GEOS 24705 / ENST 24705
Internal combustion engine and transportation III, fossil fuels

Engine choice

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, heaviest choice: requires generator (or heavy battery)

Locomotives: all diesel-electric trains are series hybrids

Hybrid technology: engine (2-stroke diesel for maximum power) drives generator; electricity carried to each wheel to drive separate electric motors. *No need for battery in between.*

Right: EMD 12-710G3B engine, 3200 hp (2.5 MW)

12 cylinders, each with 11.6 liter displacement, twice that of the biggest gasoline engines. 16:1 compression ratio.

The generator is 6 feet in diameter, weighs ~18,000 pounds, turns at 900 rpm (very slowly).

Figure: Wikipedia

Locomotives: all diesel-electric trains are series hybrids

Individual motors weigh 6000 pounds and draw over 1000 amps.

Electric motors providing braking (avoid friction brakes). Electric motors act as generators and torque slows train.

Electrical energy from braking not necessarily recovered – often dissipated in resistors on top of train.

Batteries to store electrical energy are expensive and trains don't brake often.

Figure: howstuffworks.com

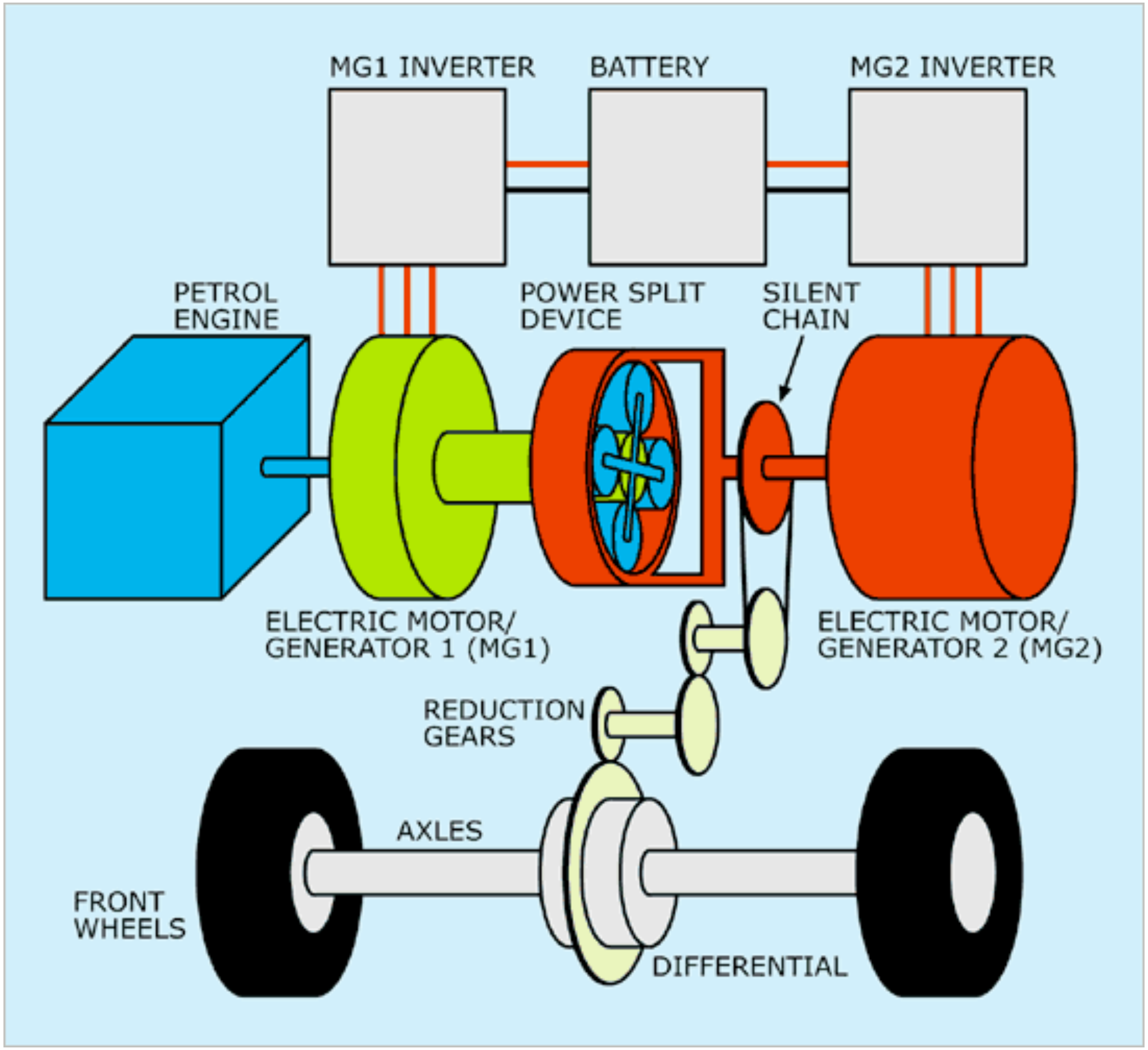
Electric motors driving wheels have single fixed gear

New (old) automotive technologies

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.

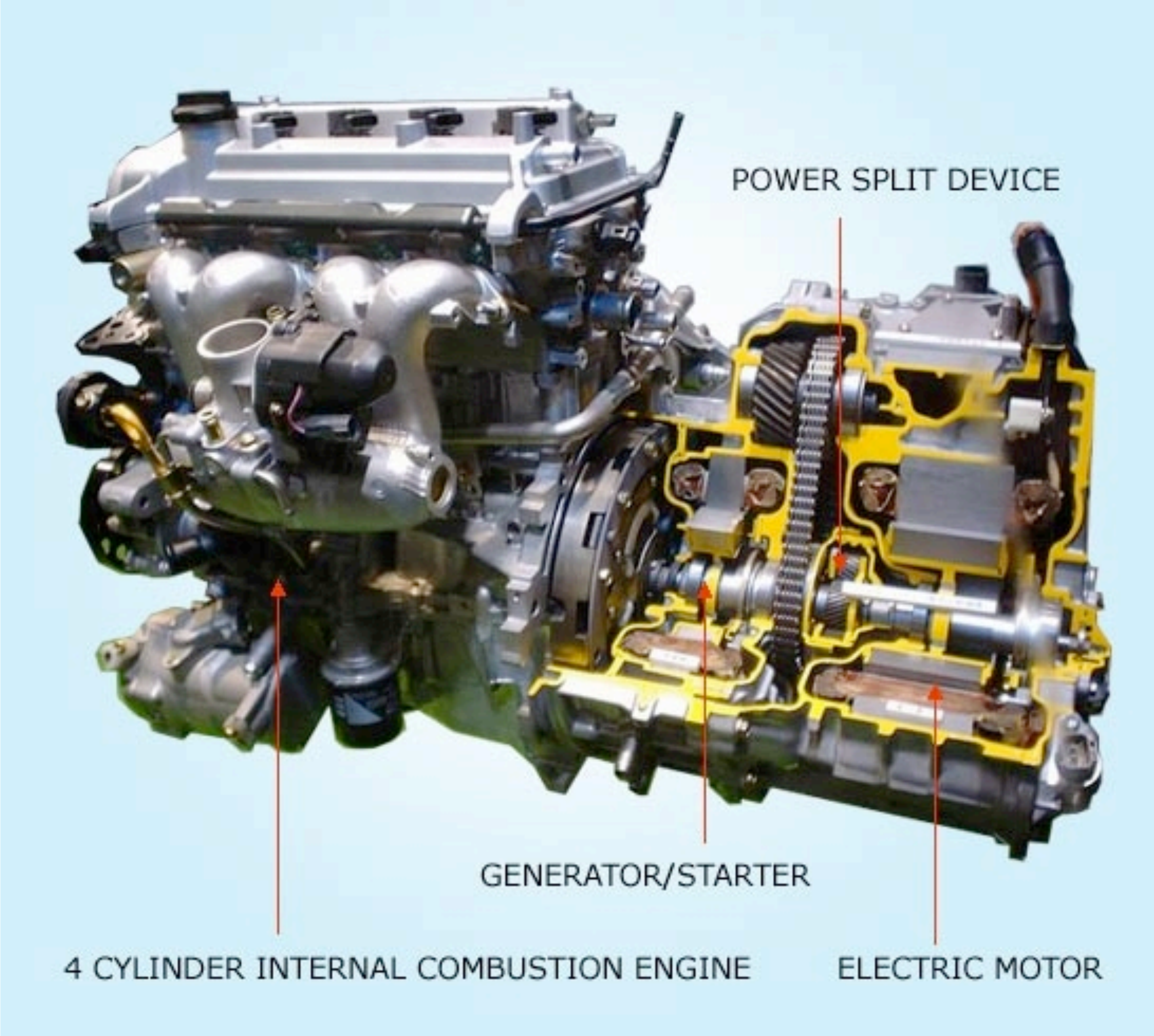
Figure: CleanGreenCar



Parallel hybrids: “power split device” fantastically complicated

Toyota Prius engine

Figure: CleanGreenCar



Why are automobiles parallel and not series 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."

