GEOS 24705 / ENST 24705
The internal combustion engine and transportation II, fossil fuels

Fuel usage in transportation: where does energy go?

Thermodynamic losses in engine (typically Otto cycle in real engines gives ~ 75% loss to heat, only 25% becomes kinetic energy)

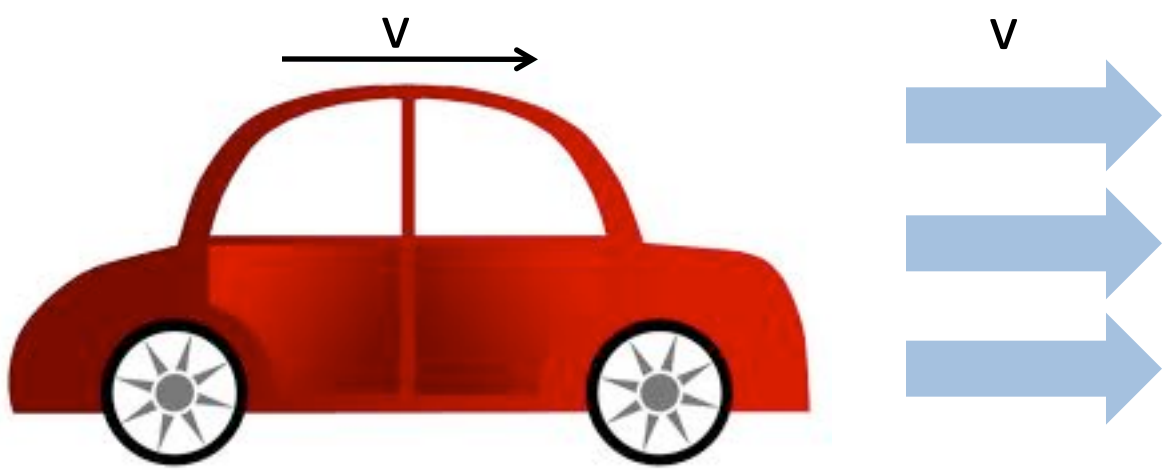
..and then what happens to the kinetic energy?
Must dissipate somehow…

Roughly equal in size

1. **Braking** (kinetic energy must be replaced later on acceleration)
2. **Frictional losses in gears, bearings**
3. **Rolling resistance**
4. **Air resistance** (aerodynamic drag)

Fuel uses in transportation: air resistance

Energy used to push air in front of car – goes into kinetic energy of the air



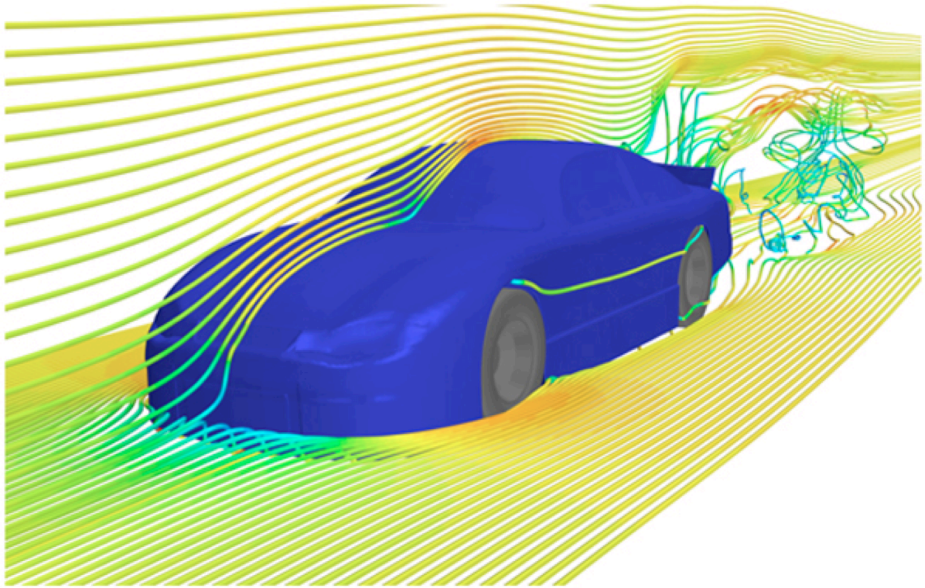
Worst-case scenario: the car pushes all air it intersects up to its speed v. Power to do this is same as energy in flow of air at that speed:

$$P = \frac{1}{2} \rho A v^3$$

where A is the cross-sectional area of the car.

Fuel uses in transportation: air resistance

Real life is not the worst-case scenario – car slips through air without having to accelerate it all to v



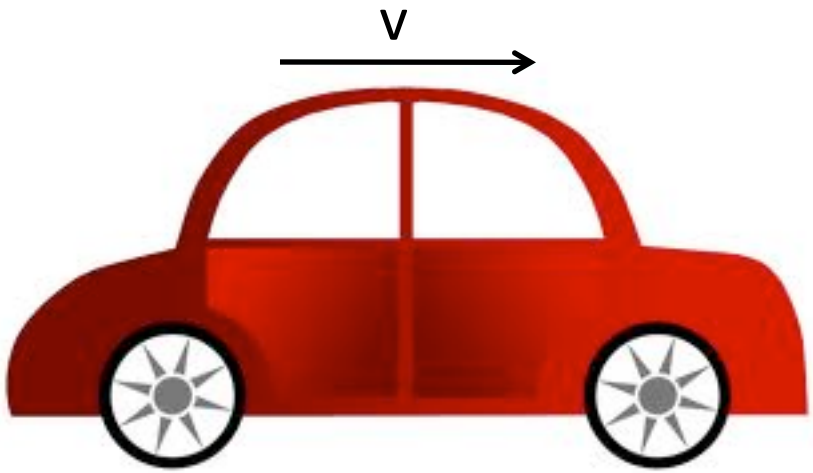
So less power is used to accelerate the air. Adjust formula by some fudge factor that describes how "streamlined" the car shape is:

$$P = C_a \tfrac{1}{2} \rho A v^3$$

Sports cars want low C_a because of v^3 depend. Typical C_a: Porsche 0.3, Hummer 0.6.

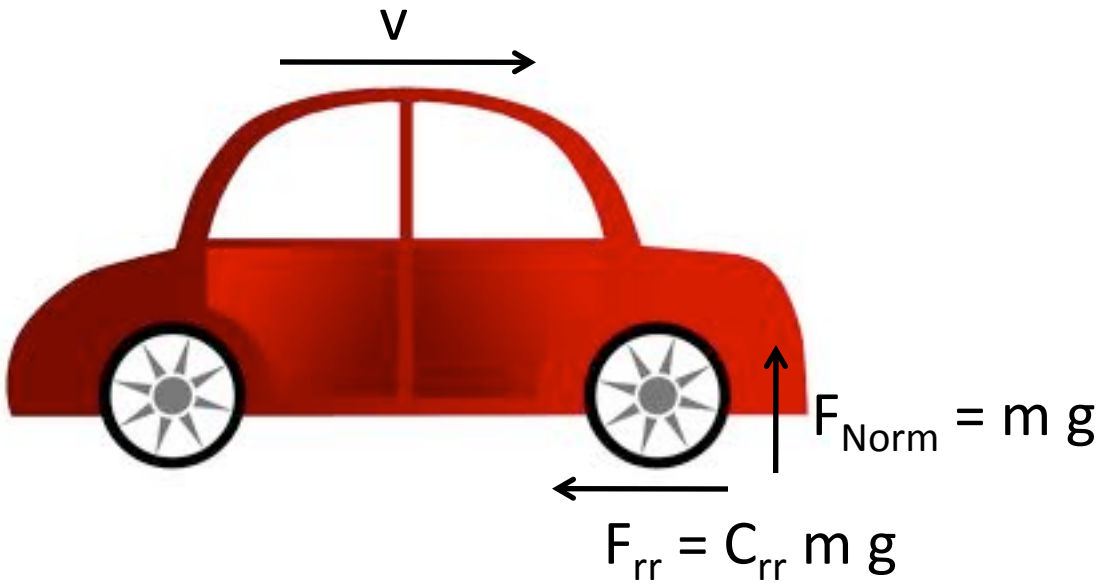
Fuel uses in transportation: rolling resistance or "rolling friction"

In real deformable tires, friction between tires and road causes force opposing motion of the car.



Fuel uses in transportation: rolling resistance or "rolling friction"

In real deformable tires, friction between tires and road causes force opposing motion of the car.



Force of rolling friction is proportional to normal force that opposes car's weight against ground.

