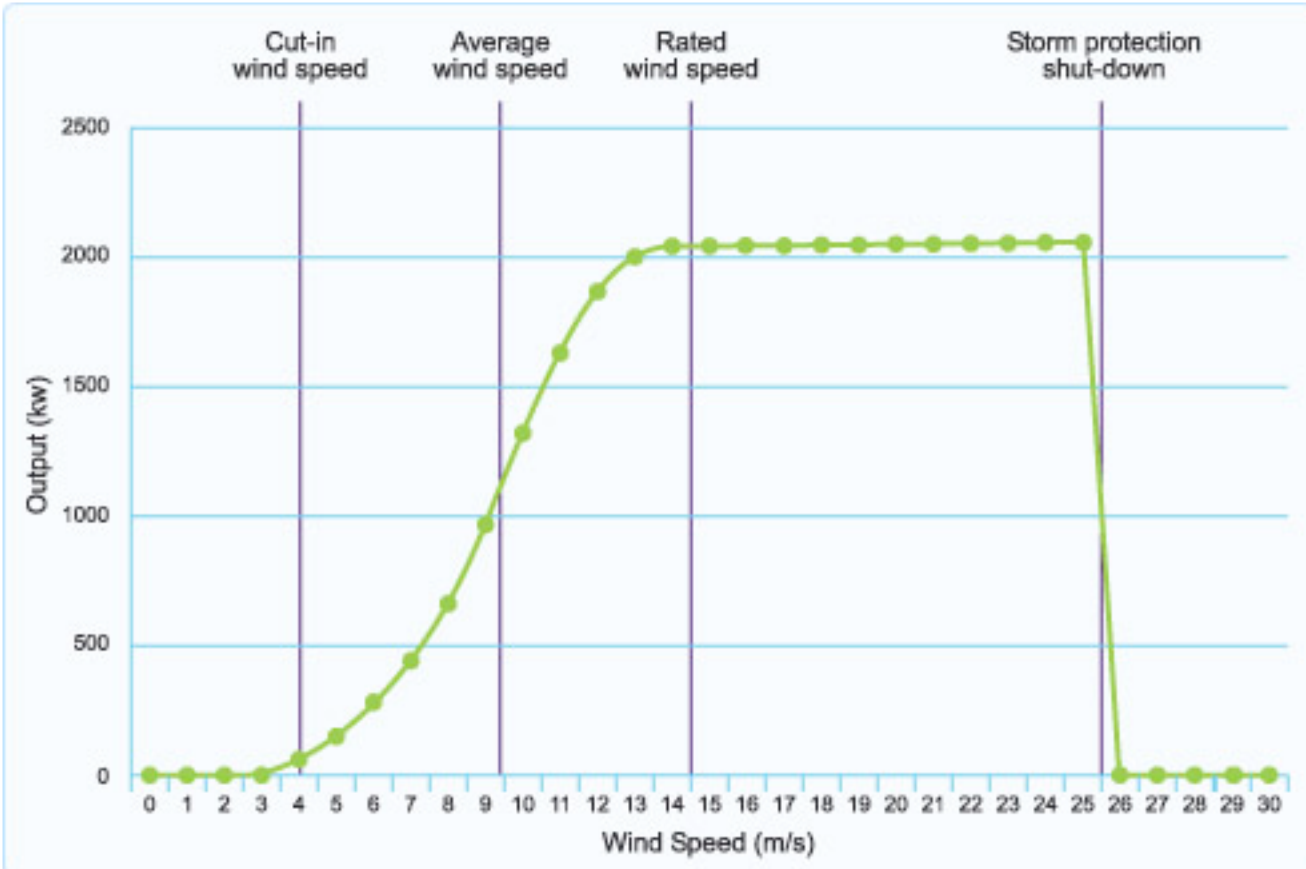
# Turbines IV: Wind
# Transportation & engines
# GEOS 24705/ ENST 24705

# Actual windpower is less than rated power

(and rated power is itself less than power in wind)