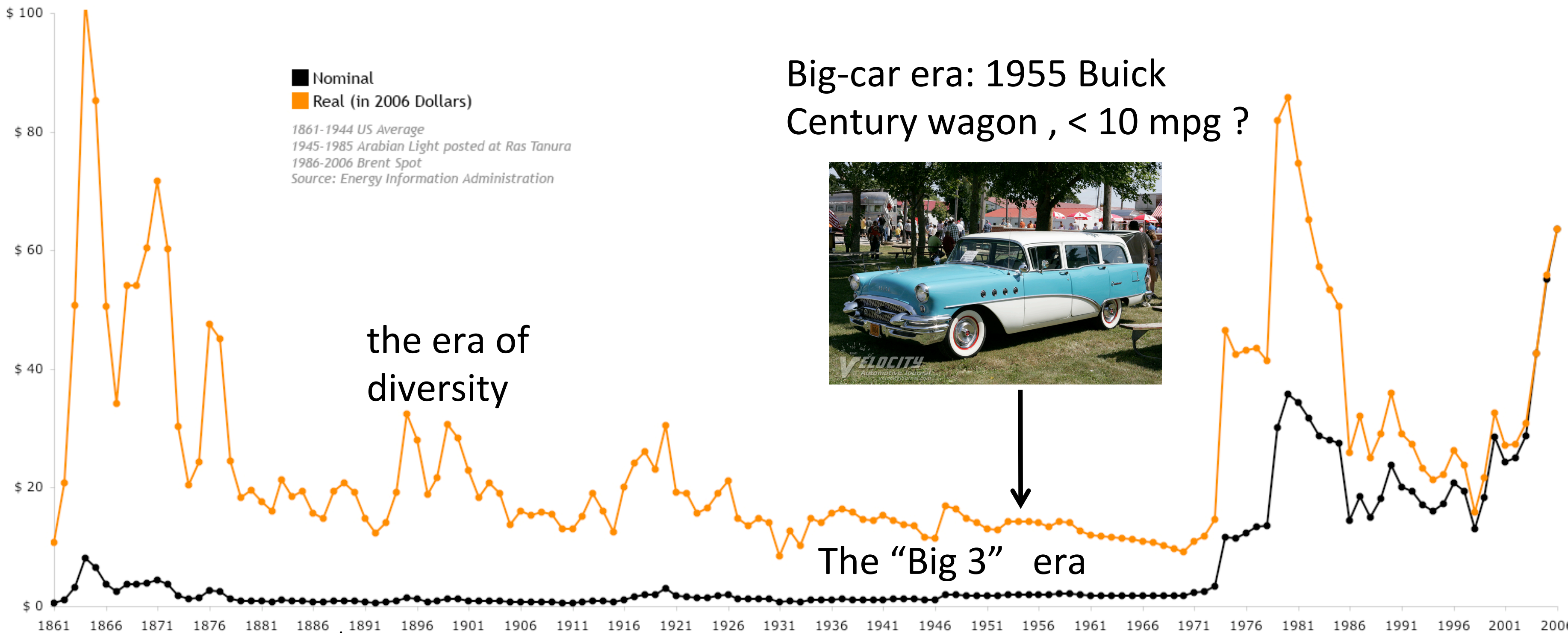
Irv Miller

Group Vice President, Corporate Communications, Toyota

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

Fuel economy

Why did the internal combustion engine win out?



