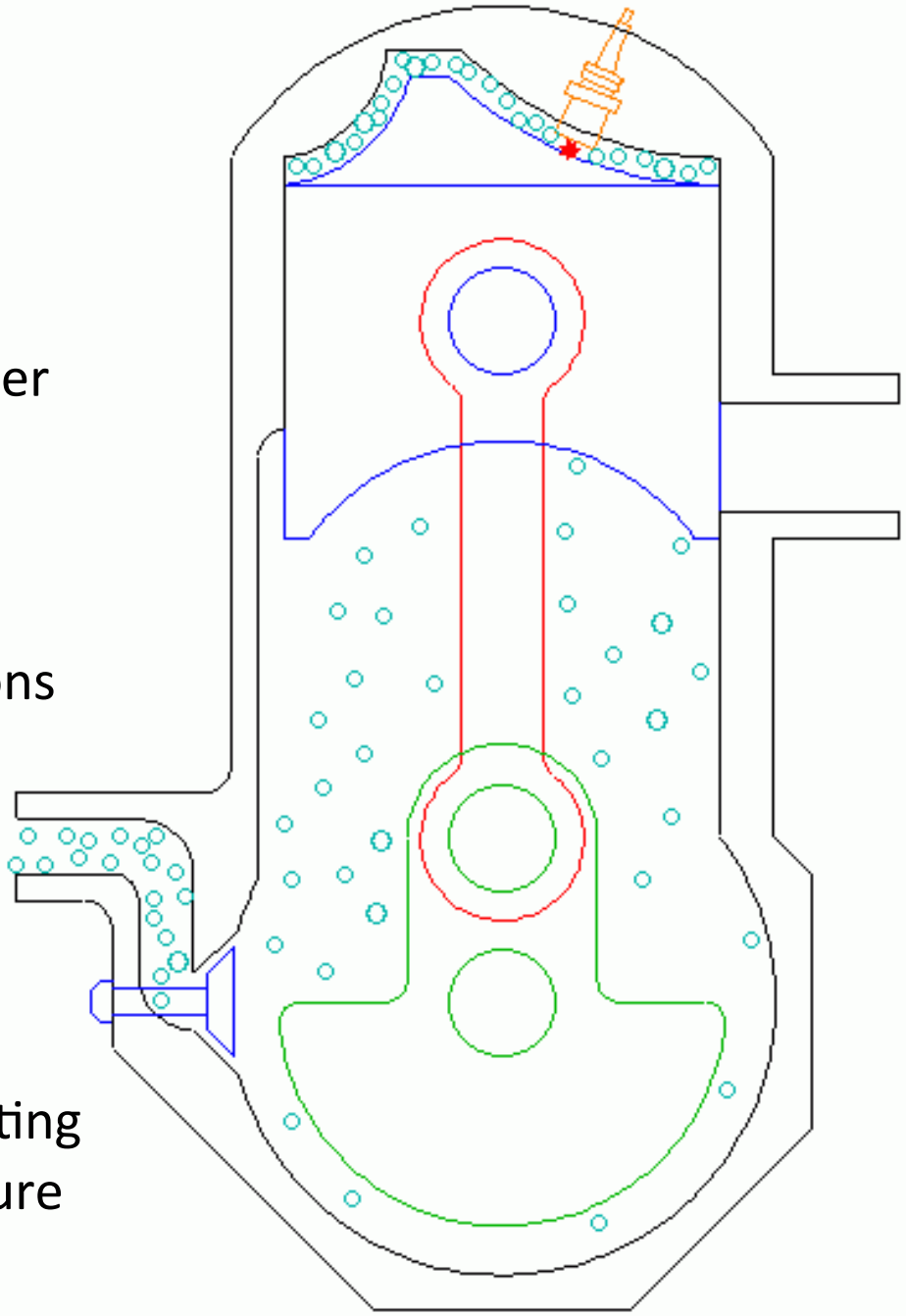
Higher power-to-mass since is never "off" – each stroke is power stroke. Smoother power in one-cylinder engine