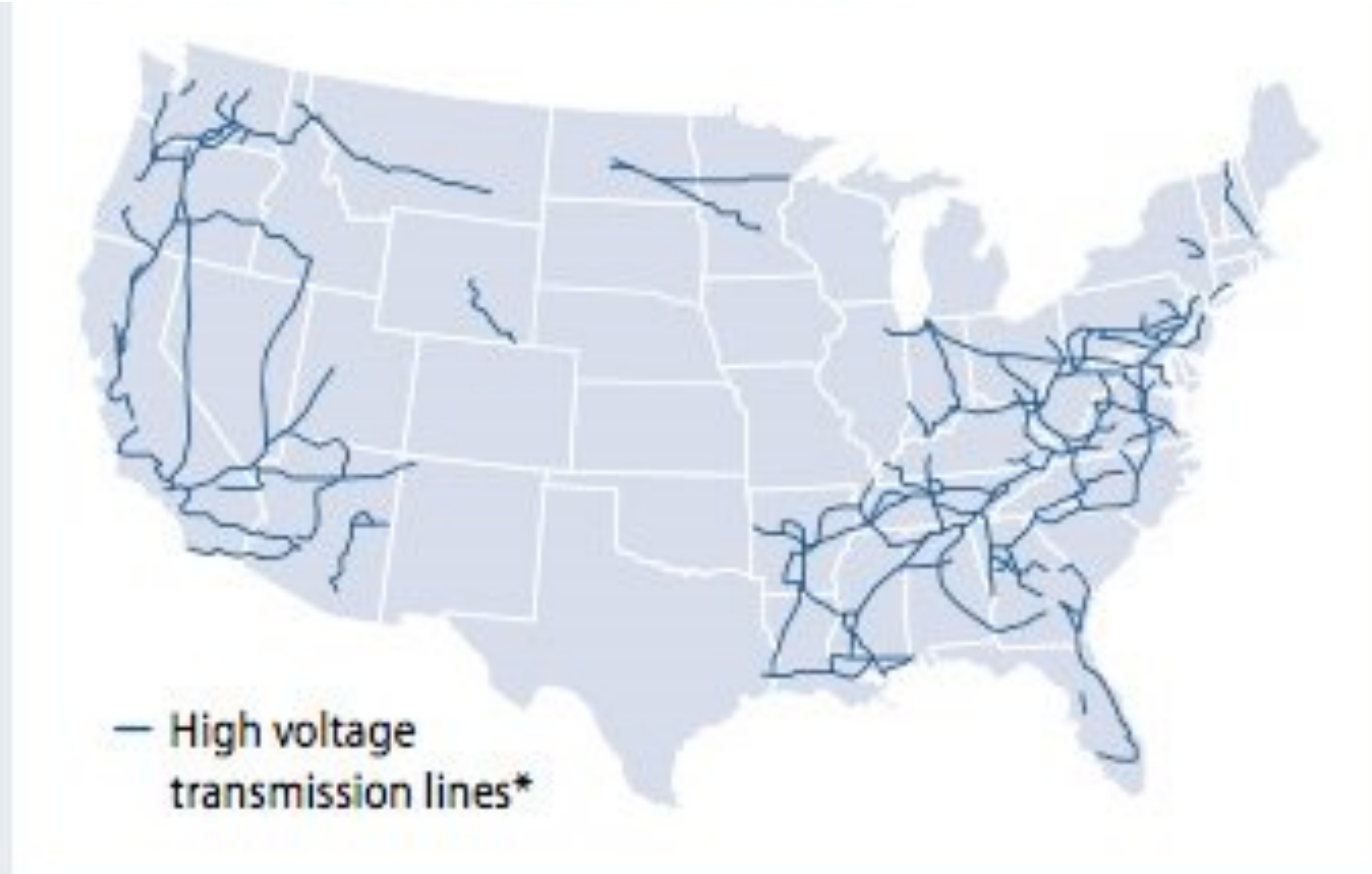

Betz' law: 59%, or ~ 50% in practice recoverable *(this is rated power)*

.... Then capacity factor ~ 30% *(of rated power)*

→Total recoverable from wind kinetic power ~ 15%

*(Image from Partnerships for Renewables)*

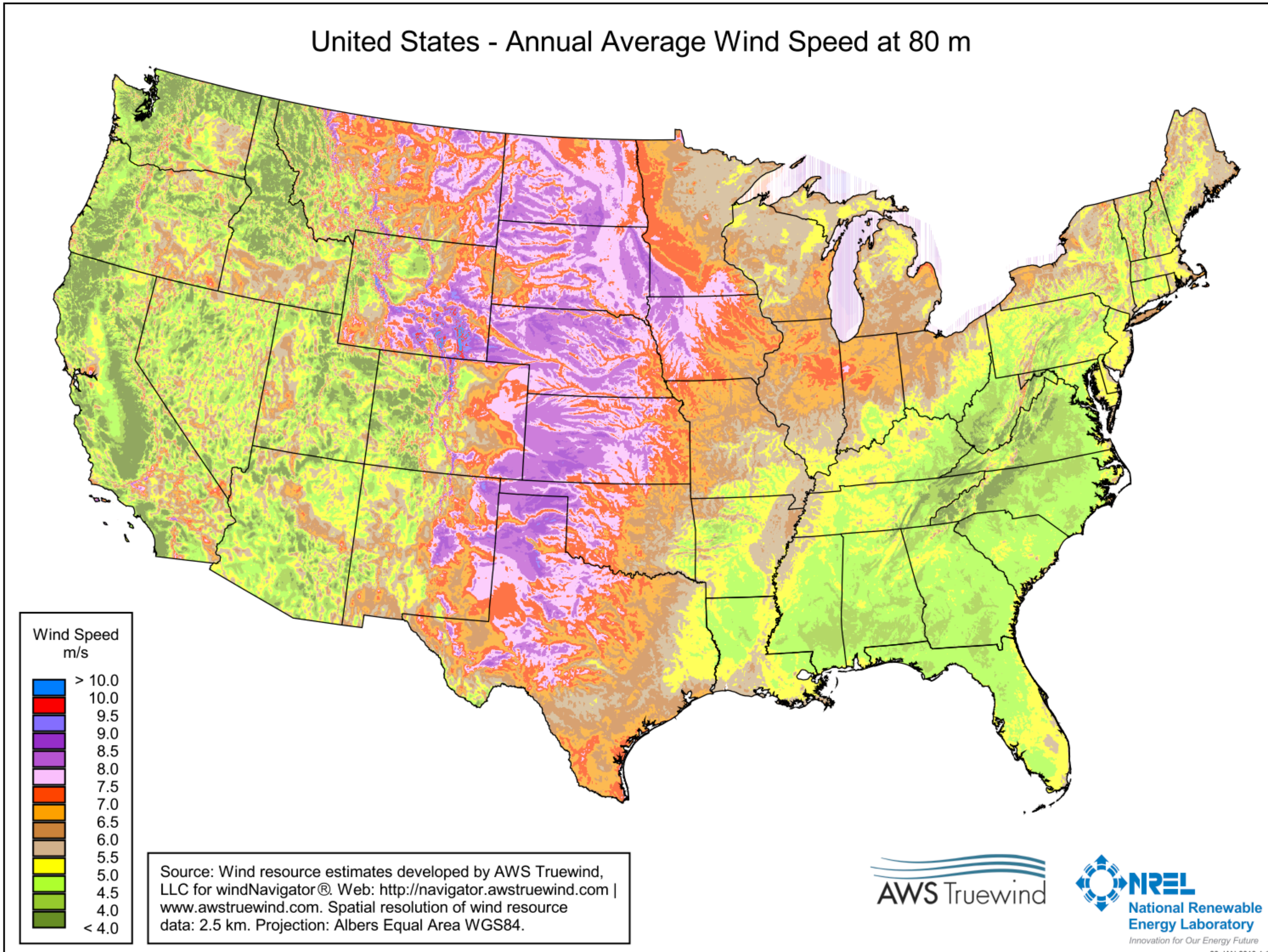
# Electrical transmission is not where wind is




* Depicted lines are 500 kV–999 kV and DC.