the era of diversity

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

The “Big 3” era

1888: Bertha Benz’ drive

1908: Production of Model T Fords begins in Detroit

1973 oil shock
1973 Datsun 510

Fuel economy standards for cars and trucks enacted in 1975

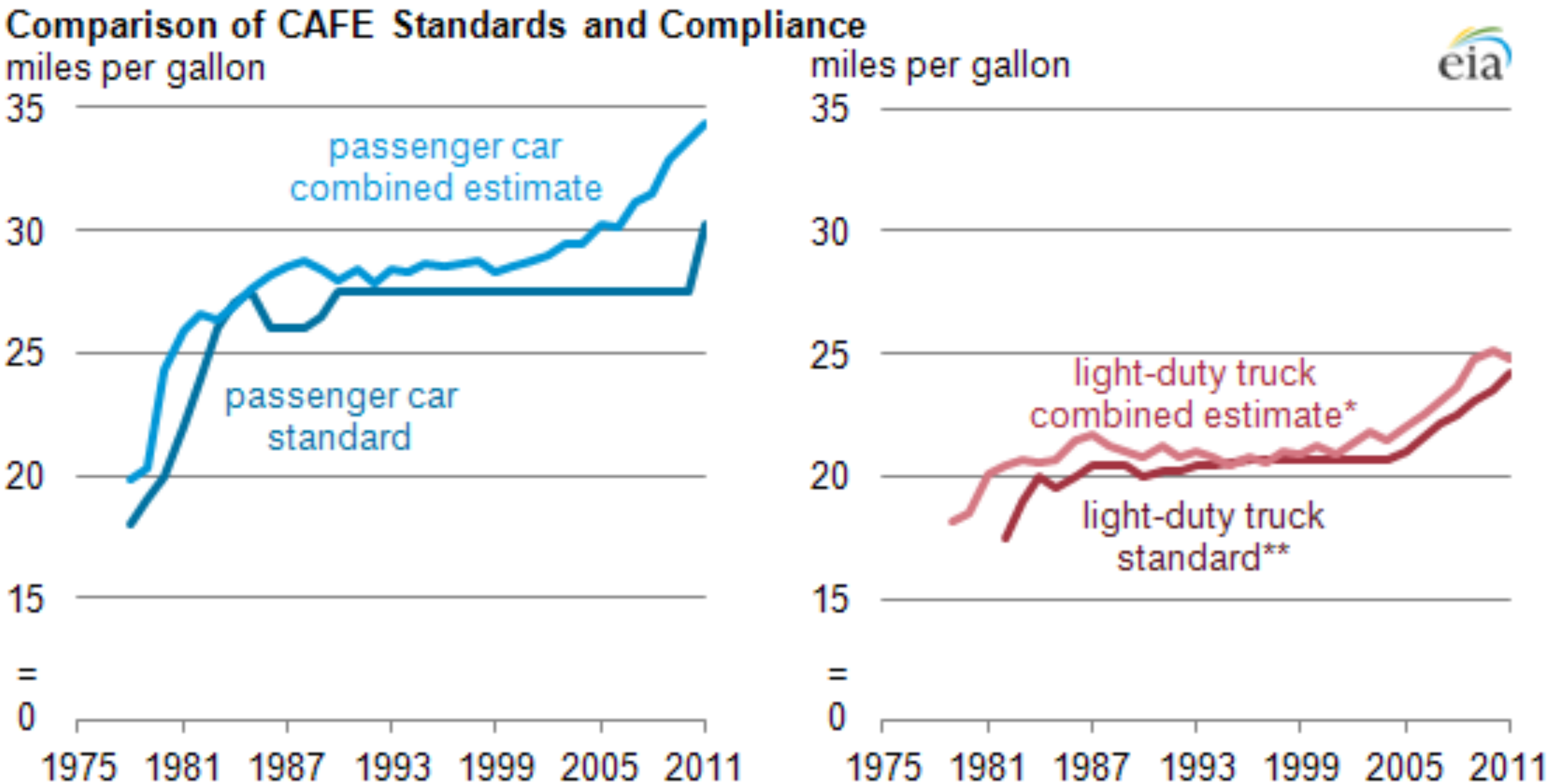
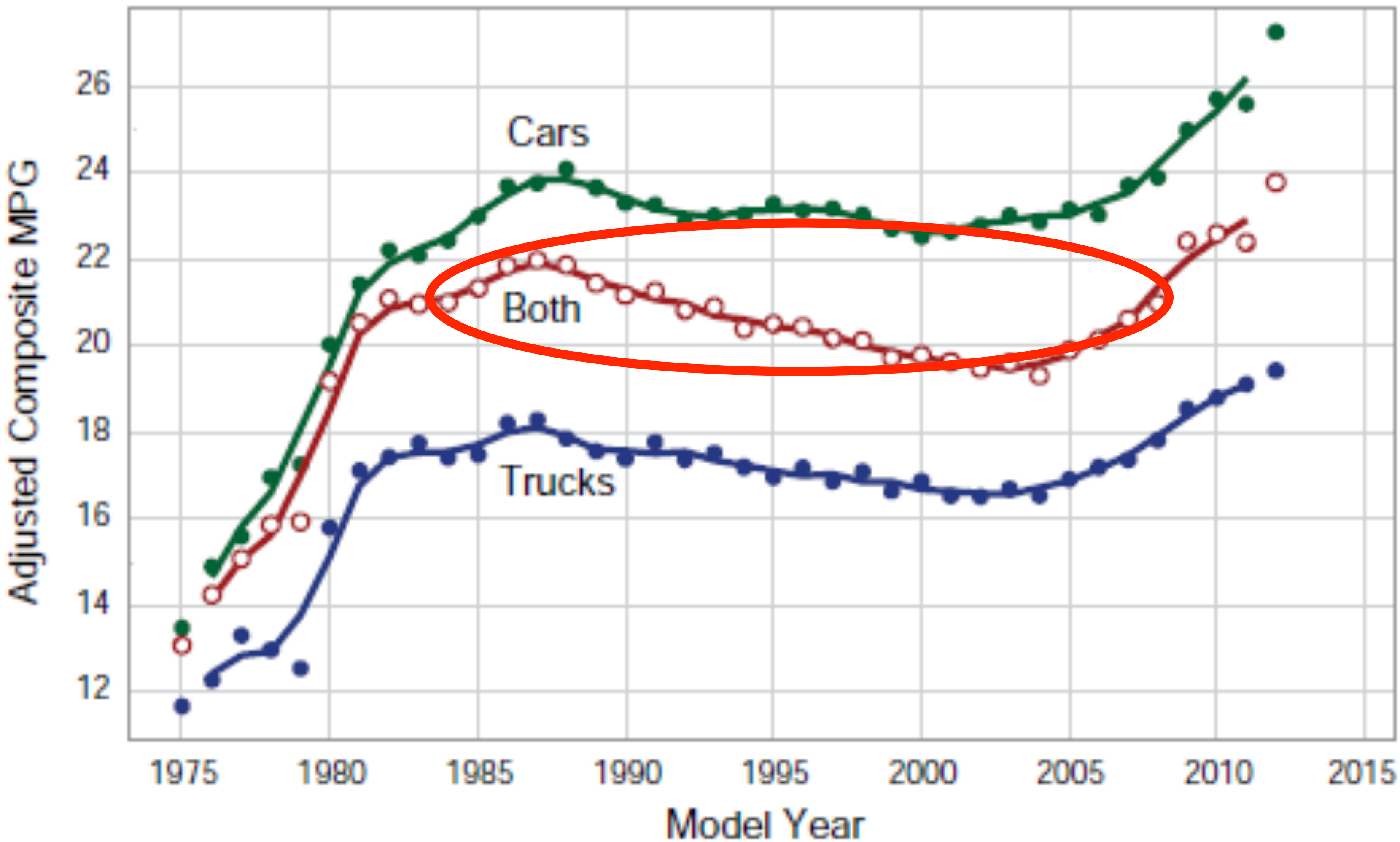


Figure: EIA

Pitching small cars to the American people required new approaches….

But note complications:
U.S. vehicles actually get worse in 1990s...

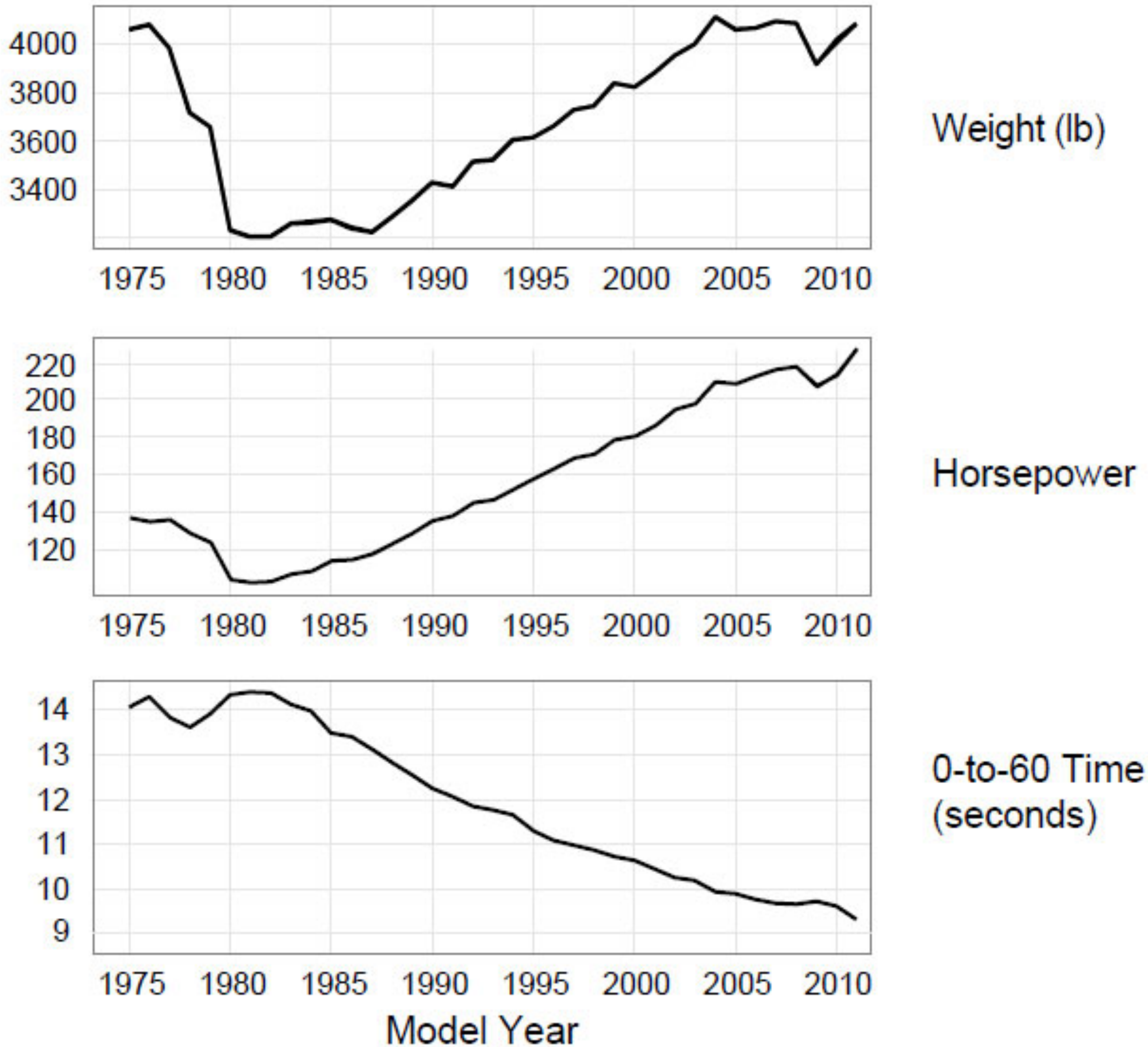


Why?