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*



Copyright 2000, Kaveney.com

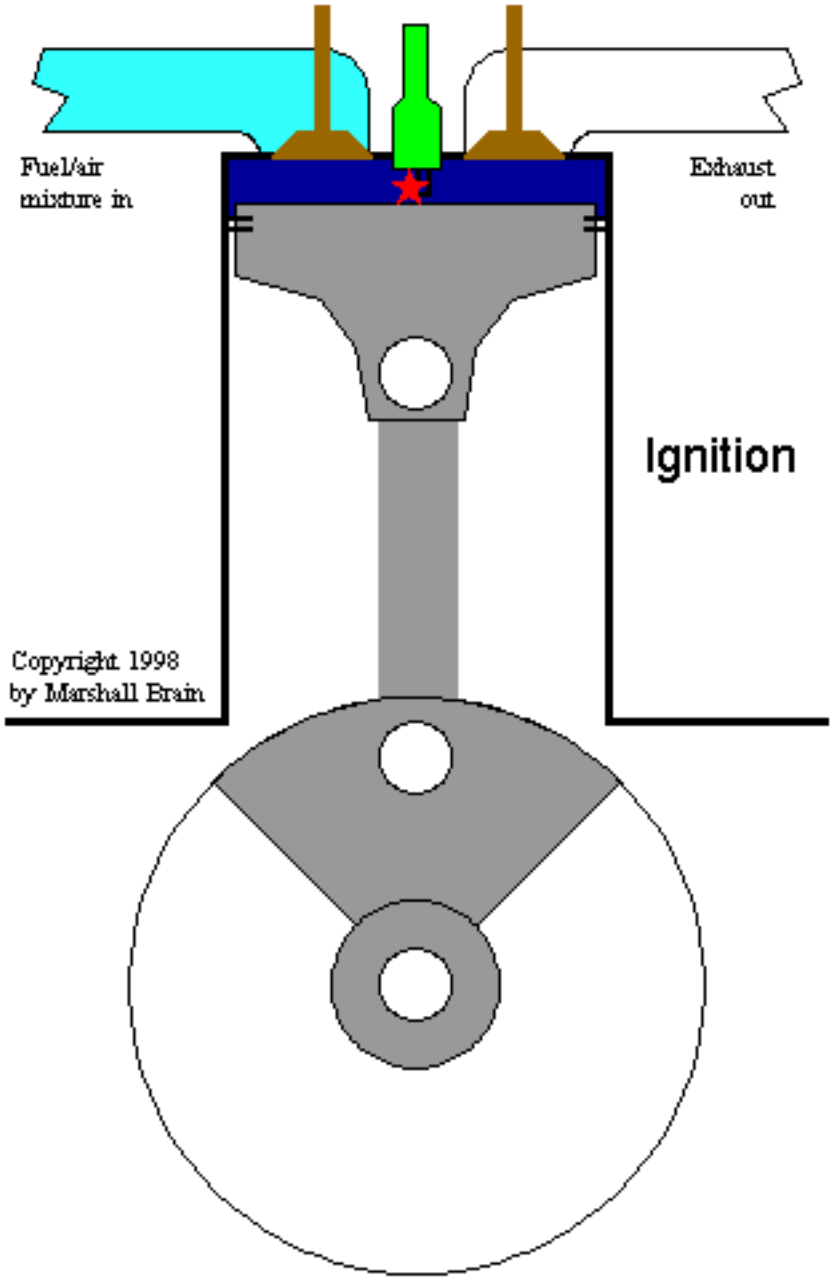
Four-stroke engine: Otto cycle

driver of most transportation

One preparation cycle and one power cycle *(down/up/down/up)*

1.Intake
2.Compression
3.Combustion
4.Expansion *(Exhaust)*

Note use of spark plug to set off combustion (same for 2-stroke)



Four-stroke engine: Otto cycle

driver of most transportation

Advantages:

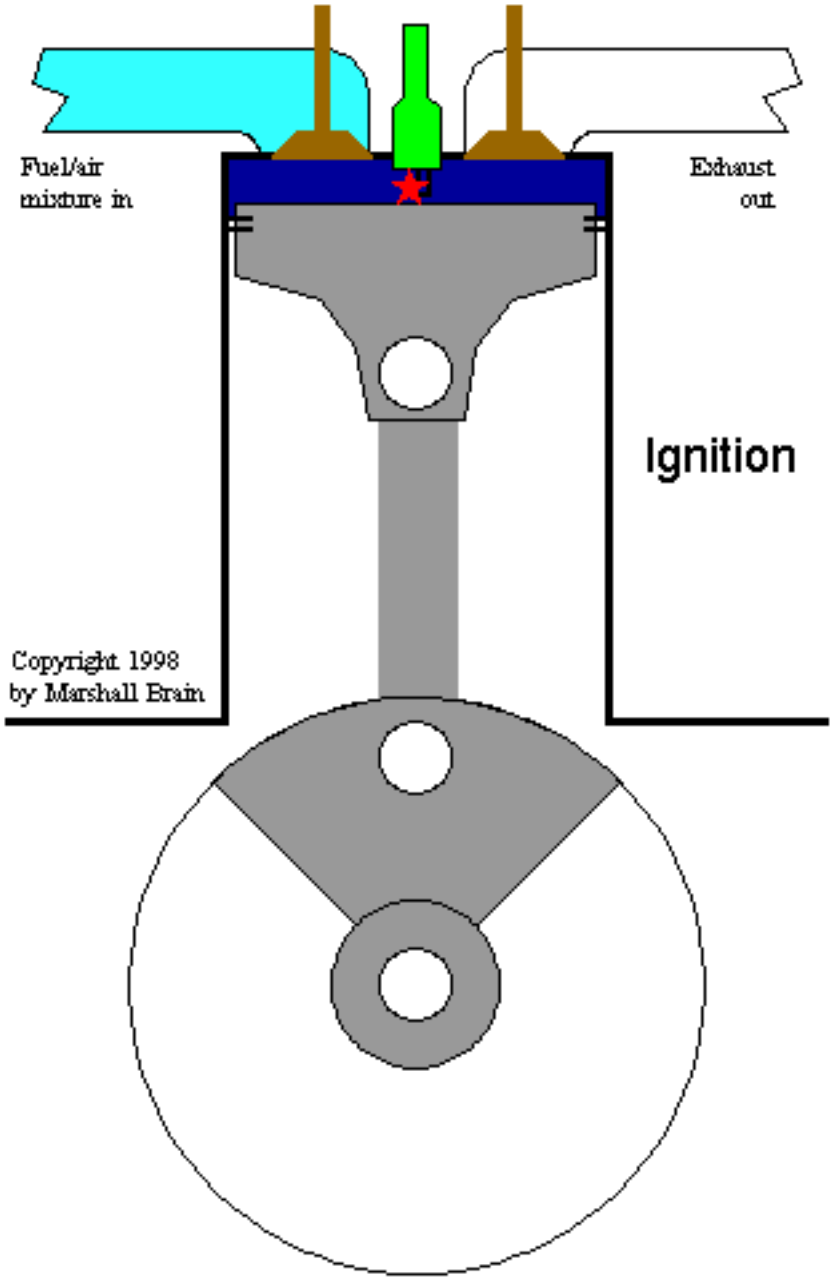
Produces heated, compressed, very dense fuel/air mixture

Separation of unburnt fuel/air from combustion cycle

Disadvantages:

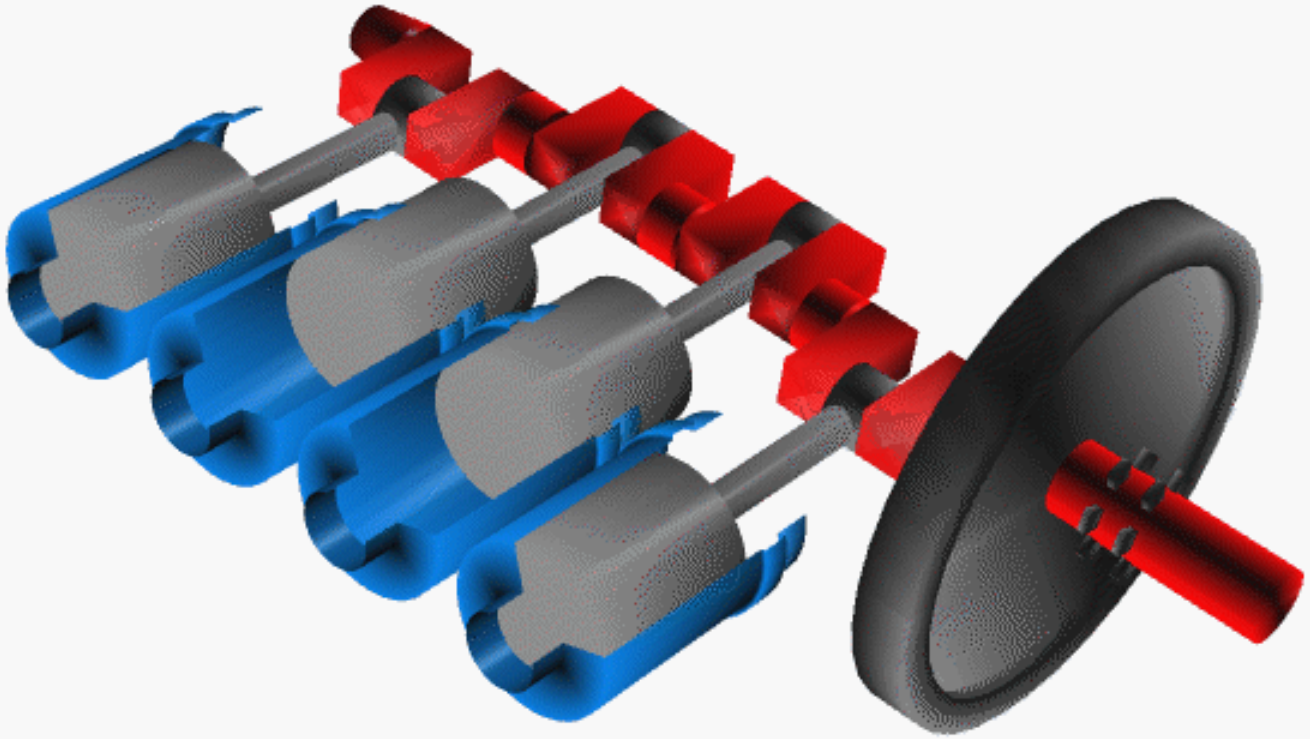
"off" half the time – half the power-to-mass ratio that it might have