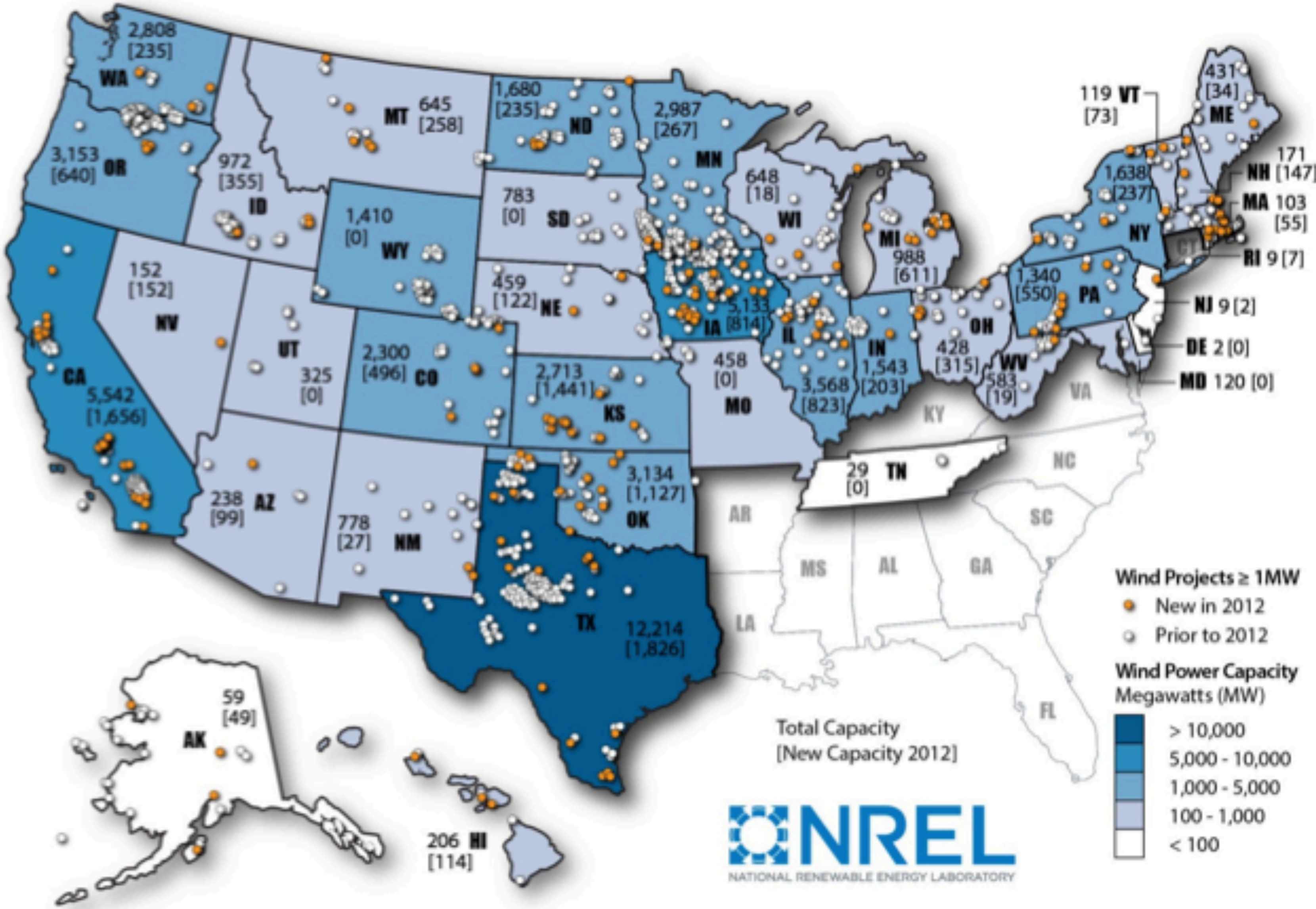
*Source: Platts PowerMap*

# “Wind belt” runs through the middle of the U.S.



# What’s driving wind power growth in U.S.?

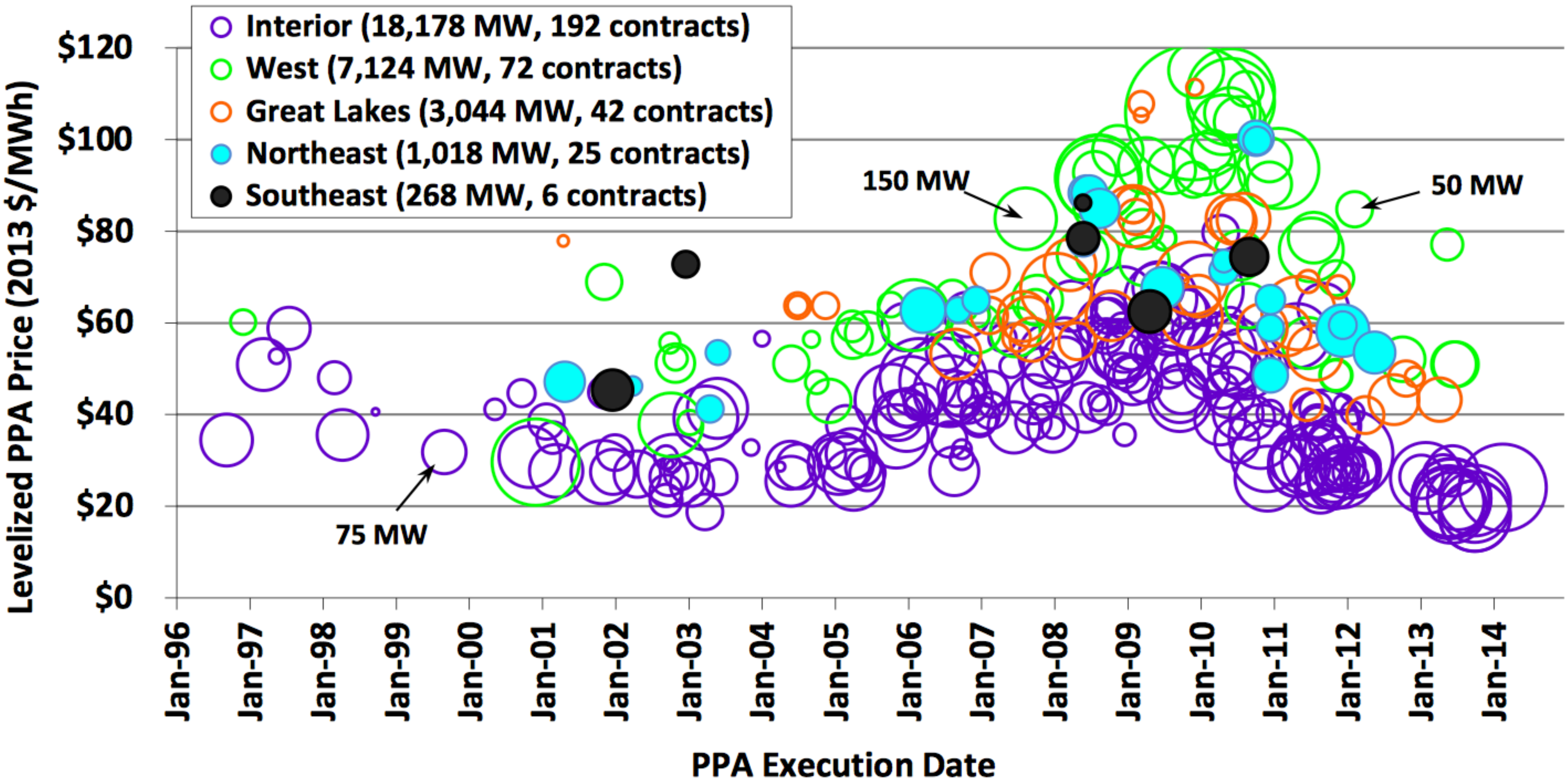
*Wind is biggest installation type, but not always in obvious locations*




Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2012.

# Wind power levelized costs differ by location

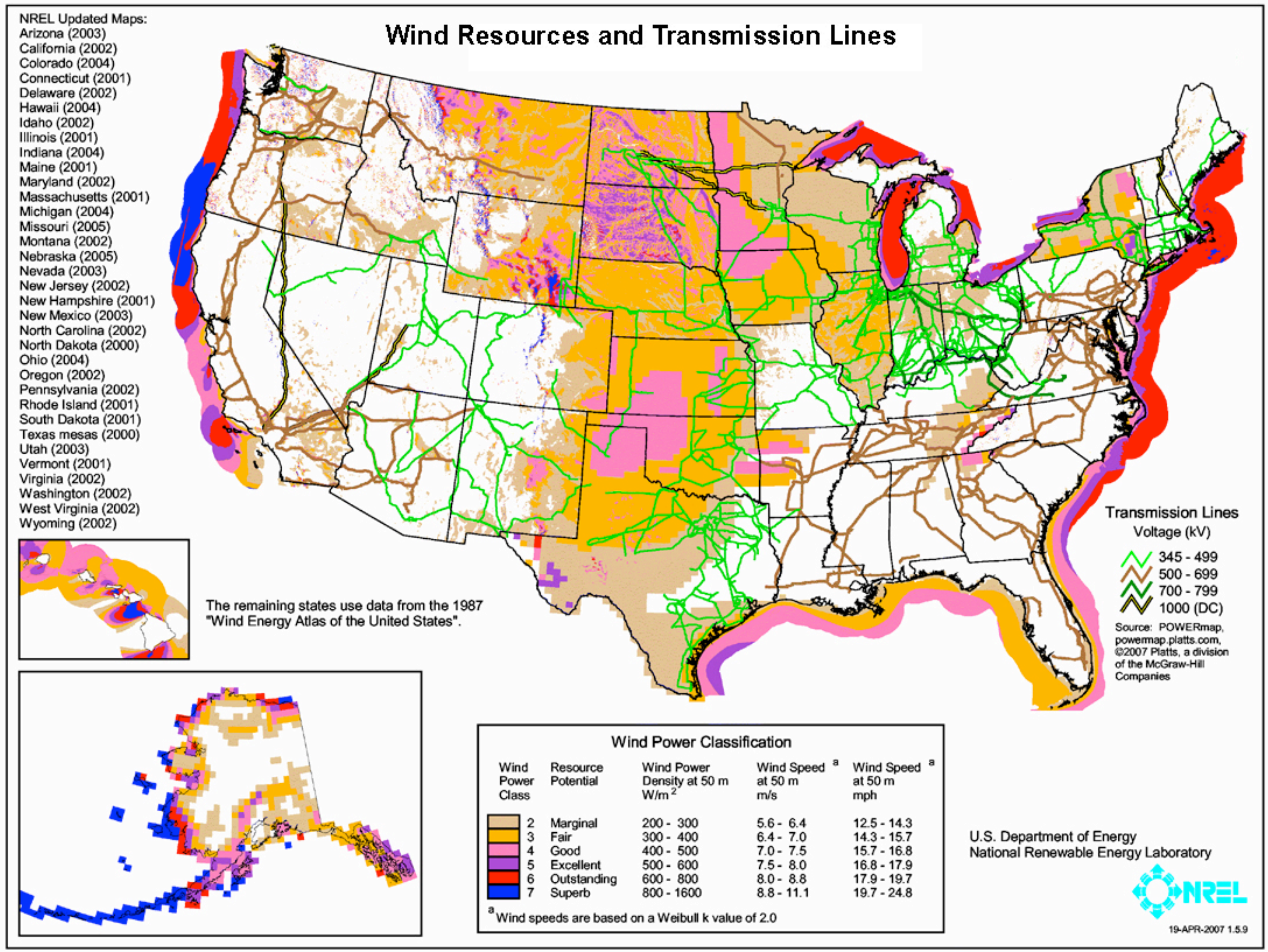
*(Note: these costs include effect of federal subsidies)*