(Stick in a constant C_{rr} , the "coefficient of rolling resistance")

Power dissipated is energy/time = force x distance / time :

$$P = C_{rr}\ m\ g\ v$$

Fuel uses in transportation: rolling resistance

Value of C_{rr} depends on tire and surface properties – including deformability of tires

Approximate C_{rr} values

Steel wheels on steel rails	.001
Car tires on concrete	.01
Car tires on asphalt	.03
Car tires in sand	> .1

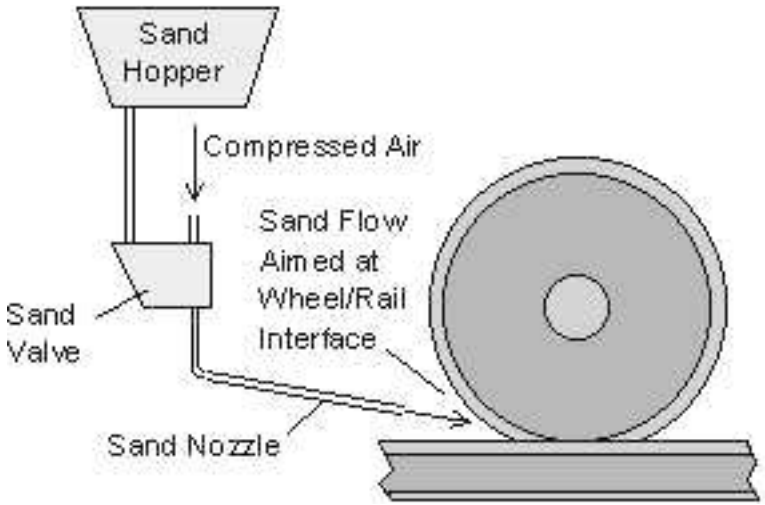
Slickness of steel rails – low friction – also means low rolling resistance, great for minimizing power losses in long-distance travel.

But, when starting up or stopping suddenly, torque is high. And need some friction to permit you to apply torque to the wheel – if not enough friction, wheel just spins in place. Steel on steel doesn't work.

Trains needs some solution for braking and starting that doesn't compromise efficiency of long-distance travel.

Sand provides as-needed increases in friction for train tracks

Sand is released through nozzle onto tracks when traction needed



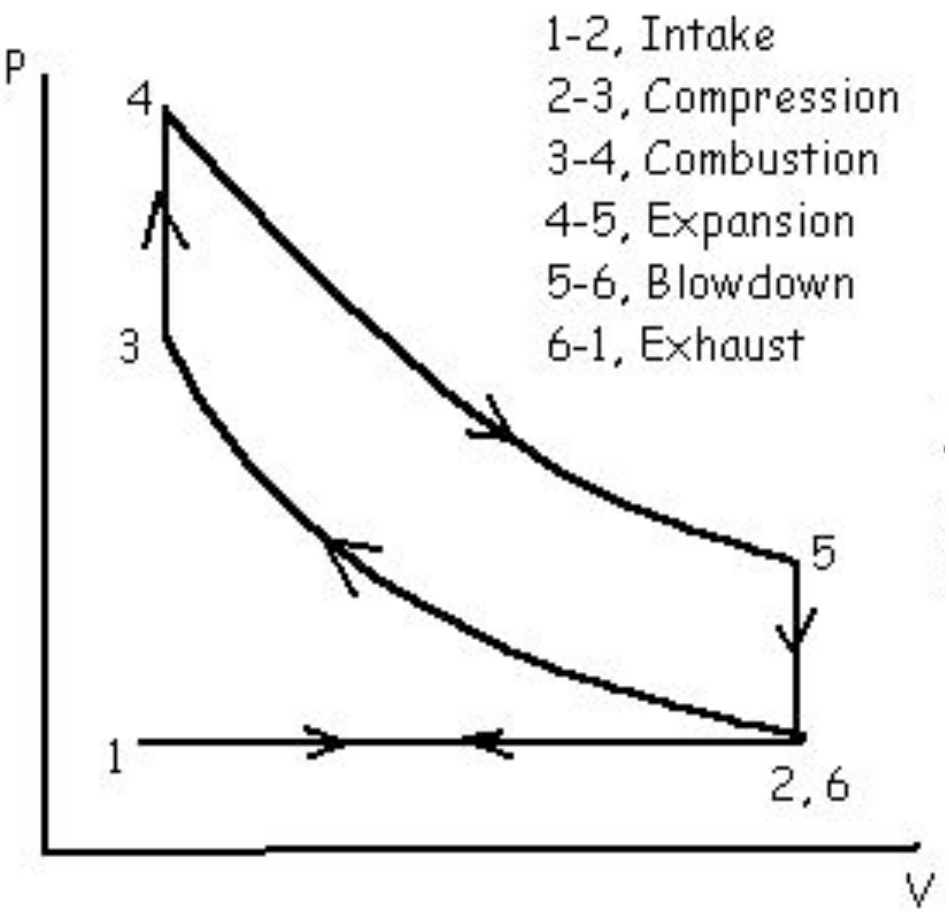
Sanding system
Image: Univ. of Sheffield

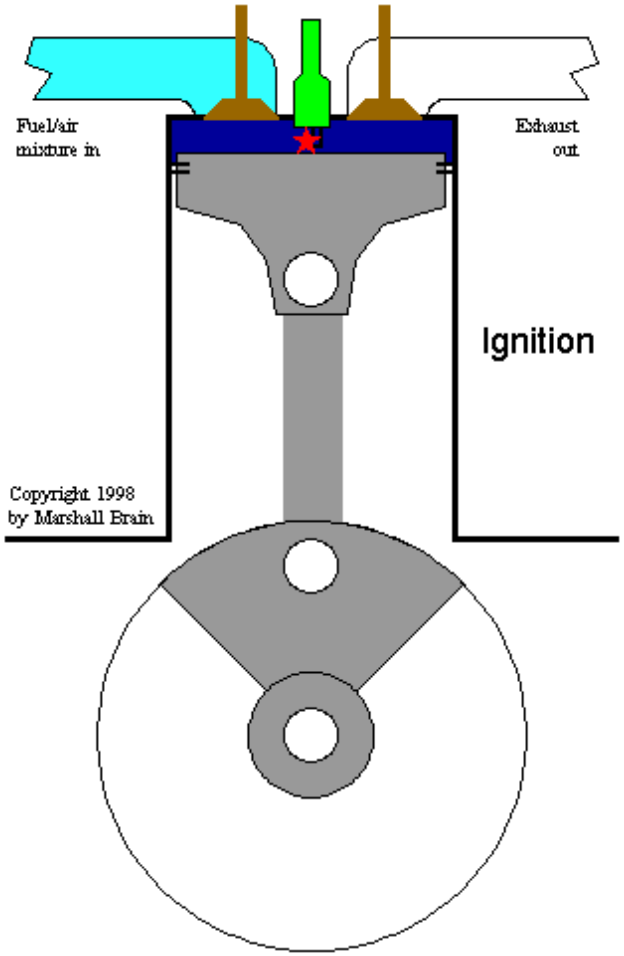
Sand temporarily increases friction (and so also C_{rr})