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 turns linear piston motion into rotational motion and puts work into the same shaft

More power = more cylinder volume

get more volume from bigger cylinders, or more cylinders

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

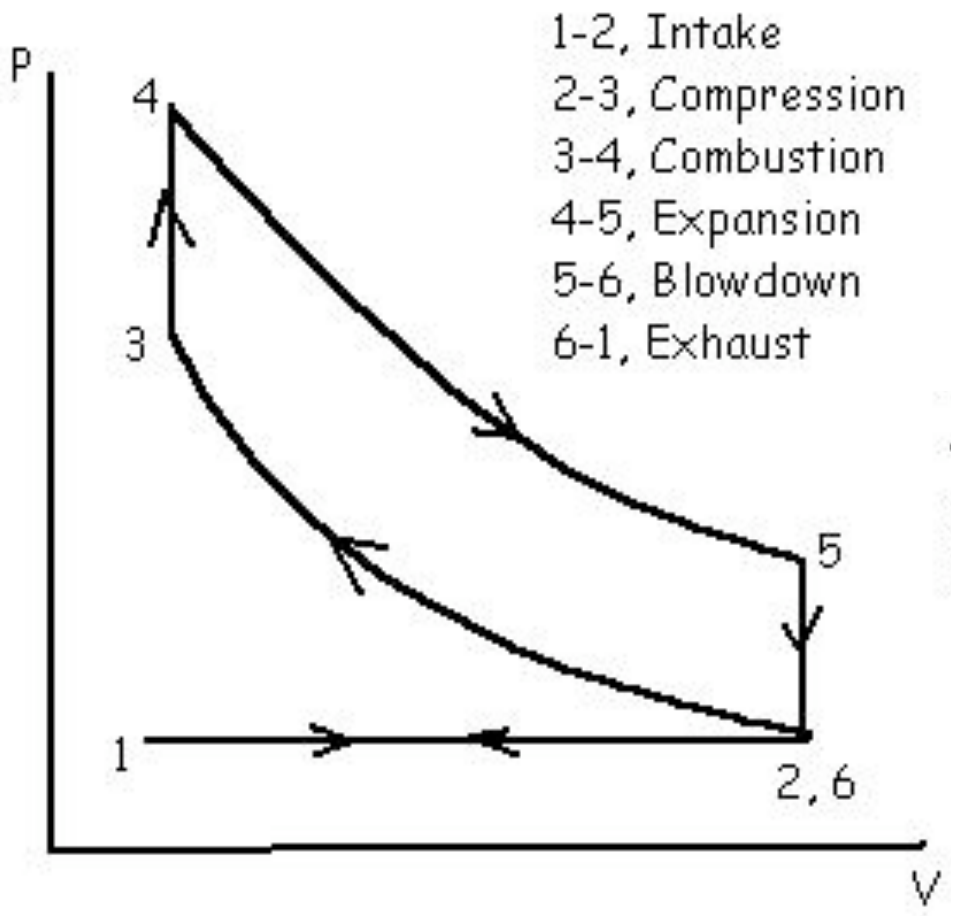


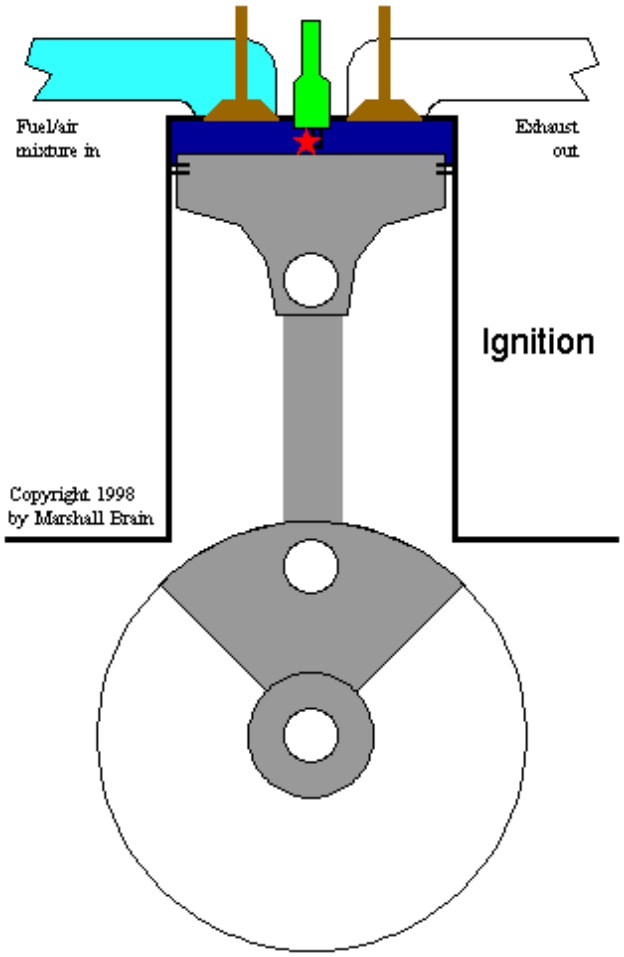