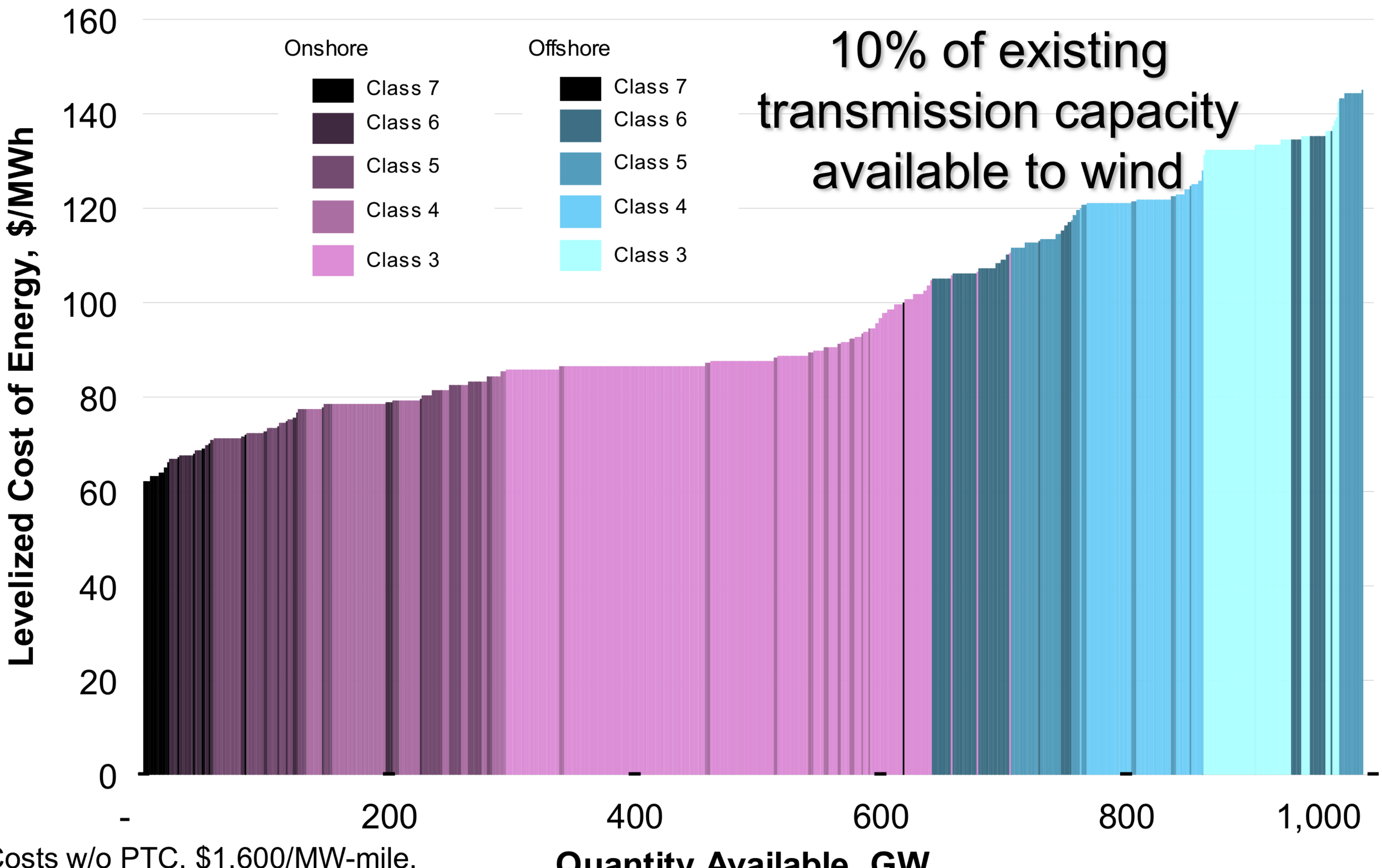

*Note: Size of "bubble" is proportional to project nameplate capacity*

*Source: Berkeley Lab*

# Wind is better offshore than onshore



# Even relatively bad on-shore wind is more cost-effective than almost all offshore wind




2010 Costs w/o PTC, $1,600/MW-mile, w/o Integration costs

*Image: NREL*

# Electrical grid operation: basic questions

- How big is the grid?

Total U.S. network: ~ 300,000 km

Most of this is high-voltage
(> 250,000 km are > 230 kV)