Sanding nozzle
Image: HowStuffWorks

Thermodynamic cycles: Otto cycle

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

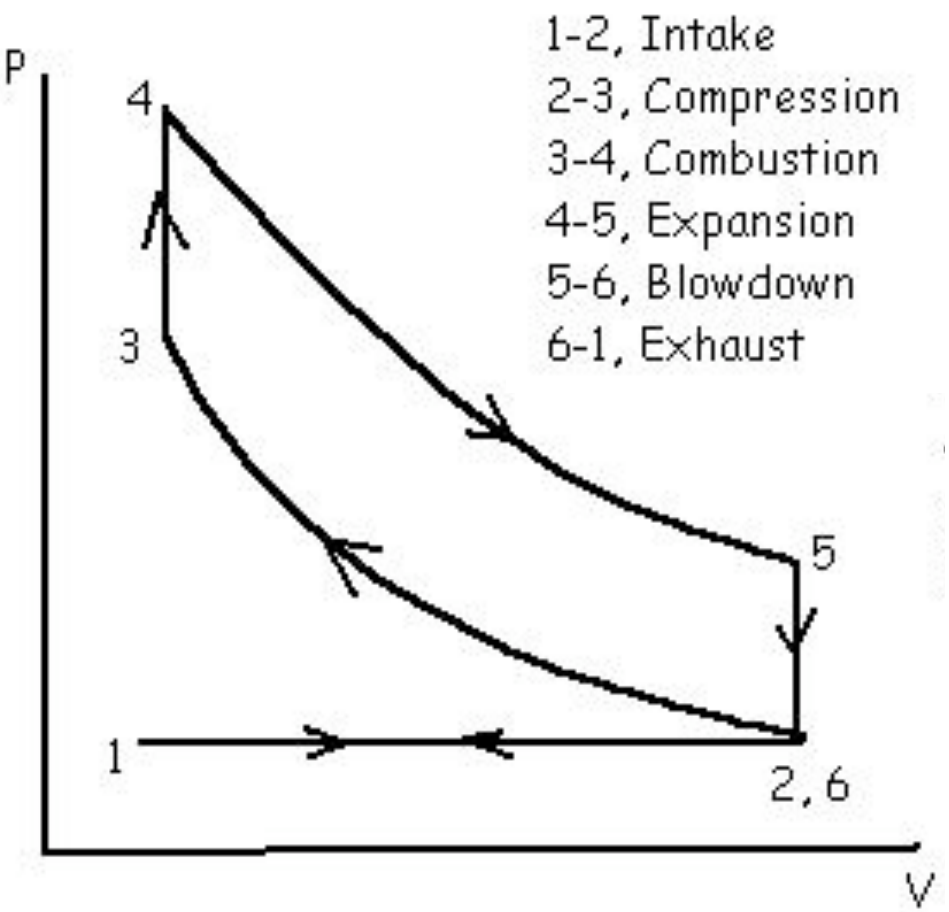




Efficiency = $1 - 1/r_k^{\gamma-1}$ where = r_k = compression ratio V_1/V_2

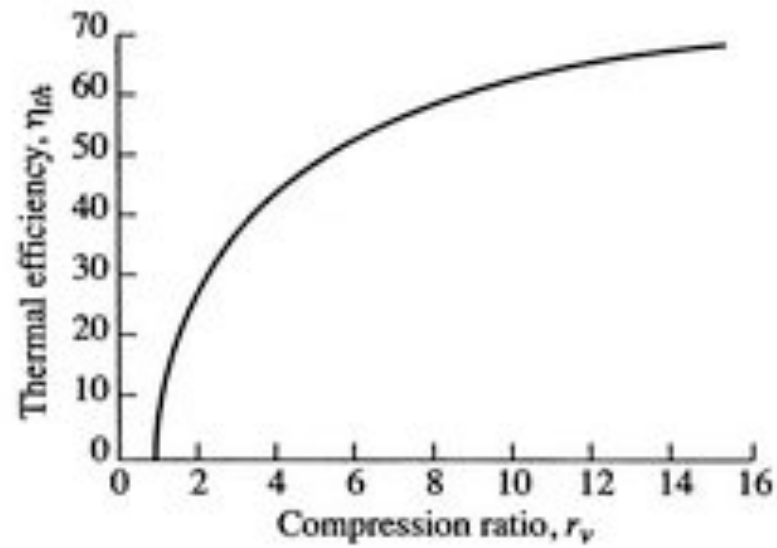
Thermodynamic cycles: Otto cycle

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



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

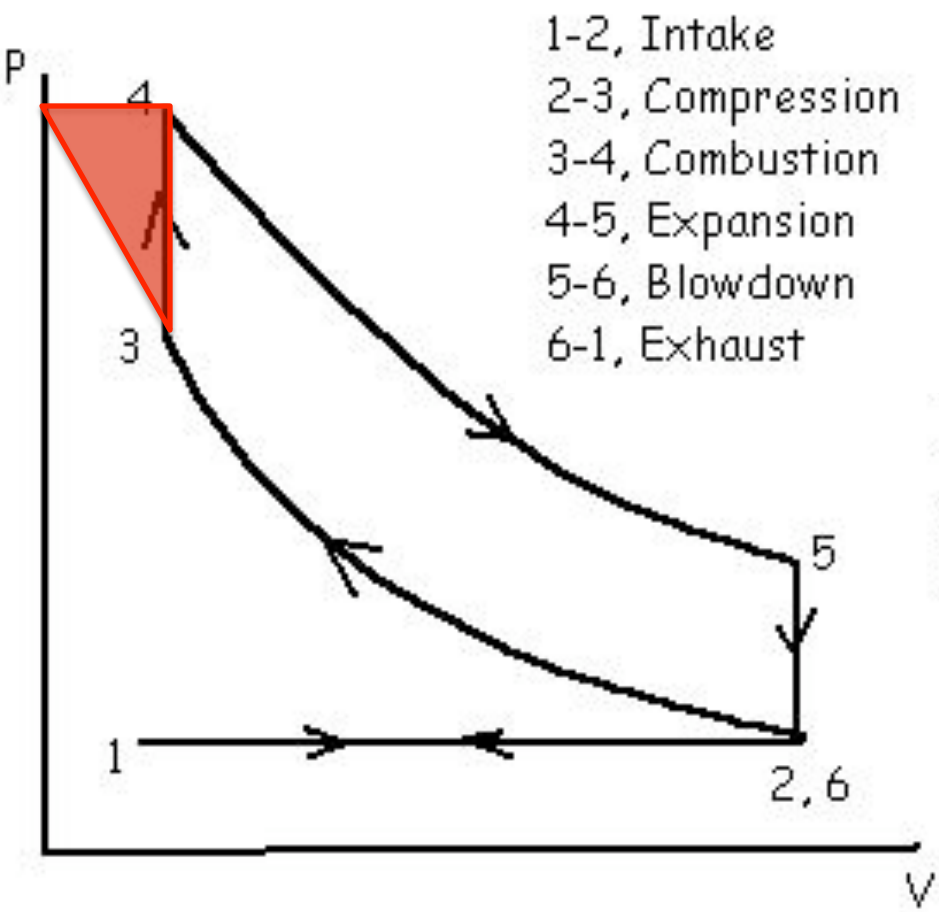
Figure: web.mit.edu



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

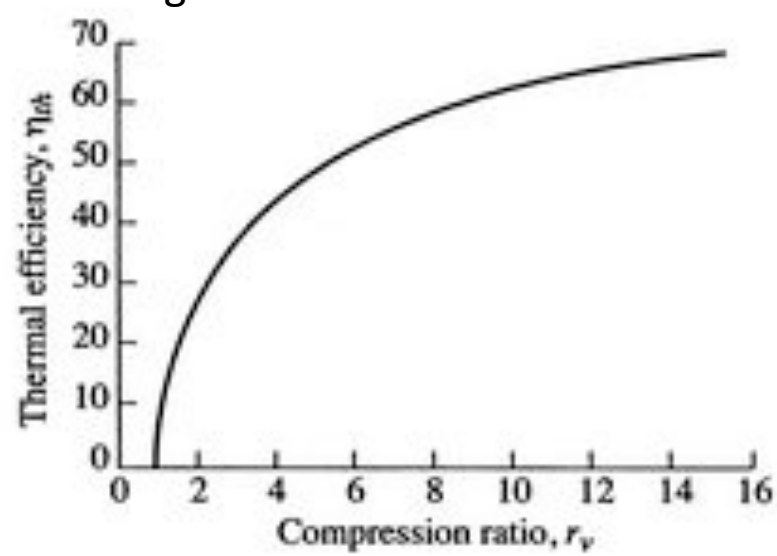
Thermodynamic cycles: Otto cycle

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



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

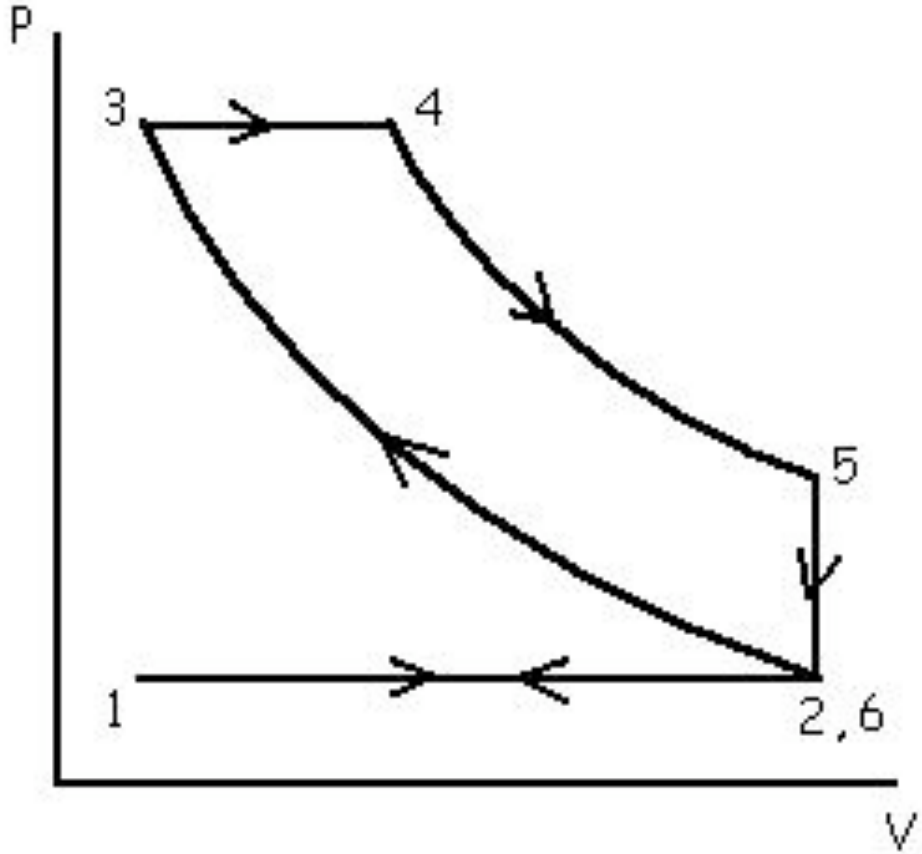
Figure: web.mit.edu



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.