BMW M3 V8 Engine: 4.0-litres total, i.e. 4000 cc in 8 cylinders
(lab lawnmower engine ~ 100 cc (1 cylinder)



Thermodynamic cycles: Otto cycle

Fast combustion at constant volume. Sparkplug to ignite quickly and completely.



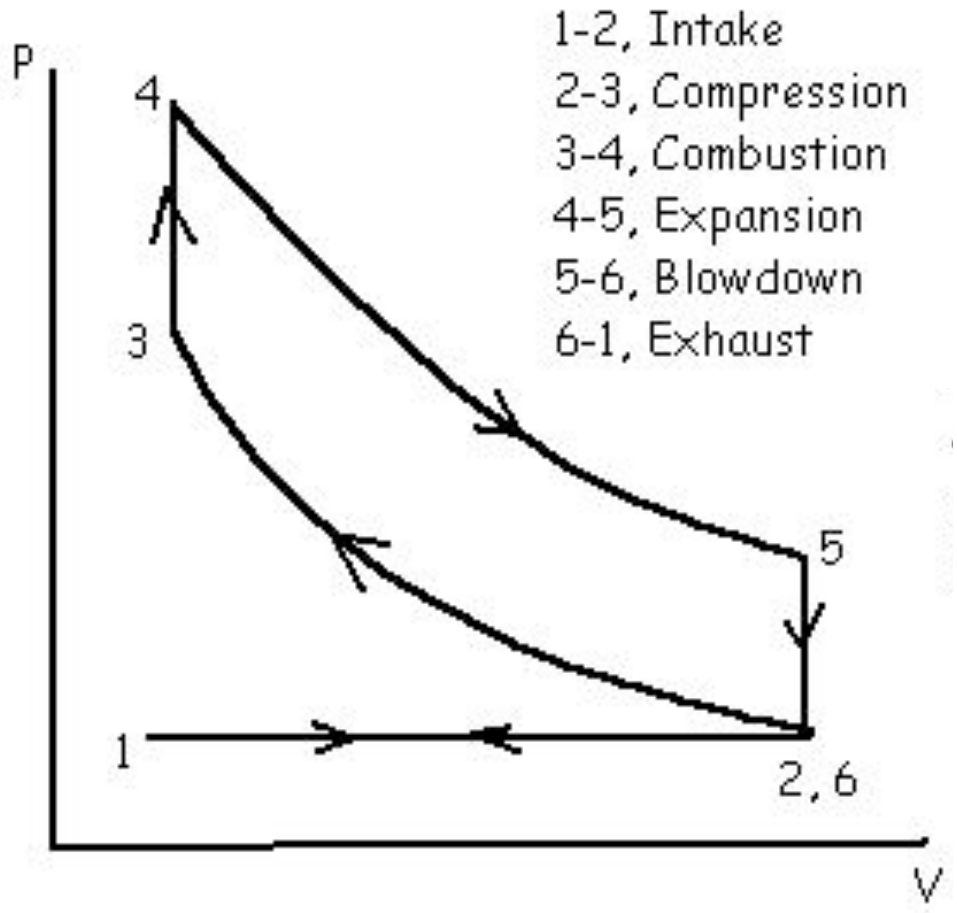


ideal Otto efficiency = $1 - (1/r)^{\gamma-1}$ where r = compression ratio V_1/V_2