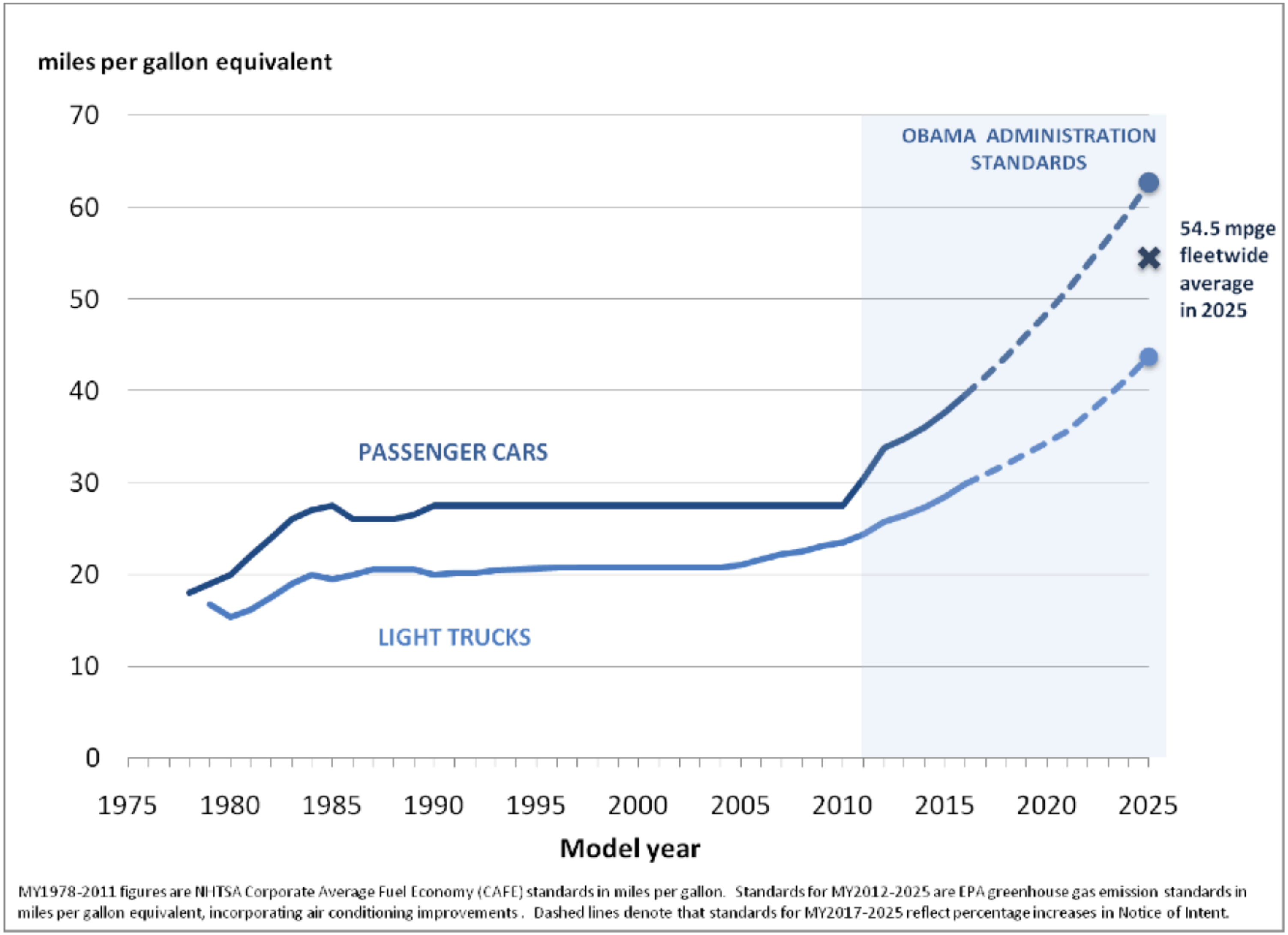
Increasingly people bought “trucks” instead of “cars”

Also: technological advances don't get used for fuel economy

technological improvements are used for other purposes



Obama standards are return to 70's era rates of change



Little publicity or protest: endorsed by automakers, UAW, etc.

Will they be met by reducing weight, reducing performance ... or real innovation?

What governs fuel economy?

What happens to the fuel burnt in a car engine?

ENGINE Typically ~ 25% to work in Otto, 30% in Diesel
~ 75-70% loss to heat

What then happens to the kinetic energy?
Must dissipate somehow…

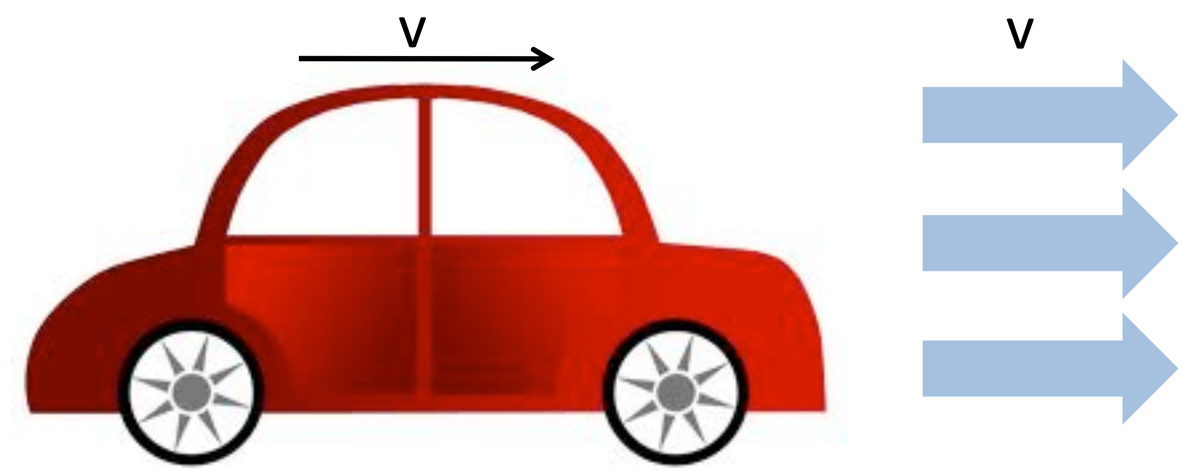
DISSIPATION

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



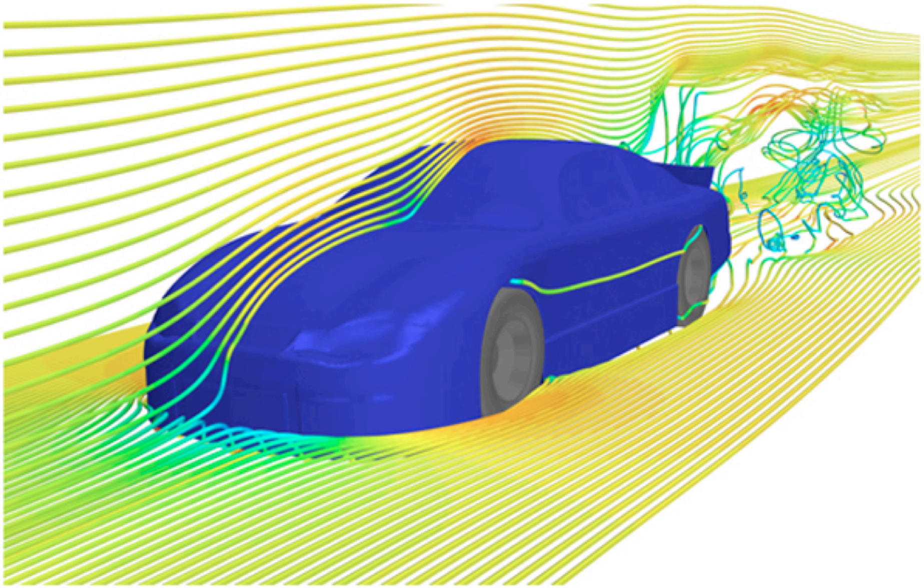
Worst-case scenario: the car pushes all air it intersects up to its speed v. Power to do this is same as energy in flow of air at that speed:

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

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



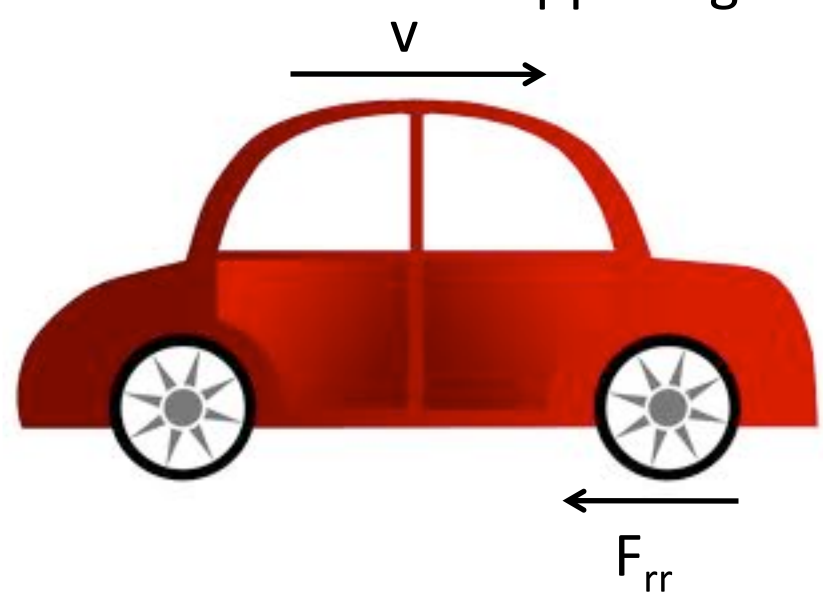
Solution: adjust formula by some fudge factor that describes how "streamlined" the car shape is:

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

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.



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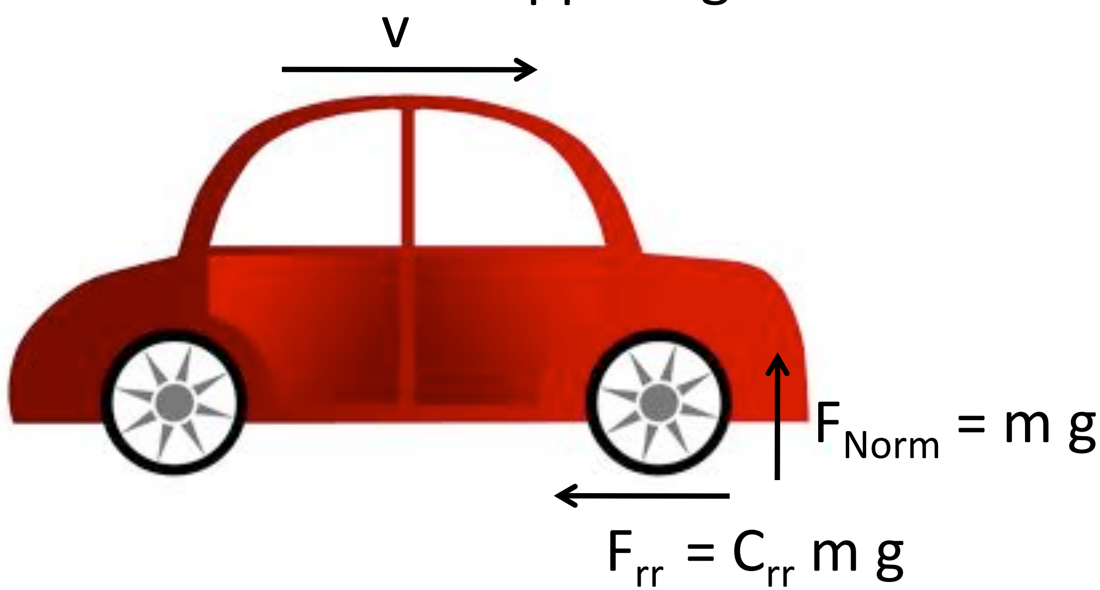


Force of rolling friction is proportional to normal force that opposes car's weight against ground.

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

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

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

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

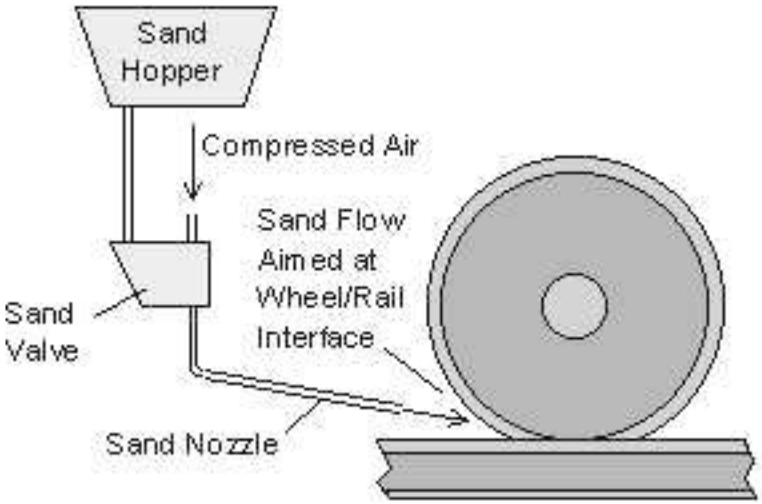
Steel rails are slick – low friction – so low rolling resistance, great for minimizing power losses in long-distance travel.

But problematic for starting up or stopping suddenly, when torque must be high. Need some friction to apply torque to the wheel, or just spins in place.

Trains needs some solution that combines efficient long-distance travel with ability to brake and start.