Cost of high-voltage on average $1M/km

***Total value of the transmission part of the grid is of order $300 billion dollars.***

# Electrical grid: Who owns and manages what?

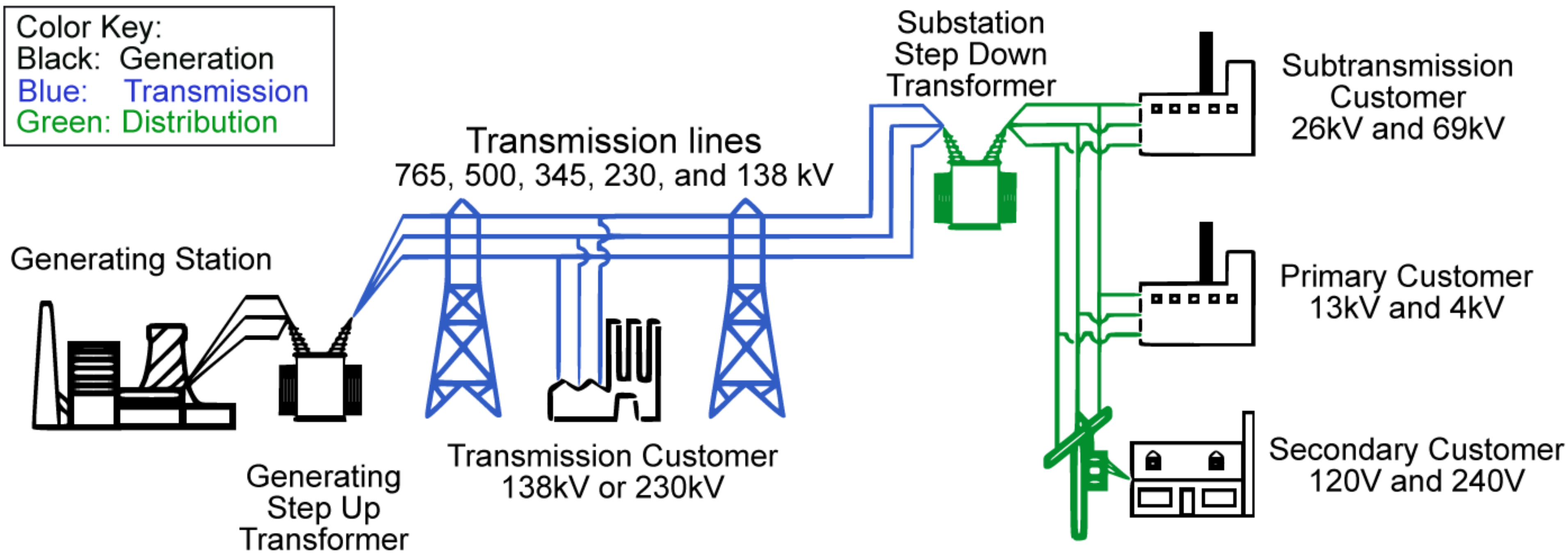



*Image: Wikipedia*

For most of 20th century, one entity owned all components in chain

Now typically owned by 2 or 3 diff. entities, managed by another, and market can be managed by outside broker – up to 5 players in game

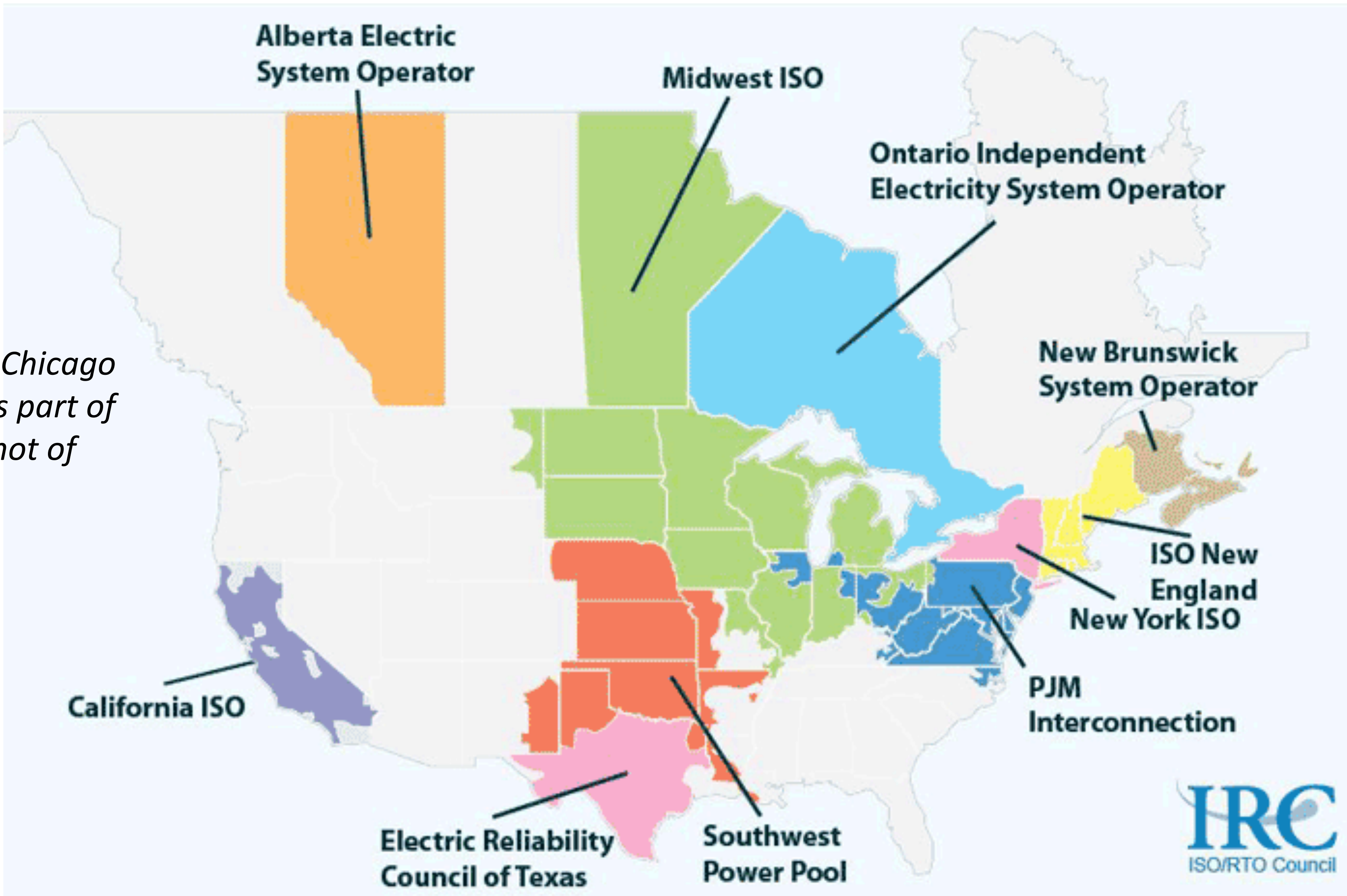
- Generator
- Transmitter (long-dist. wires)
- Grid operator (wires operator)
- Utility for distribution (local wires)
- Load-serving entity (seller to consumer)

# Electrical grid organization and management: basic questions

- Who owns what? (generation, transmission, distribution)

*RTOs as of 2010 (ISO/RTO Council)*

*Note: Chicago area is part of PJM, not of MISO*



# Electrical grid organization and management: basic questions

- Who sets the amounts that people pay?

***In the old days***

The utilities owned everything, and would charge customers enough to recover their costs. The state utilities commission would approve the rates.

***Nowadays***

**Generator price set by the day-ahead market:** Sets the hour by hour price that generators receive for power or for capacity.

**Wholesale price set by market and by FERC:** Sets the markup that the RTO can charge over market. Sets the transmission rates.

**Retail price set by state utilities commissions:** Determines the rates that the utilities can charge their customers. Flat rates – no hourly changes.