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

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

What you might care about in an engine:

1. **Weight:**
   heavier = takes more energy to move

2. **Efficiency:** how much mechanical work you get out of a given amount of chemical energy in fuel. NOTE – not the only factor in "fuel efficiency"

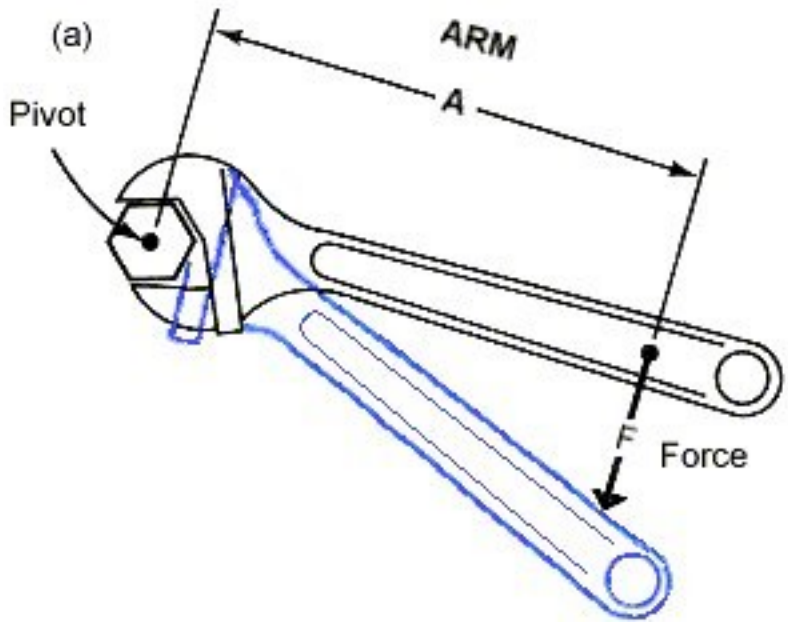
3. **Power:** how much energy / time you can put out

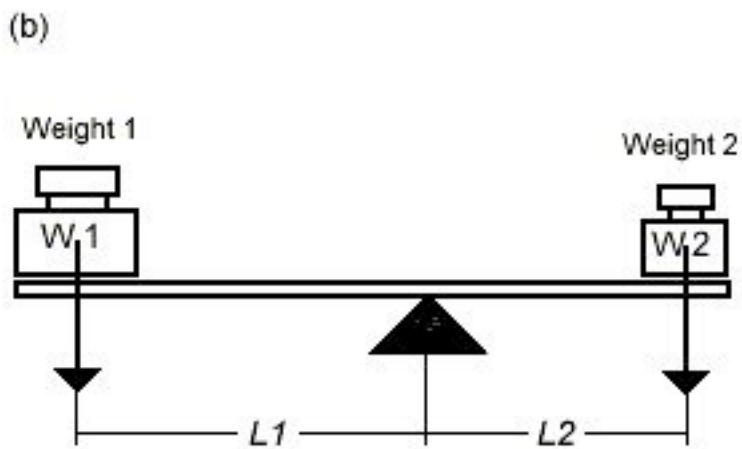
4. **Torque:** "turning force". Affects how fast you can accelerate, or how big a load you can get moving.

5. **Side-effects:** pollution, noise, etc**.**

6. **Cost/durability/reliability**

Torque = “turning force”

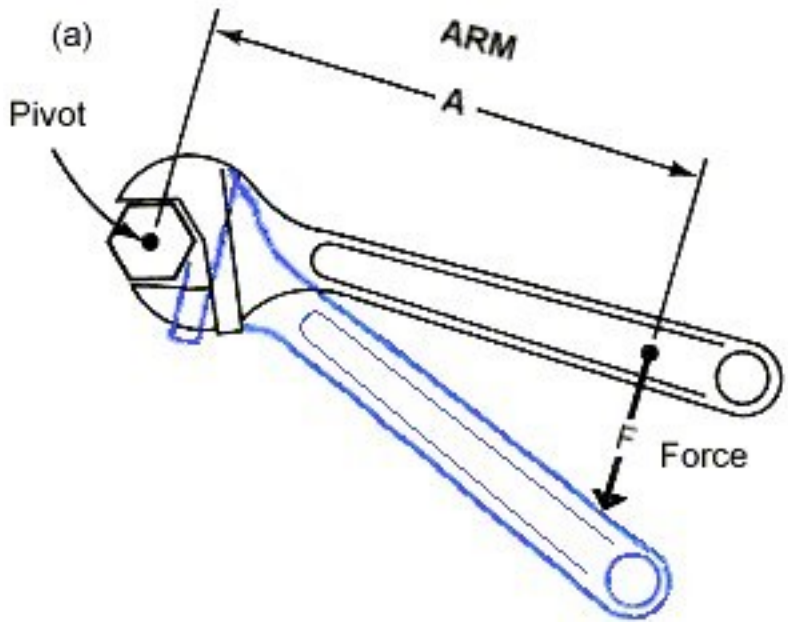


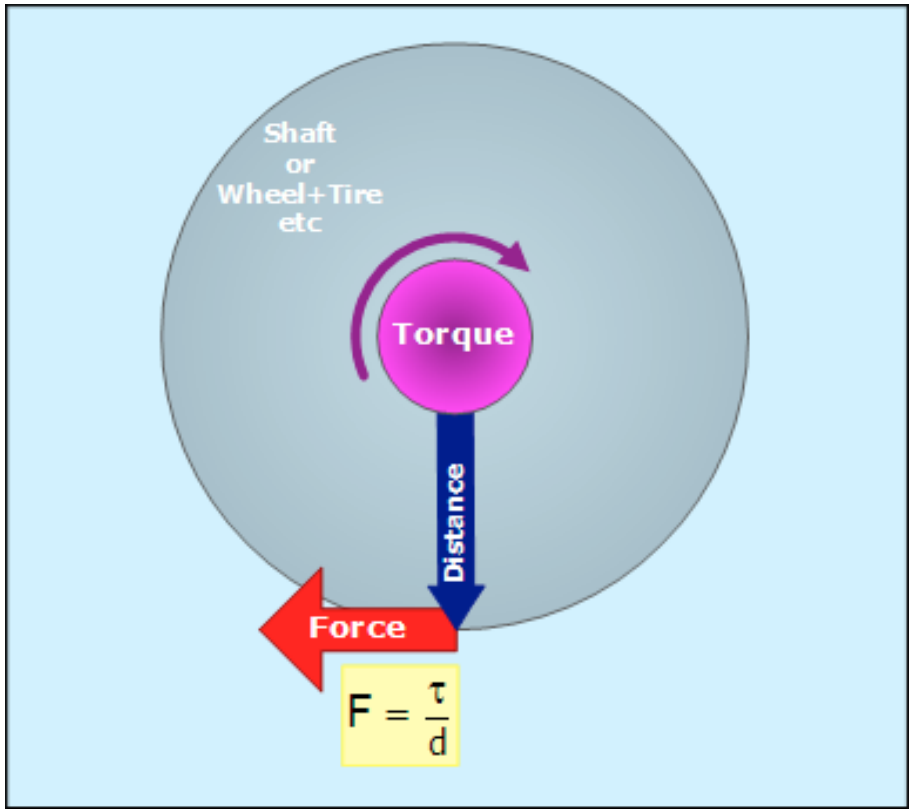


Torque = force x distance

Your ability to turn something depends not just on the force you apply but on the lever arm you have

Torque = “turning force”





Torque = force x distance

Your ability to turn something depends not just on the force you apply but on the lever arm you have

Diesel: advantages

1. **Higher compression ratios = higher temperatures = higher efficiency** (theoretically up to 75%, in practice 40%, up to 55% in some demonstrated engines)

   Fuel efficiency greater than with gasoline hybrids

2. **More torque at low speeds** (will discuss later – very useful for pushing big loads. But has high torque ONLY at low speed – poor acceleration at speed.)

3. **Reliability:** no sparkplugs – ignition occurs from compressional heating alone

4. **Lubrication:** fuel is better lubricant than gasoline, so piston rings and cylinder bores last longer

Diesel: disadvantages

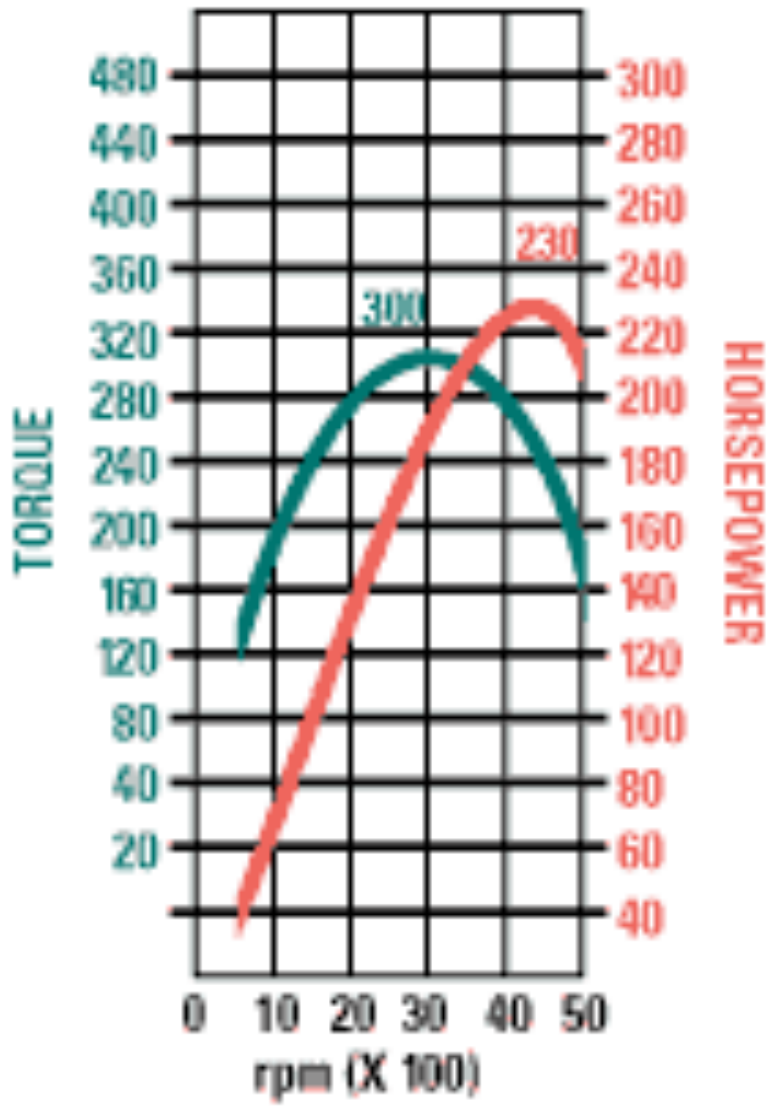
1. **Weight –** longer pistons to get bigger compression ratio, heavier engine materials