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

Sanding nozzle
Image: HowStuffWorks

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

Fossil fuels

Fossil fuels: organic matter buried and exposed to high T, P

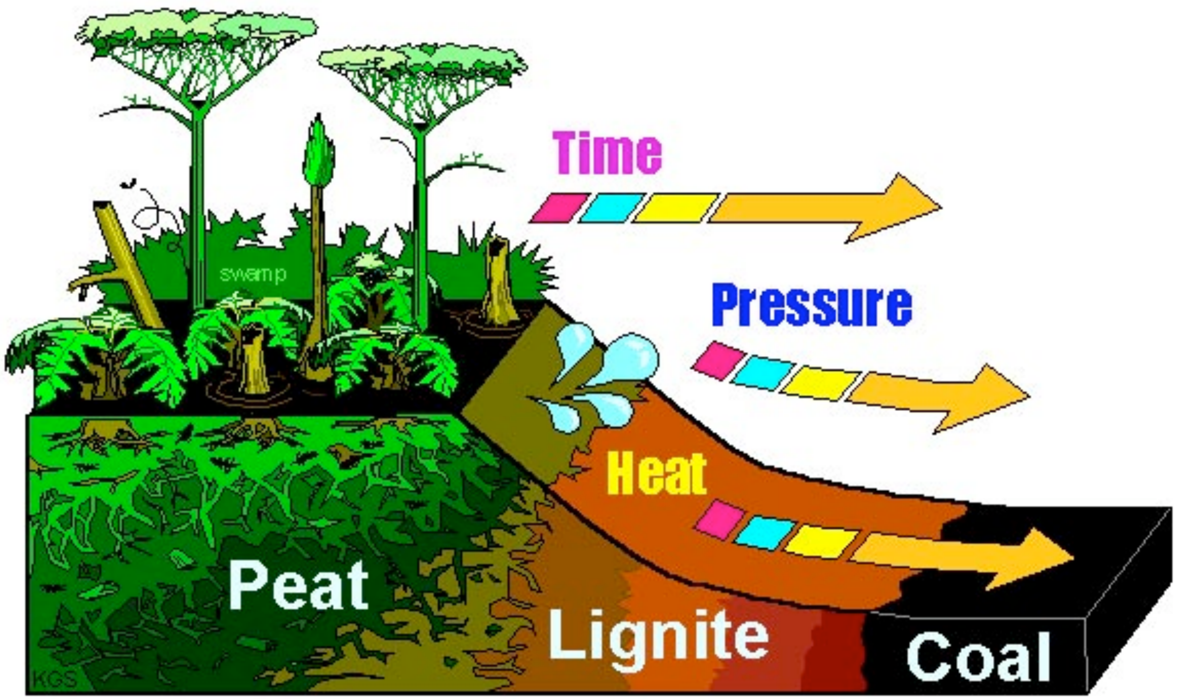


Image: Kentucky Div. of Mine Permits

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

anthracite

Age / processing

Peat = modern preserved 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

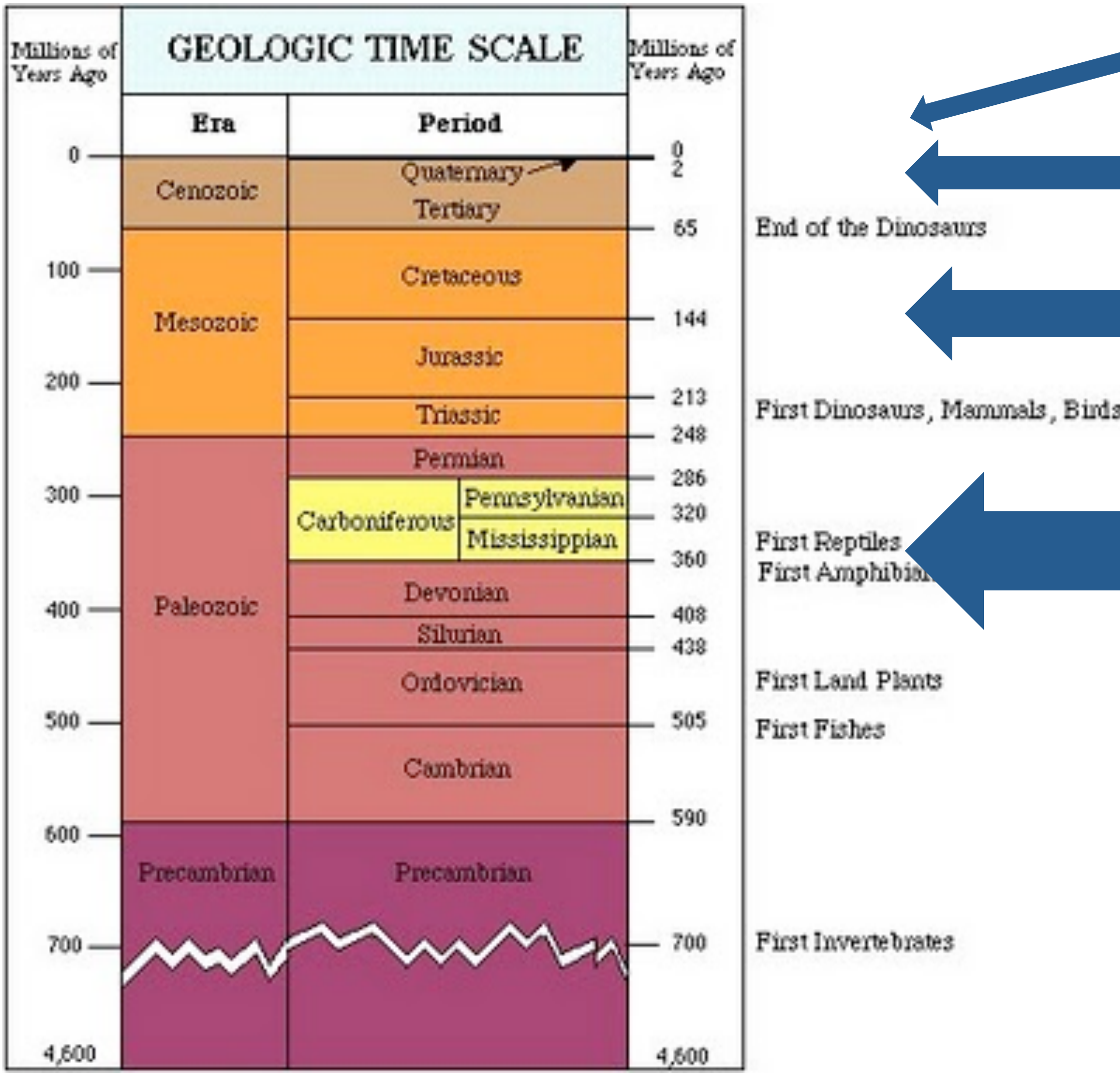
Plant matter in peat bogs doesn't decay .. and neither does other organic matter

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

Photo: Rob Clark, National Geographic

Coal is dead plants from shallow nearshore swamplands

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)

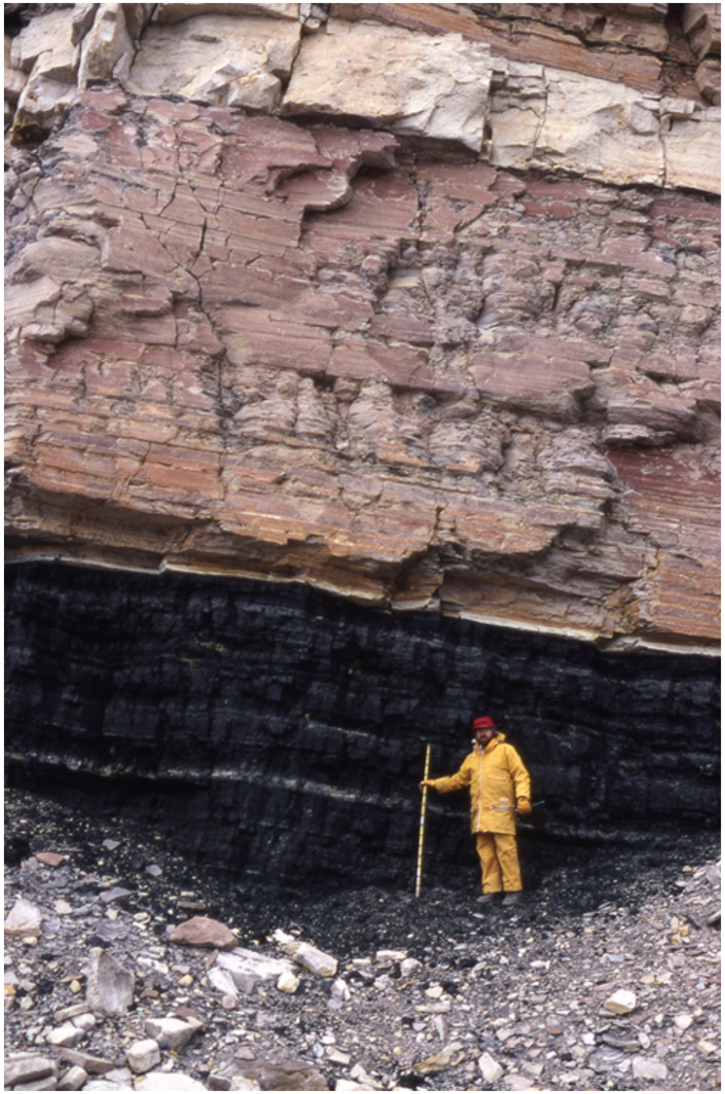
Some from mid-late Mesozoic (age of dinosaurs, 150-65 Mya)