# Usefulness of electricity market driven by
# 1) diurnal demand curve

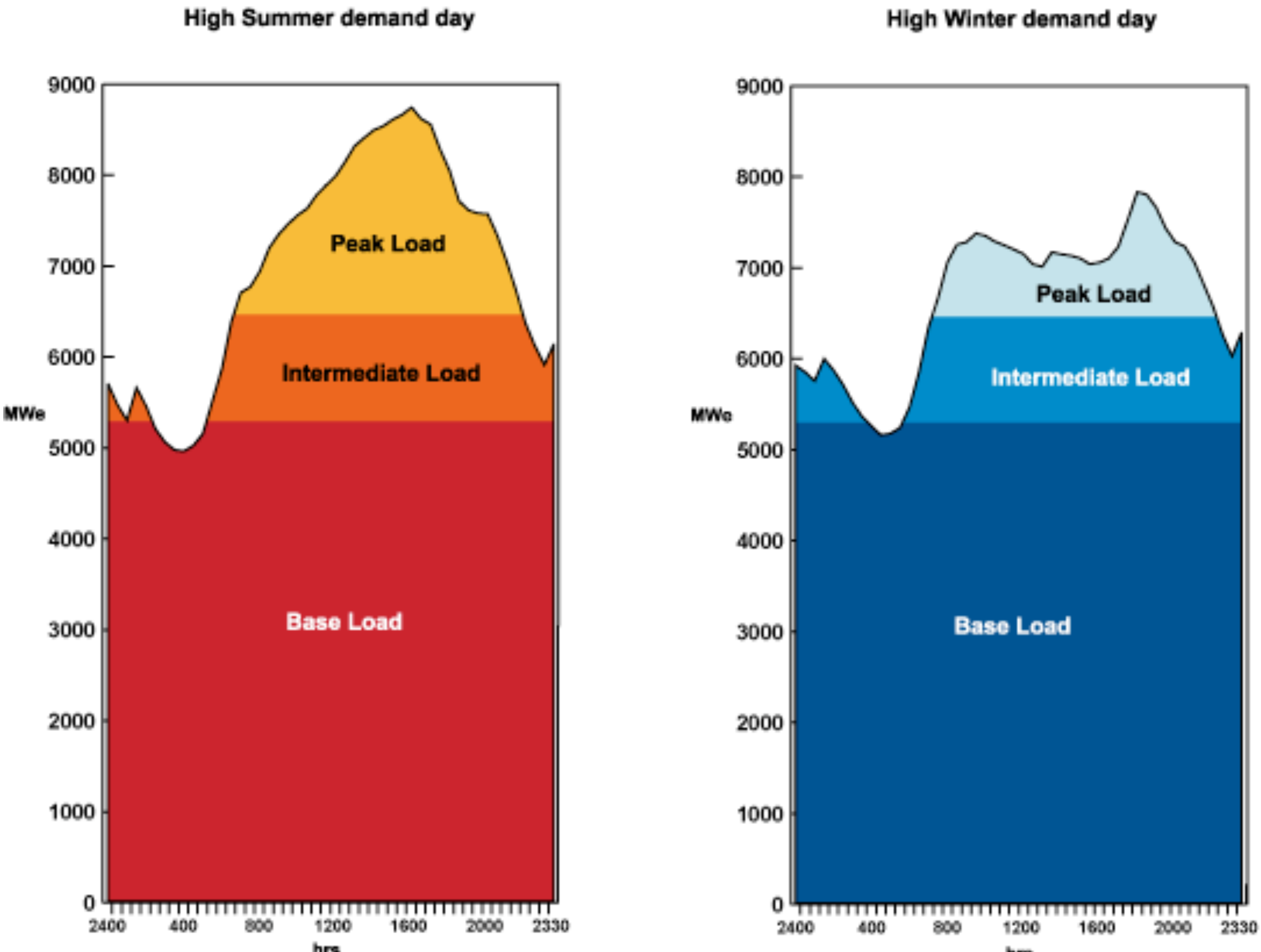
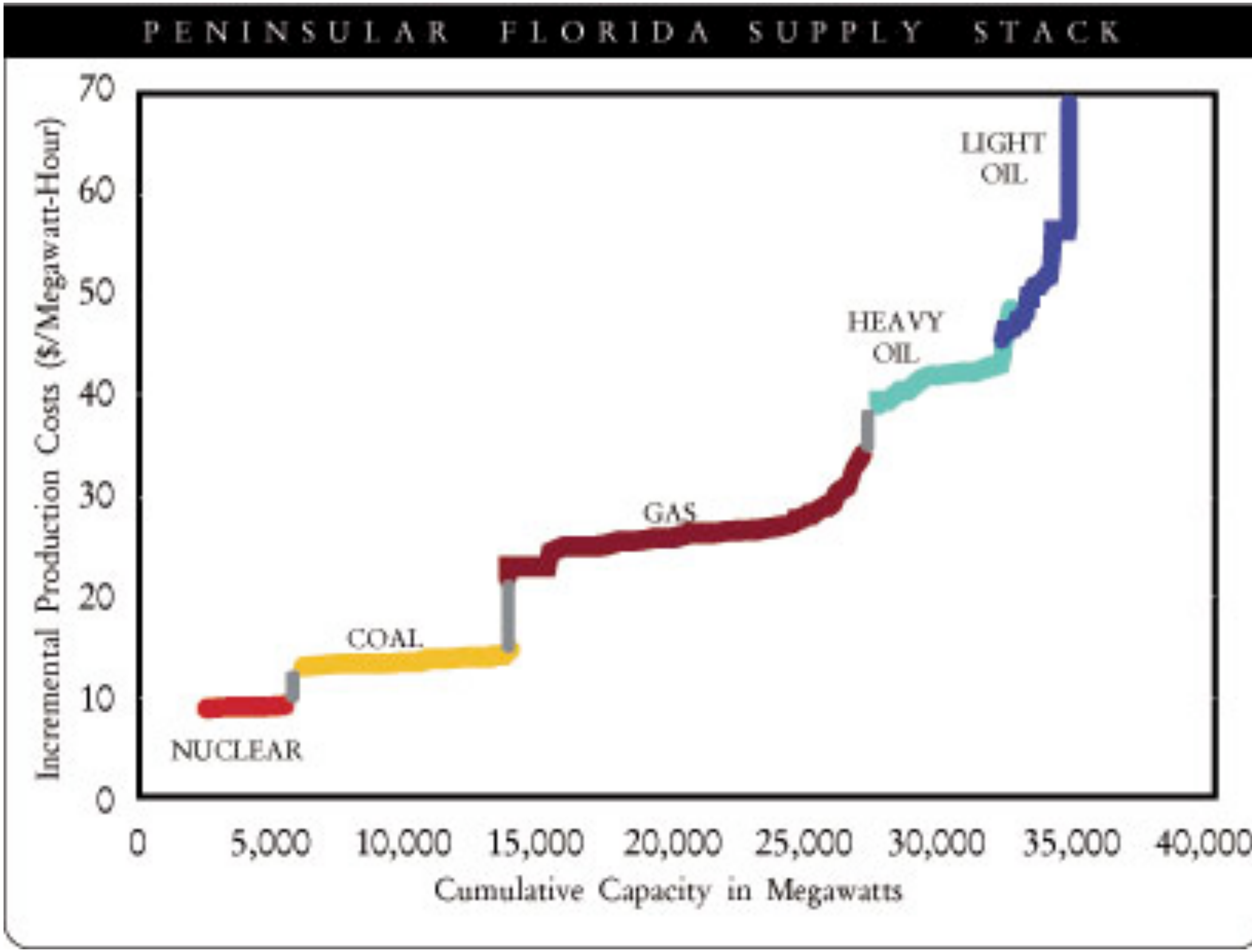