(γ = specific heat ratio, property of the gas, ~ 1.4 for air)

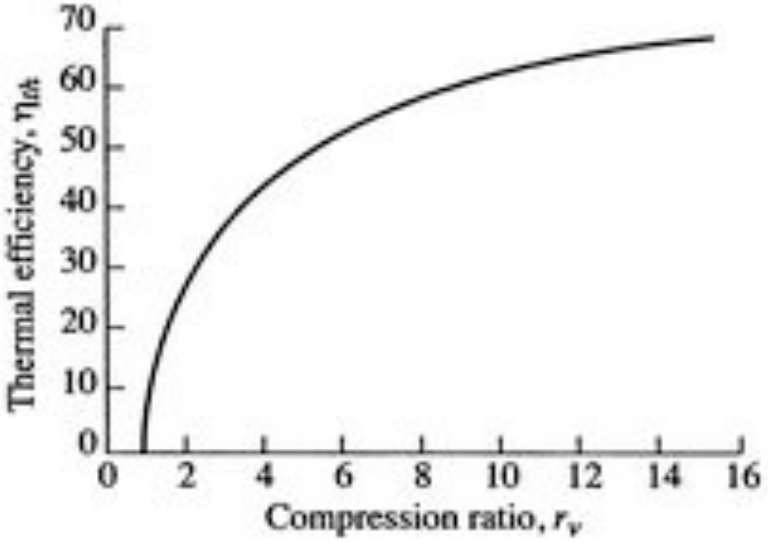
Thermodynamic cycles: Otto cycle

Fast combustion at constant volume. Sparkplug to ignite quickly and completely.



Efficiency is a function of compression ratio, so design for high ratios: r ~ 10 in cars

Figure: web.mit.edu

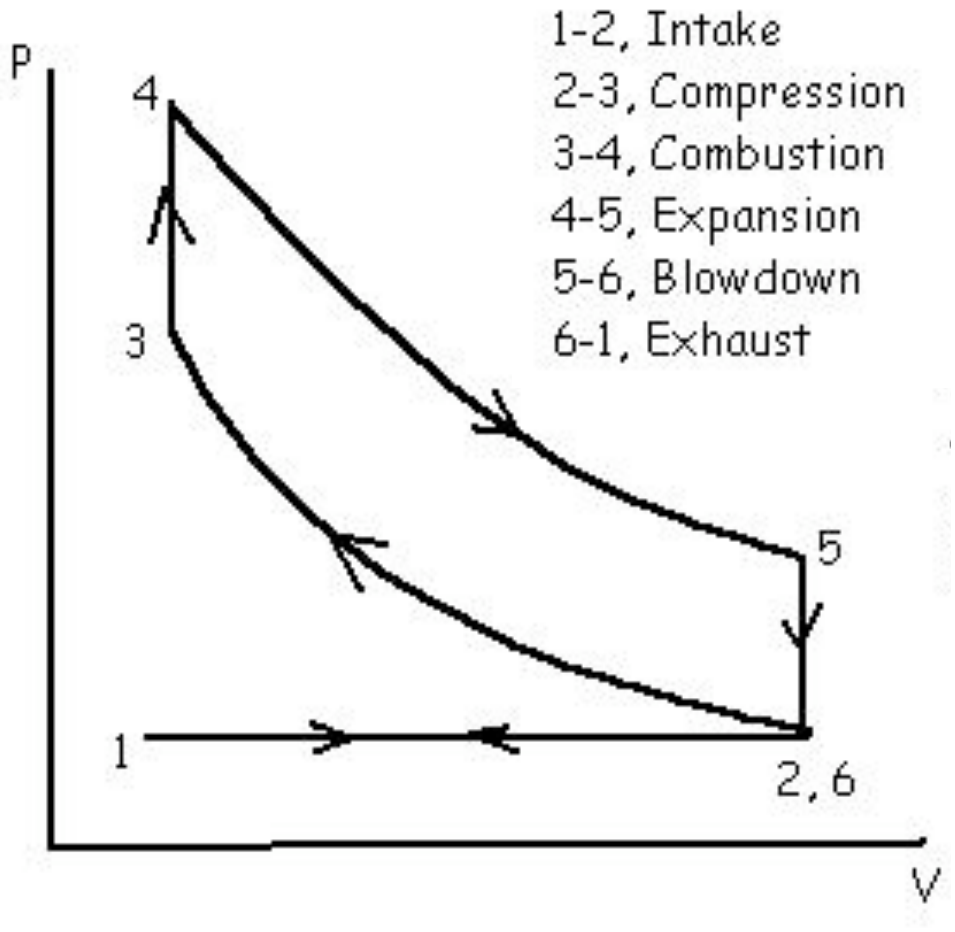


ideal Otto efficiency = $1 - (1/r)^{\gamma-1}$ where r = compression ratio V_1/V_2