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

Coal seams produced by changing sea level

periodic shallow swamplands develop



Typical height 10-12 m

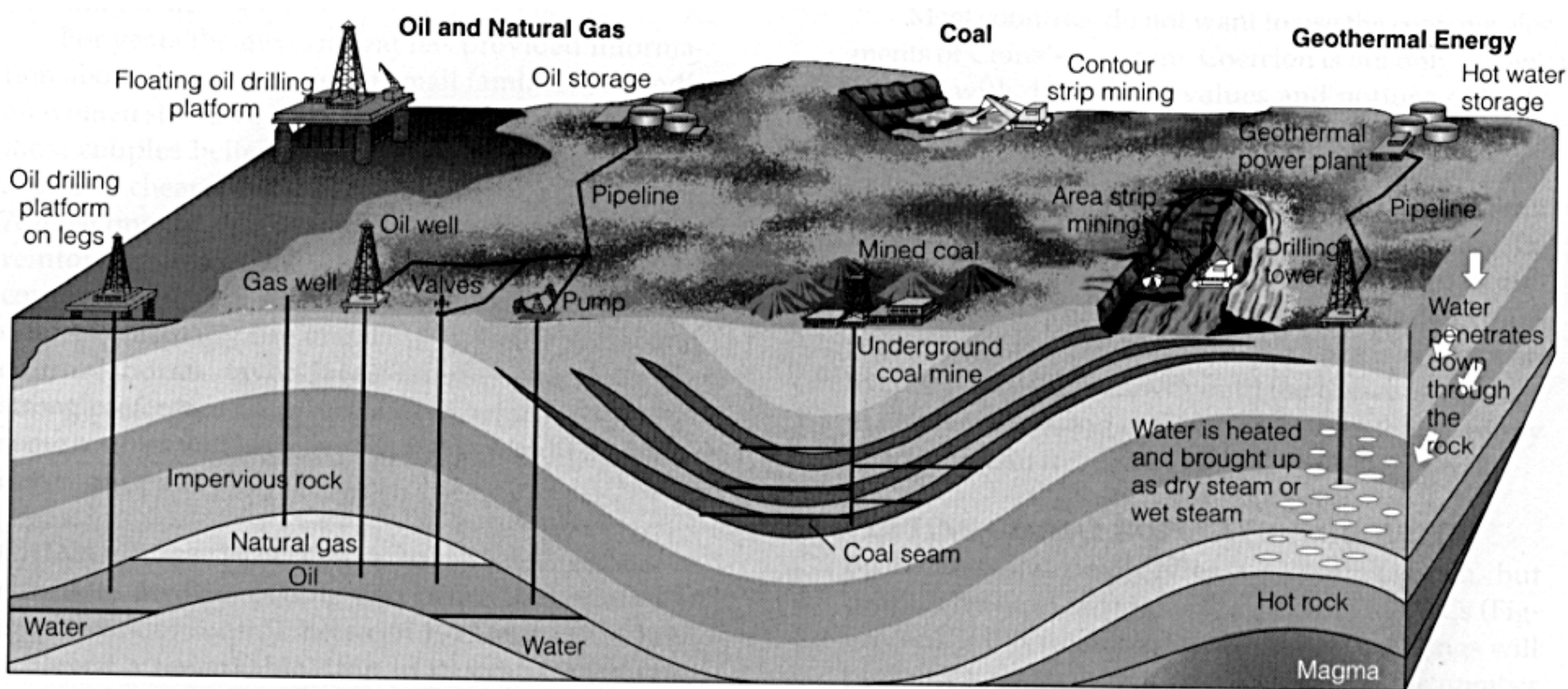
L: Permian coal seam in Antarctica. Photo: Stephen McLouglin
R: Coal seams along Lignite Creek, Alaska. Photo: Erin McKittrick.

We know the ages of coal deposits but not ages for oil and gas.

Why?

While coal stays, oil and gas migrate

- *Coal:* remains in place, found when seams are brought near surface (typ. mine depths less than 300 m). Seams often 10 m but can be as thin as 1 m.
- *Oil and gas:* lighter than water so migrate til trapped in anticlines under impervious sediments (shale, clay). No way to identify geologic ages.



Some gas is associated with coal:

that's why coal mining is so dangerous

Thousands of deaths each year in coal pits; 30/yr in U.S.

2010, W Virginia: 29 dead

News flash and local signs after 2010 explosion at Massey Upper Big Branch W. Virginia mine.

President of coal subsidiary convicted and sentenced in 2013.

T: Mark Humphrey, Associated Press

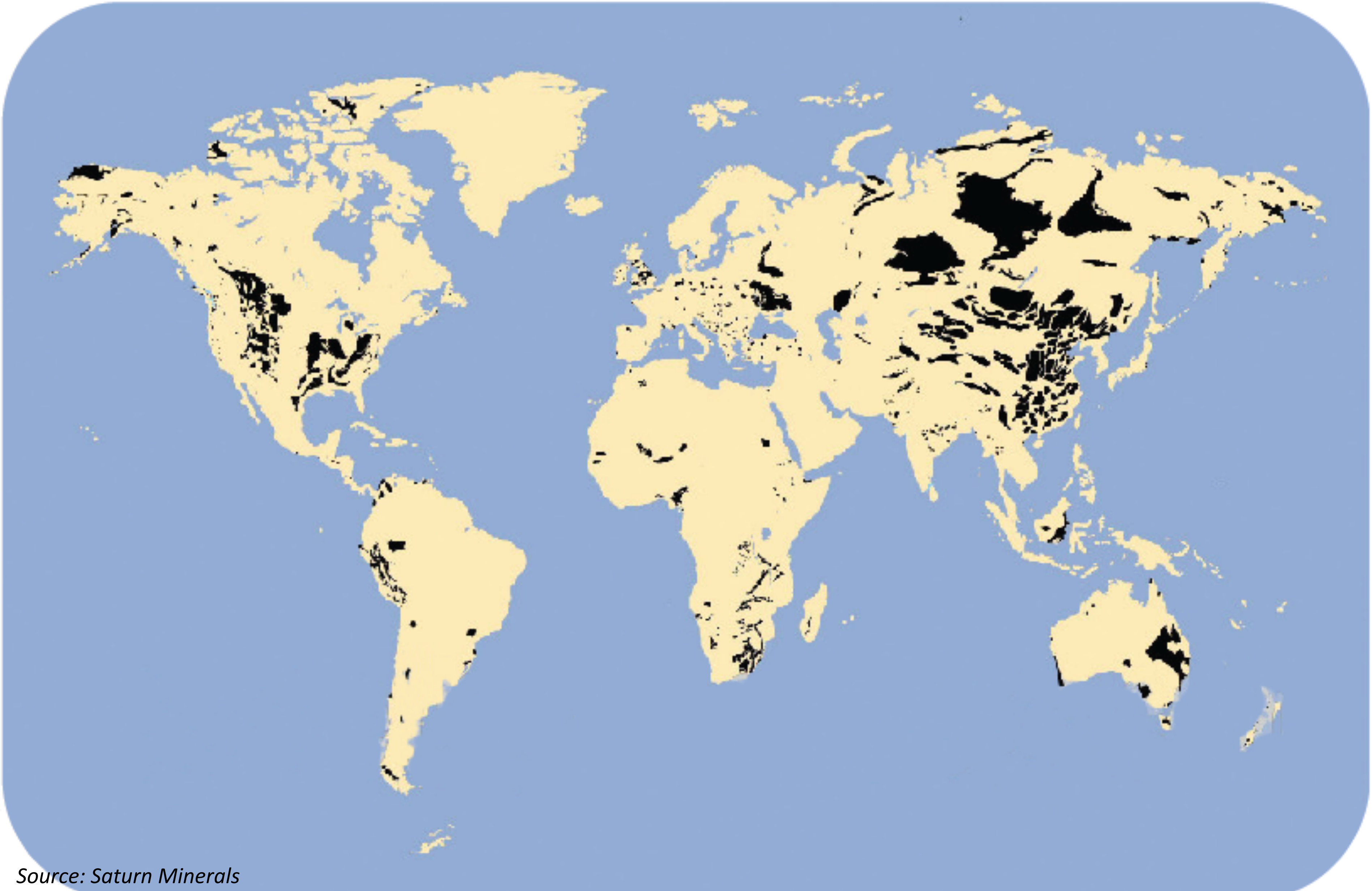
Coal mine disasters even worse where regulations weaker

Carrying injured miners after May 2014 mine fire in Soma, Turkey: 301 dead

Note 95 dead in multiple smaller incidents in 2013

T: Photo, Associated Press
L: Photo, Bulent Kilic, AFP/Getty Images

Coal deposits depend on geologic history



Source: Saturn Minerals

U.S. has largest coal reserves

Over half world's proven reserves 500 Gt / 900 Gt proven.