2. **Poor torque at high speeds** – bad acceleration when at cruising speed

3. **Inherently polluting -** incomplete combustion gives sooty particulates (injected just before combustion, after compression, not mixed throughout cylinder stroke)

   Pollution problem greatly fixed in recent engines

Torque-speed: a drawback of internal combustion engines



Otto engine, Dodge Ram pickup V8 5.9 L engine, 2004

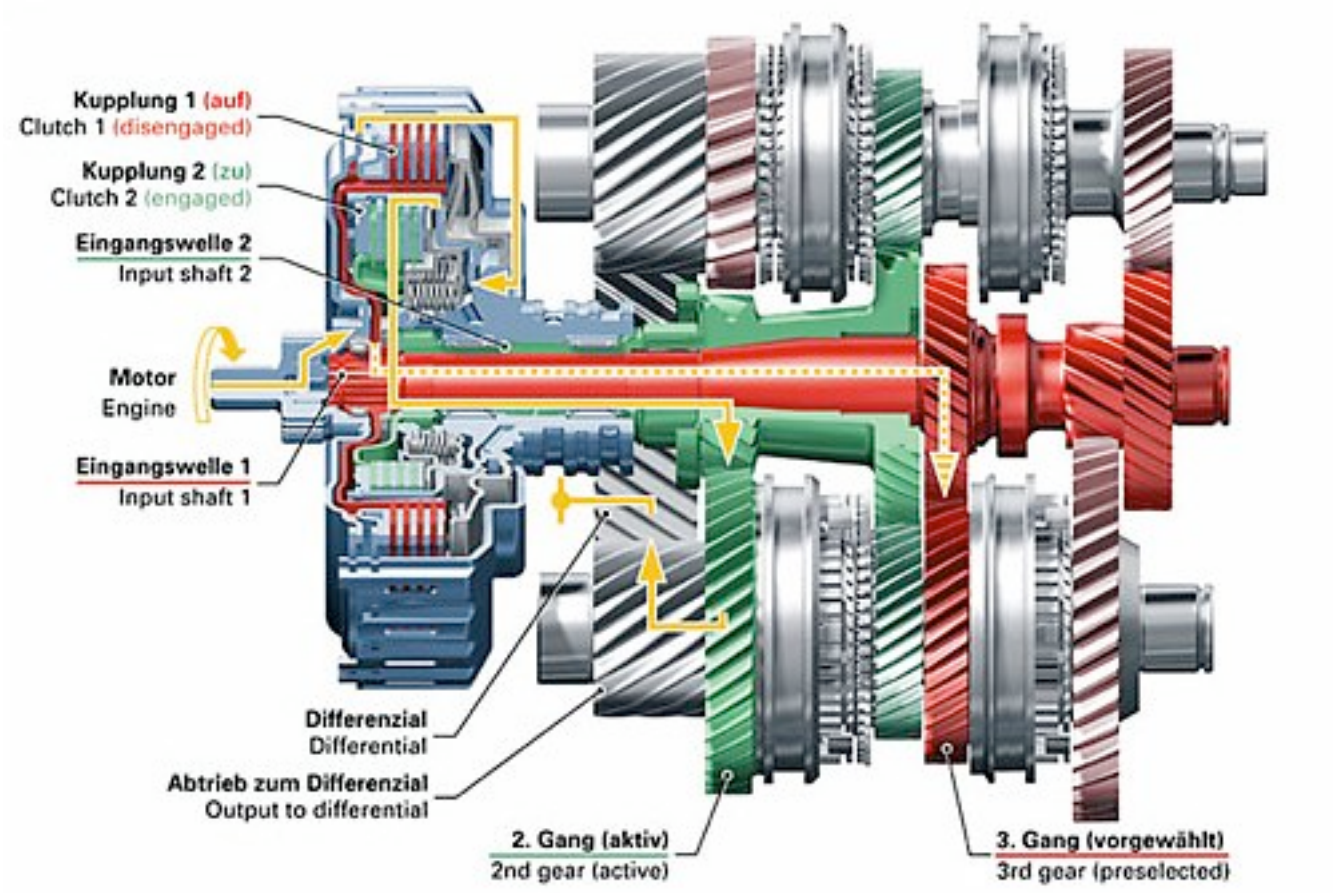
ICEs just do not run well at slow speeds

Low torque at low rpm. How do you start the car from a standstill? How do you accelerate?

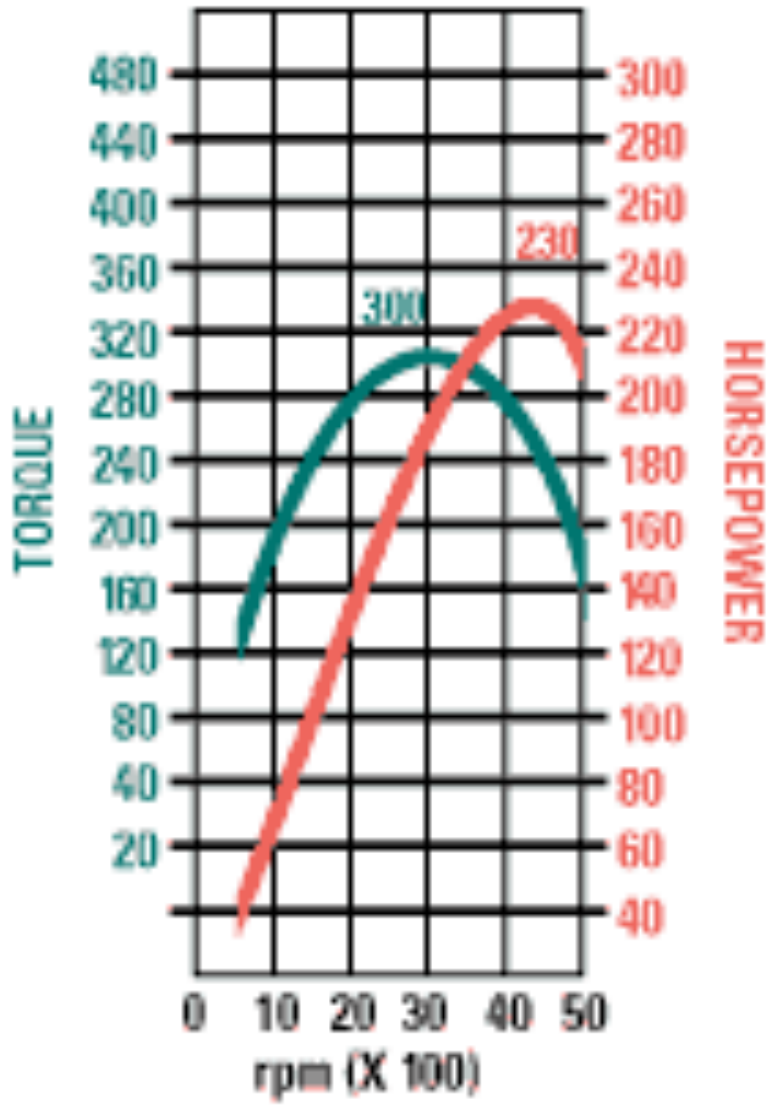
Note that ICEs do **nothing well at low speed**: not torque, not power, not efficiency (not shown here)