(γ = specific heat ratio, property of the gas, ~ 1.4 for air)

Thermodynamic cycles: Otto cycle

But do you need to combust at constant volume? Wastes power (area on graph)
You would get more power if you continued compressing gas before igniting...



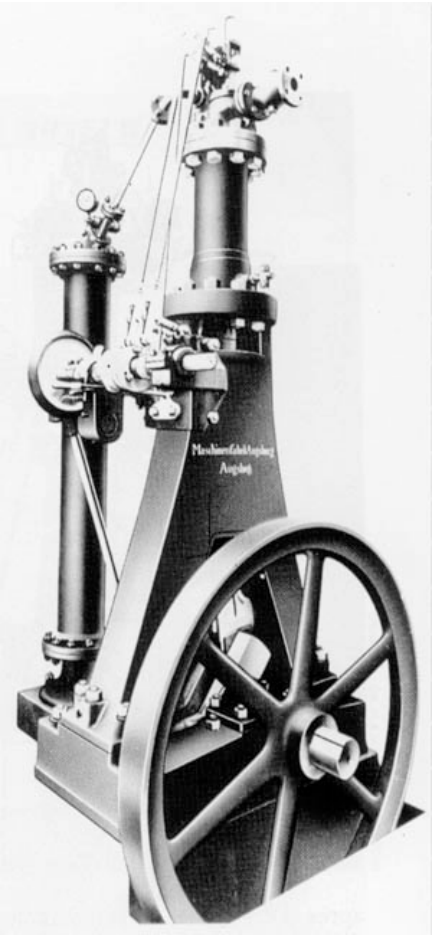
Engine history: *non-Otto-cycle engines*

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 **bio-fueled engine** running on peanut oil, operating on a new thermodynamic cycle he'd invented from 1st principles



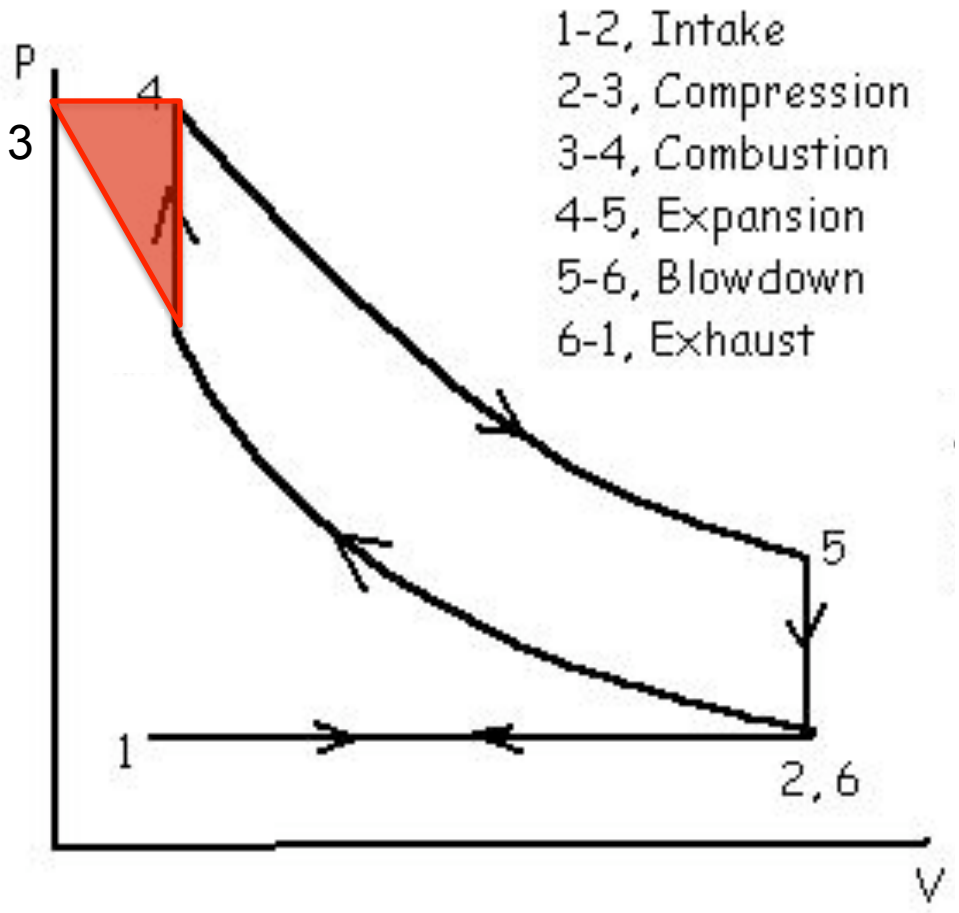
Diesel engine, invented 1893, 17% efficient. Designer: Rudolf Diesel, German-trained