(Estimated total world coal reserves are ~ 5000 Gt vs ~ 1000 Gt oil + gas

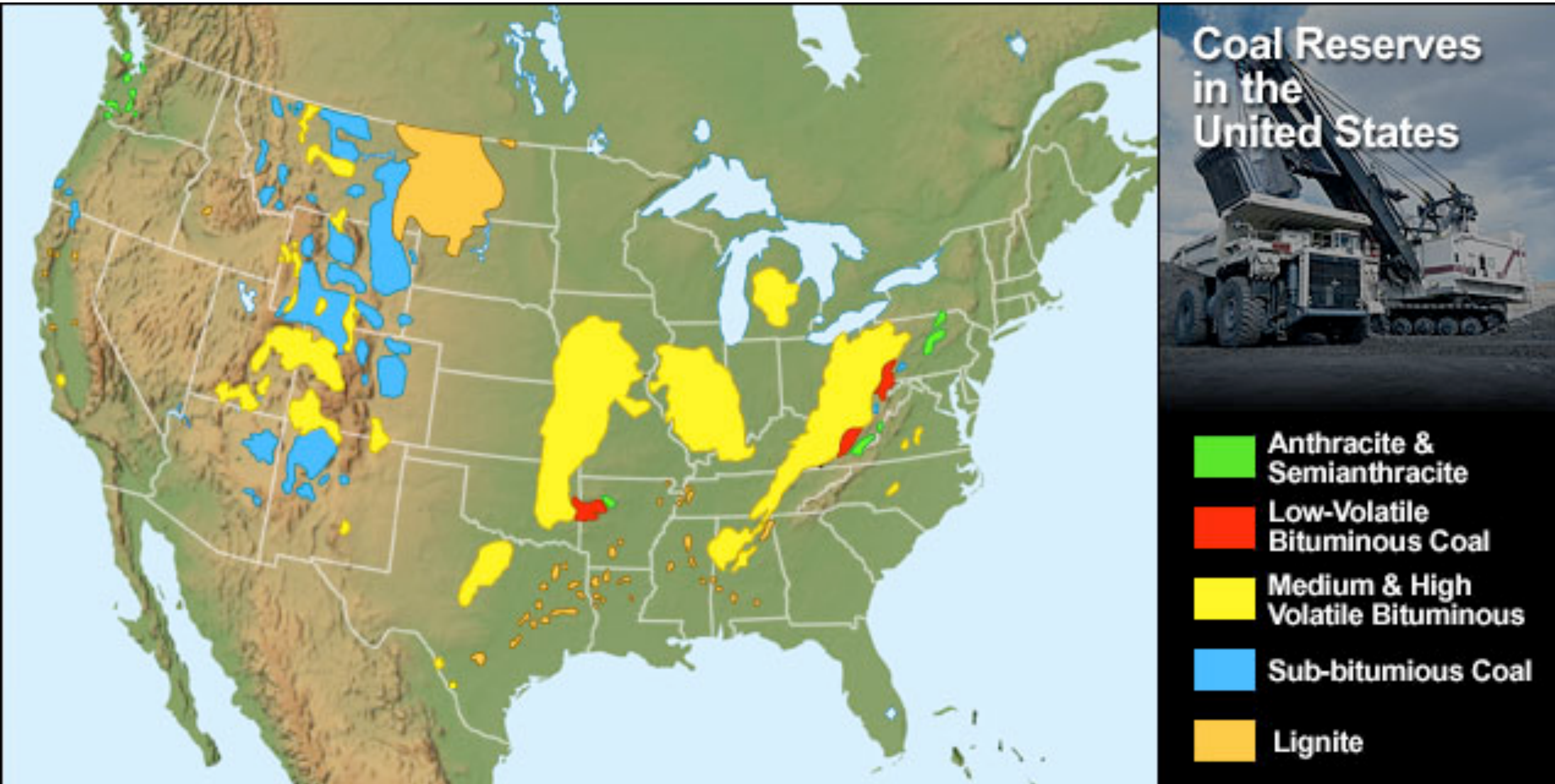


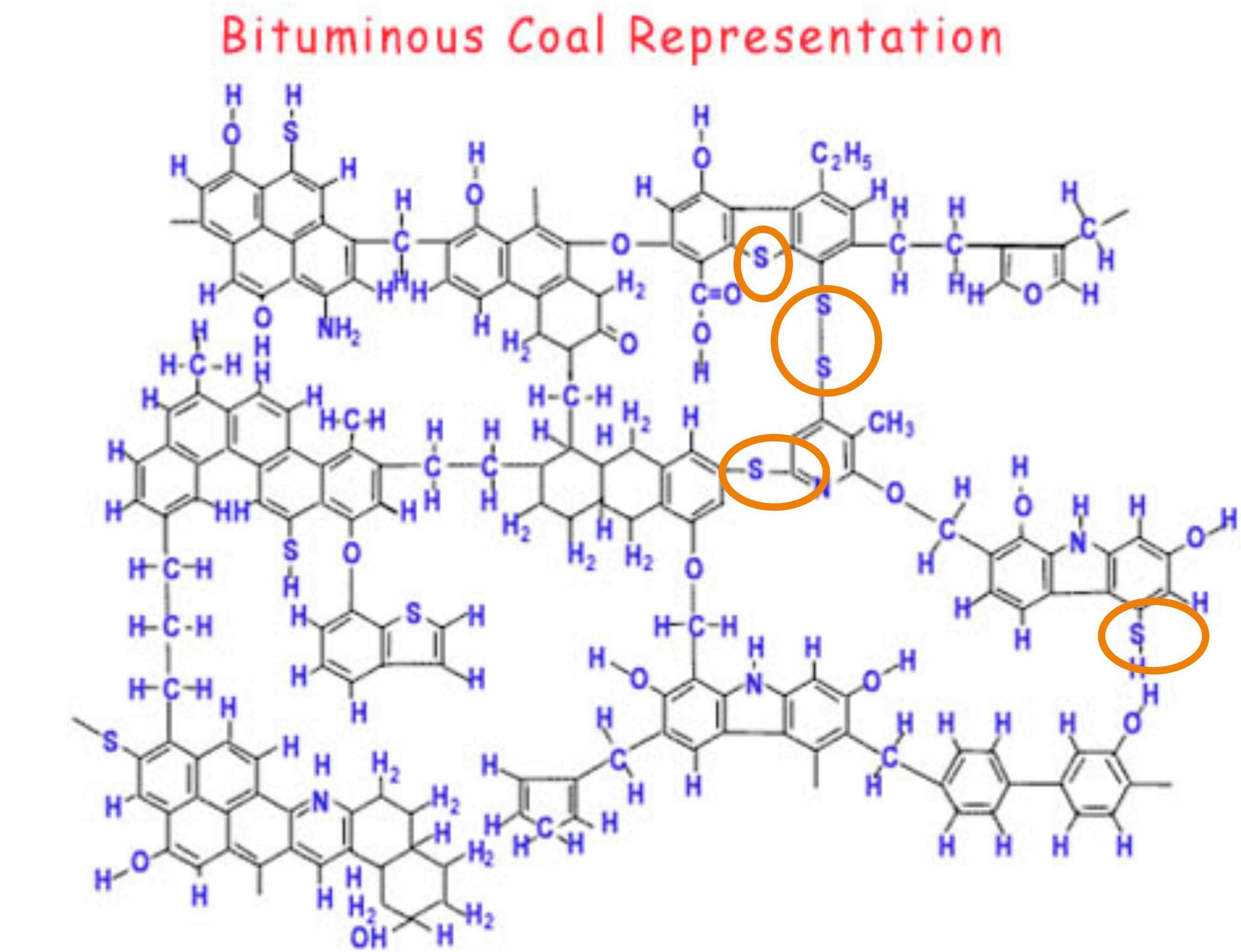
Image: American Coal Foundation

Data: Speight, J.G. "The Chemistry and Technology of Coal"

Biggest production: Wyoming, Kentucky, W. Virginia, Pennsylvania, Illinois (but PA and IL peaked in 1918, PA coal down by factor of 4 since). Anthracite production peaked in 1920s. Sulfur content: Western < 0.5%. Midwest > 1.5%

Molecular composition of coal

mineral structure, complex and highly variable (mostly C & H)



Not all C, H, and O – some sulfur impurities. If burnt in a combustion chamber without a sulfur scrubber, S oxidizes to become sulfur dioxide, or SO_2, which then makes sulfuric acid (H_2SO_4) and acid rain.

Theoretical model of "typical" coal, from Western Oregon University

As fossil fuels are geologically processed:

both composition and energy density change

	C:H:O	Energy density (MJ/kg)
Dry biomass (or peat)	1 : 1 : 0.4	10-30
Coal	1 : 0.8 : 0.1	20-35
Crude oil	1 : 1 : 0.02	~42
Refined petroleum	1 : 2 : 0	44-47
Natural gas	1 : 4 : 0	50

Oxygen loss: Processing of fossil fuels in Earth drives off oxygen, lowers total energy content … but increases energy density in stuff that remains. (Also drives off water).

Carbon/hydrogen separation: volatiles with lower C:H can separate out (natural gas, petroleum distillation).