Torque-speed: internal combustion engines require help at low speeds

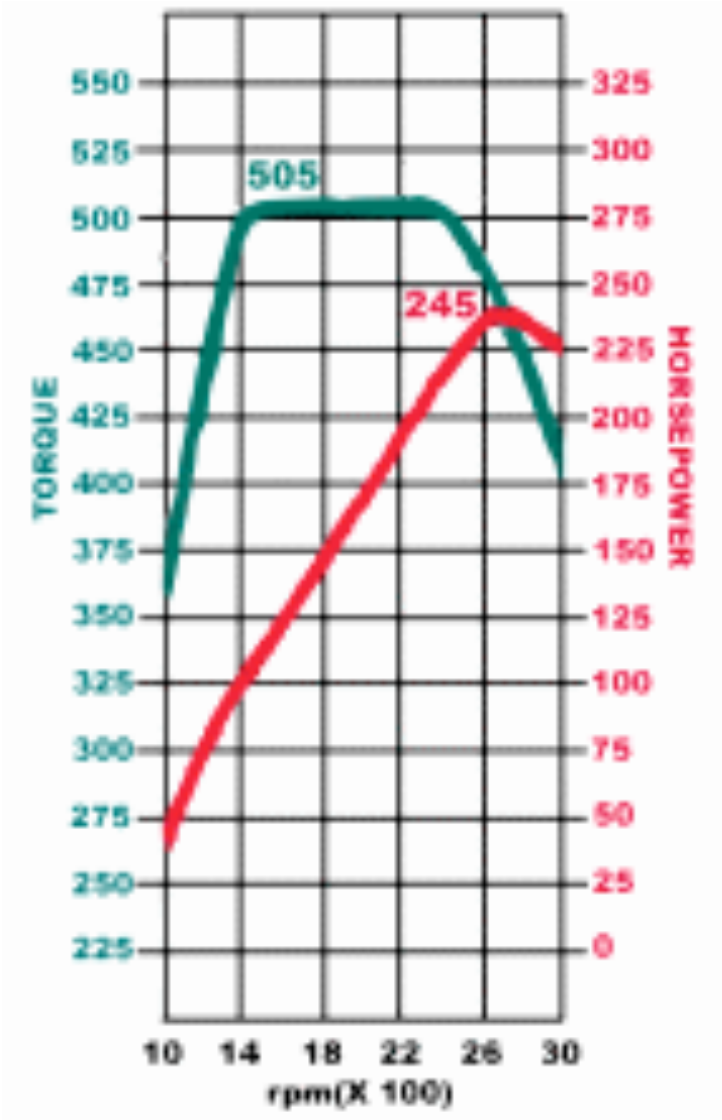
Transmission – required to allow gasoline engine to operate at high speed when wheels are low speed



Torque-speed: Diesel engine better at low speed than Otto engine



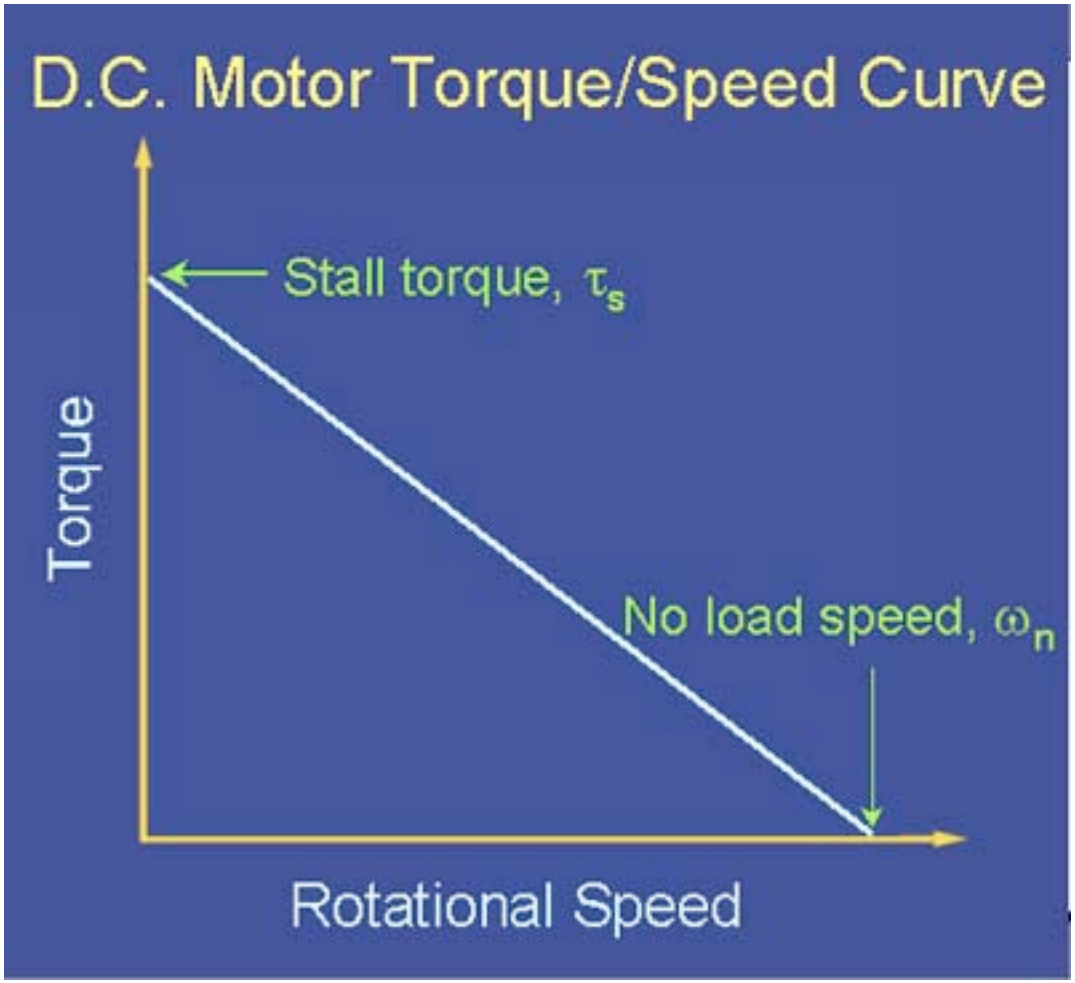
Otto engine, Dodge Ram pickup V8 5.9 L engine, 2004



Diesel engine, Dodge Ram pickup 5.9 L, standard output, 2004

Torque-speed: DC electric motors even better at low speed

DC motor torque rises linearly as speed falls



Power
$P = T*\omega$

$P = I*V$

Rotational speed ω is proportional to V

So more torque = more current

Min speed is limited by "back-emf": think of some intrinsic "stickiness" against turning

Figure: MIT Mech. Eng. 2.007

lancet.mit.edu /motors/ motors3.html

What is each engine type best for?

Gasoline: poor torque at low speed, good torque (acceleration) when at cruising spd., light weight

Diesel: higher torque at low speed, less torque at cruise, heavy weight but high power

Electric: max torque at low speed, very little torque once at cruise, requires generator (or heavy battery) to drive

Locomotives: all diesel-electric trains are series hybrids

Hybrid technology: gasoline engine drives generator; electricity carried to each wheel to drive separate electric motors

General motors EMD 710 series engine. Each cylinder of the engine has a displacement twice that of the biggest gasoline engines (11.6 liters). 3200 hp (2.4 MW) with 16:1 compression ratio. The generator is 6 feet in diameter and weighs nearly 18,000 pounds. 904 rpm (very slow).

Two-stroke diesel requires compressed air to force out exhaust, produces greater power.

Figure: howstuffworks.com

Locomotives: all diesel-electric trains are series hybrids

Individual motors weigh 6000 pounds and draw over 1000 amps.

Braking via electric motors rather than friction brakes: electric motors act as generators and torque applied to motors slows train.

Electrical energy from braking not necessarily recovered – may be dissipated in resistors on top of train. Batteries to store electrical energy are expensive and trains don't brake often.