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

Thermodynamic cycles: Diesel cycle

But do you need to combust at constant volume? Wastes power (area on graph)
You would get more power if you continued compressing gas before igniting...



Diesel cycle involves

- higher pressure
- lower final volume

→ higher compression ratio

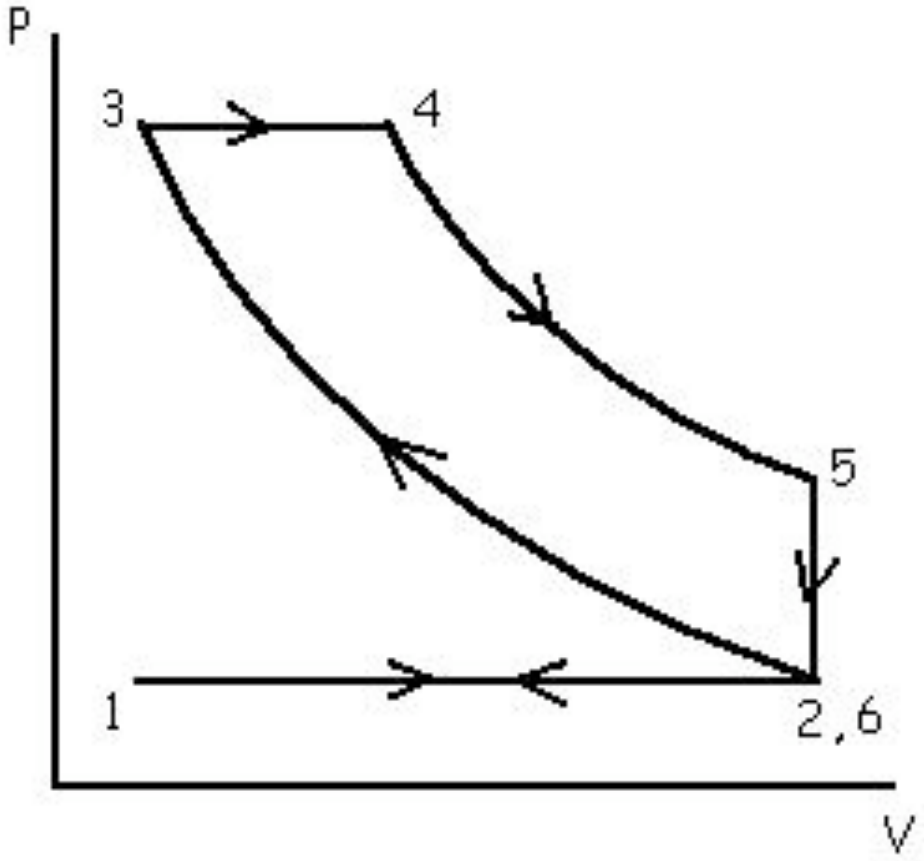
r ~ 14 – 22 or more

ideal Diesel efficiency = $1 - [(1/r)^{\gamma-} * (\alpha^{\gamma} - 1)/(\gamma(\alpha - 1))]$

where α is the "cutoff ratio" V_4/V_3. Lower than Otto for a given r, but r is bigger for Diesel.

Thermodynamic cycles: Diesel cycle

Cycle designed for higher efficiencies.



Diesel cycle achievable ***only*** if system can withstand higher pressures before igniting.

1) First compress air, THEN spray fuel in to control ignition.

2) Use specially designed "Diesel fuel" that can reach higher pressures before ignition (originally used peanut oil)

Diesel fuel is less volatile than gasoline, ignites on compression... but only at very high P

ideal Diesel efficiency = $1 - [(1/r)^{\gamma-} * (\alpha^{\gamma} - 1)/(\gamma(\alpha - 1))]$

where α is the "cutoff ratio" V_4/V_3. Lower than Otto for a given r, but r is bigger for Diesel.