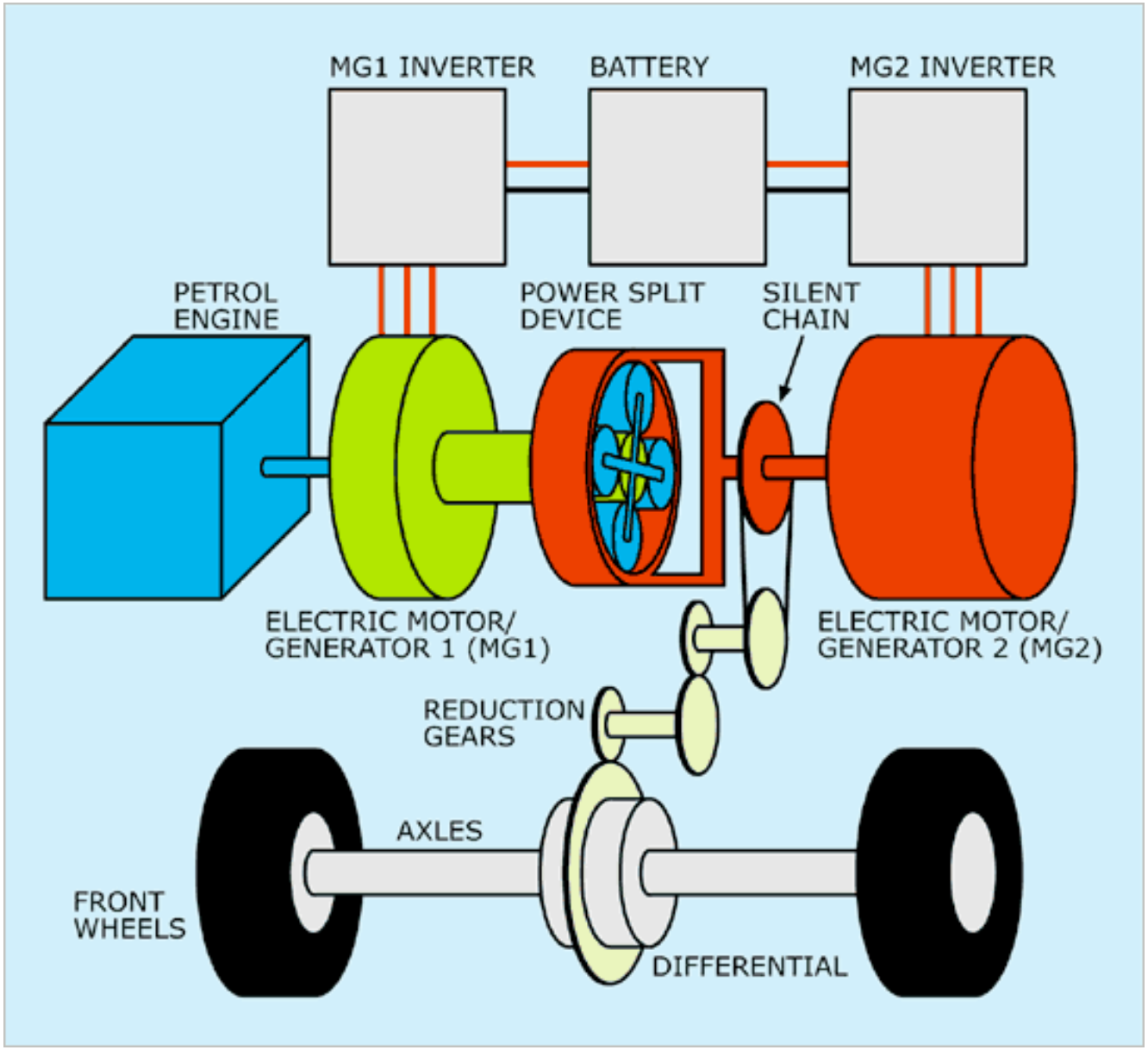
Electric motors driving wheels have single fixed gear

Figure: howstuffworks.com

Hybrid automobiles: most commercial are parallel hybrids

Toyota Prius uses AC motors and generators. Not only does it needs a transmission and drivetrain, it requires 2 inverters + a power split device to allow power from both gasoline and electric motors at once.

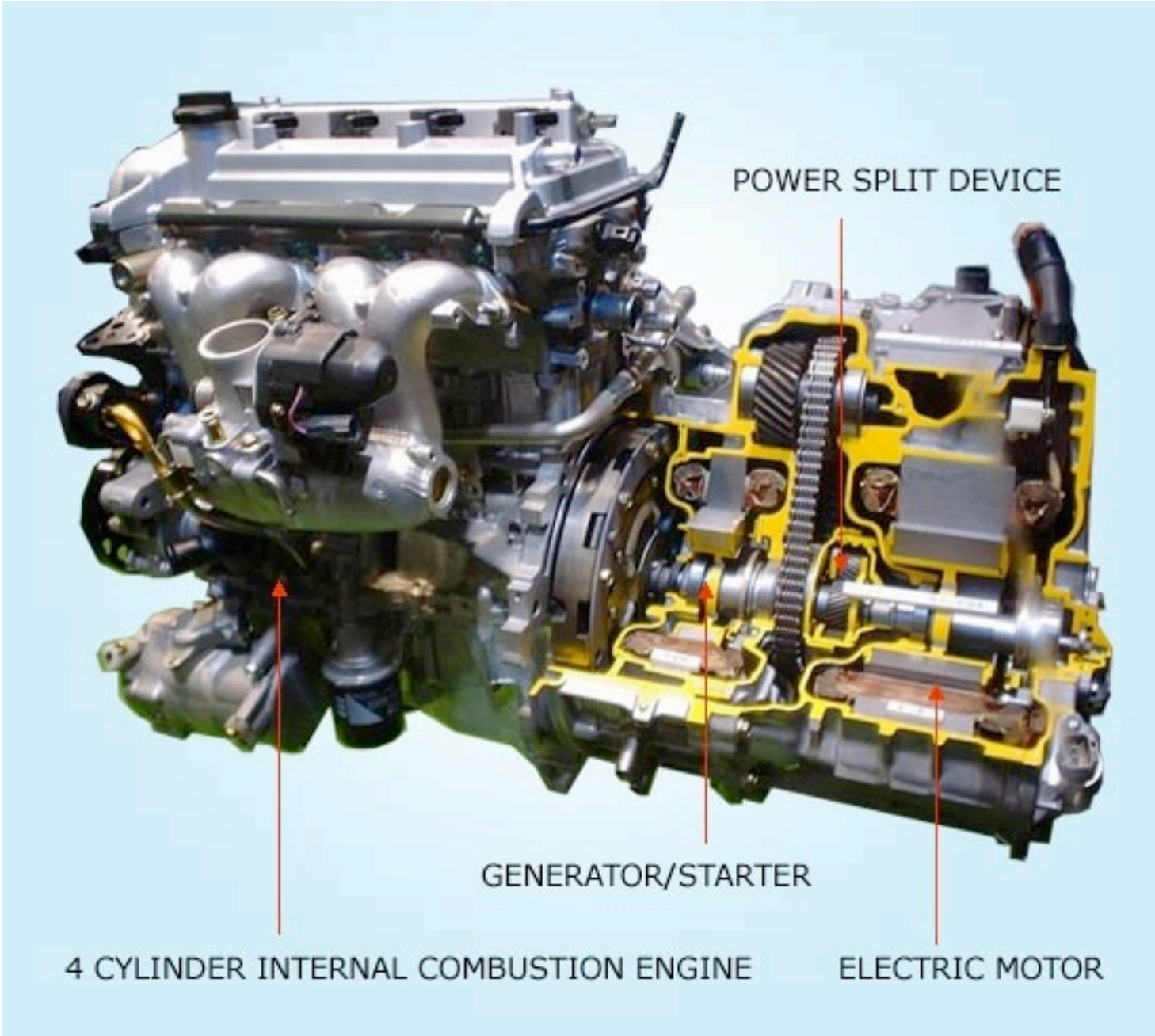
Figure: CleanGreenCar



Parallel hybrids: "power split device" fantastically complicated

Toyota Prius power split device.

Figure: CleanGreenCar



Hybrid automobiles: why parallel hybrids ?

"So the choice seems clear. If you want a product that's easy on the environment, gets great fuel economy and has good performance, the only reasonable choice is Hybrid Synergy Drive. You can buy a vehicle powered by the system right now, today. But if you want a series hybrid, well – you can cross your fingers and wait for a few years until some difficult engineering and production problems are solved. Or, you can look into buying a locomotive."

Irv Miller, Group Vice President, Corporate Communications, Toyota

defending Toyota's choice of parallel vs. series hybrid for the Prius

GEOS 24705 / ENST 24705
Fossil fuels

Organic matter must be buried and see high T, P

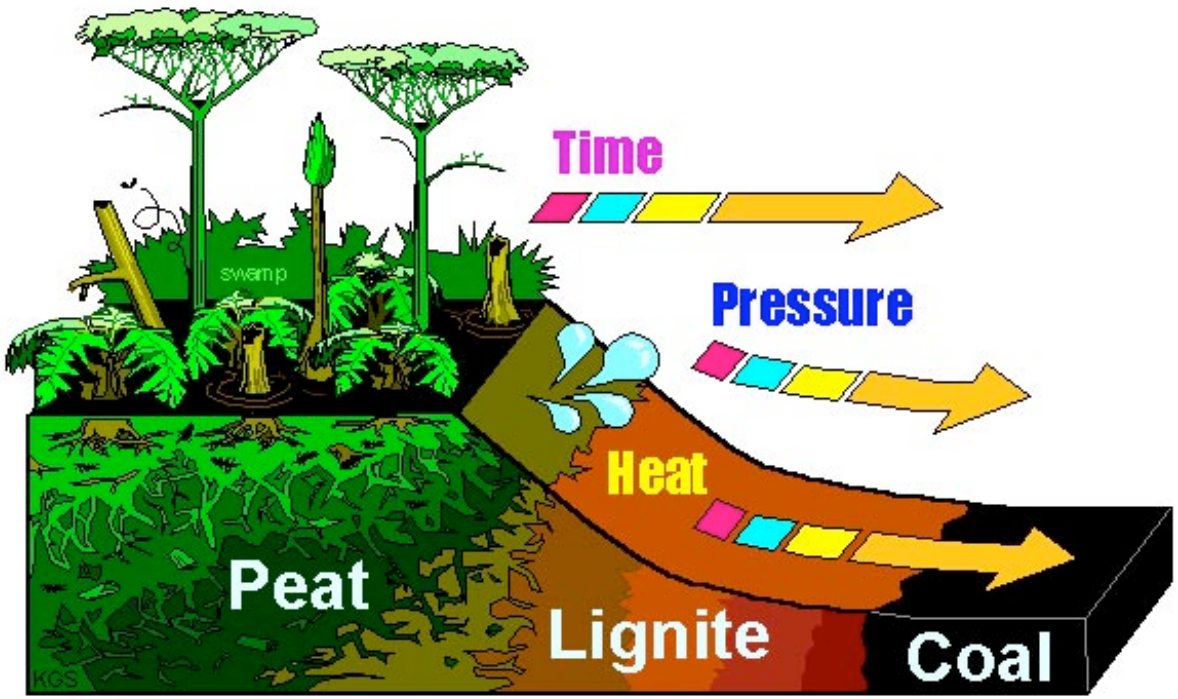


Image: Kentucky Div. of Mine Permits

Requires anaerobic conditions to prevent oxidation

Heat and pressure cause gradual changes composition: drive off water, react off O, new compounds form

Energy density increases during process from ~ 20 MJ/kg to up to > 40 MJ/kg

Coal comes from plants

peat

lignite

sub-bituminous

bituminous

peat

Age / processing

Coal is plant matter

Peat is still being deposited today.. and has been harvested for fuel for millennia …

…by hand or by machine.

Conversion to coal would begin with burial to as little as 2000 ft, T ~ 100-150 C. Beds up to ~ 14 ft thick.

Photos: both from Ireland

Peat is preserved because of anaerobic conditions

Plant matter in peat bogs
doesn't decay .. and neither
does other organic matter

Tollund Man, ~400 B.C. (2400 years old), found in Denmark, 1952, by peat-cutters.

Photo: Rob Clark, National Geographic

Oil and gas believed to be mostly from phytoplankton

Possibly diatoms: photosynthetic plankton w/ siliceous skeleton and high natural oil production (as in some modern algae)

Unclear T, P of formation:
Does oil formation need high T, P? Or can be low temp: 100-120 C ?
Depths < 20,000 feet

Confusion still about exactly what precursor molecules are (only lipids? Also carbohydrates?). End product is a hydrocarbon (essentially only Cs and Hs), but fatty acids can become hydrocarbons via single elimination:

$$RCO_2H \rightarrow RH + CO_2$$

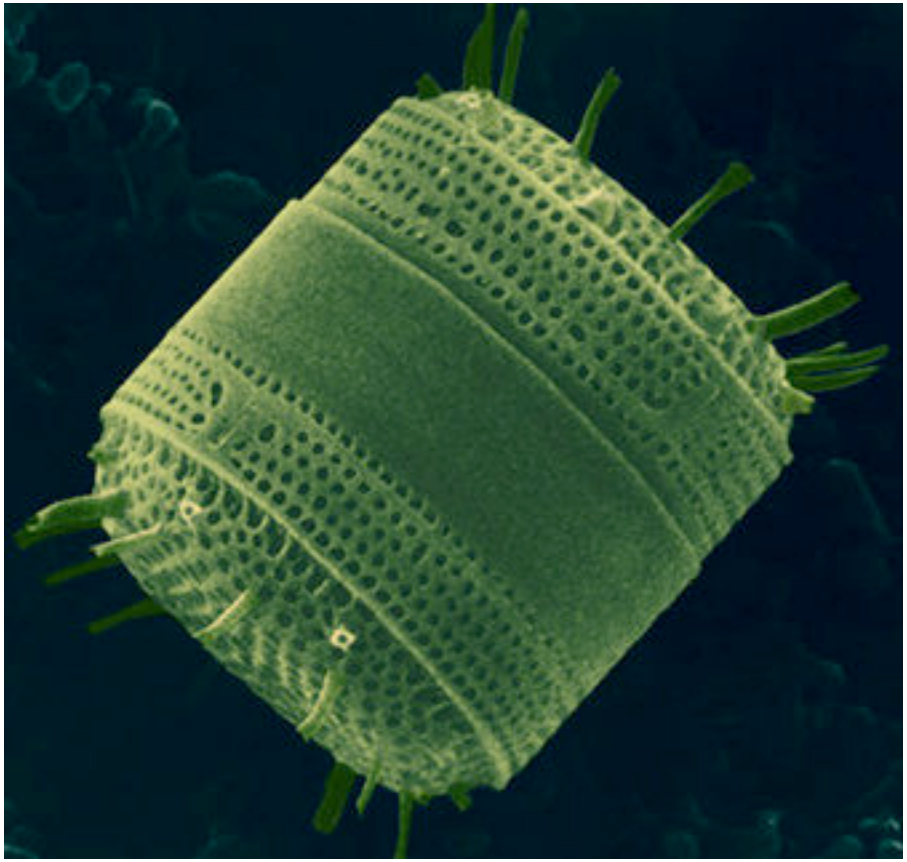
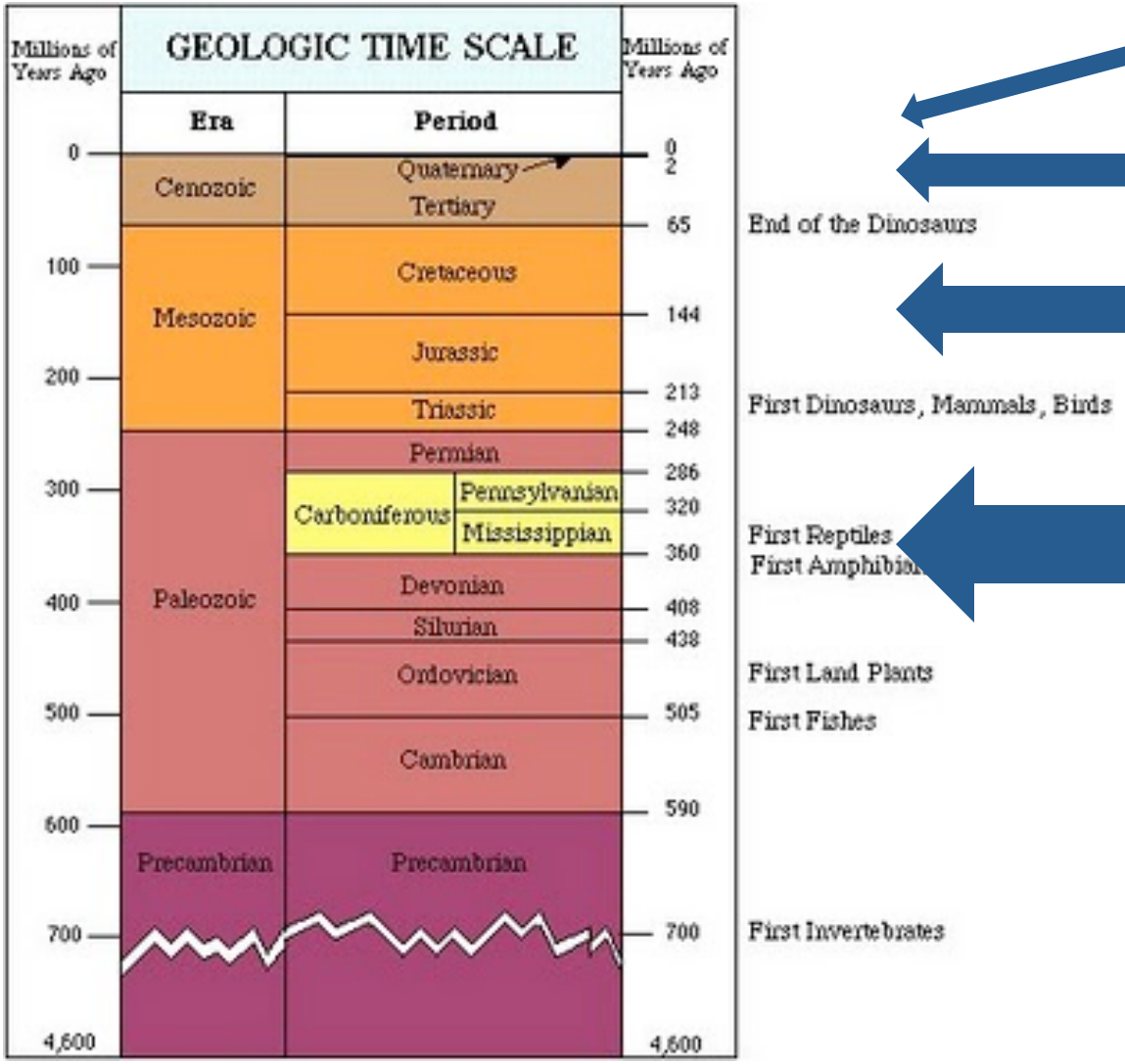


Photo: copyright Dee Berger, Lamont-Doherty Earth Observatory, 2001

What are fossil fuels? dead plants that are 10s-100s of Myr old

Laid down in particular periods…each depositional era ~ 90-150 My



Peat is < 10,000 years old

Some coal from Miocene, 20 Mya (Indonesia), or Paleocene, 65-55 Mya (Colombia, Venezuela)

Some from mid-late Mesozoic (age of dinosaurs, 150-65 Mya)

Most from "Carboniferous" (also most U.S. coal) (360-286 Mya)

L: Geologic timescale From: www.geocraft.com
R: Carboniferous flora From: Brooklyn Botanical Garden