*Image: World Nuclear Org.*

# Usefulness of electricity market driven by
# 2) different operating cost for different generation technologies

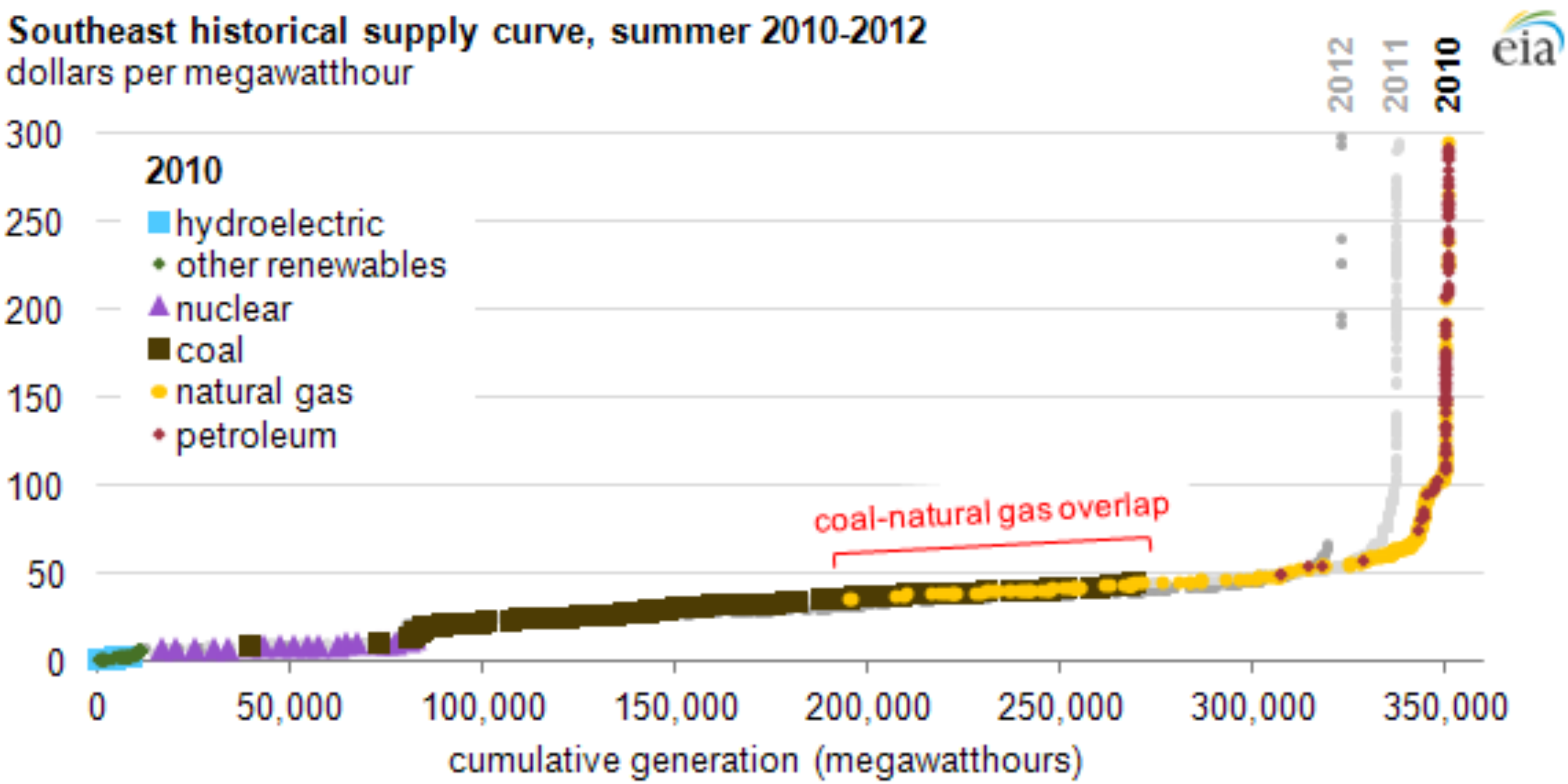
Market clearing means that everyone receives the price bid by the last (most expensive) generator whose bid is accepted. (Hourly bids).

Nuclear will bid zero because it wants to be on always and its operating costs are tiny. Oil is expensive so will bid high – will only turn on if price > operating costs.




Pre-fracking-era supply stack: coal cheaper than gas

# But, supply stack is changing dramatically




- What happens when gas becomes cheaper than non-dispatchable coal?
- When coal plants shut down?
- If bring on must-take no-marginal cost wind?

# Old system: expensive peakers on only during max load

Baseload power stays on all the time. High-marginal-cost power is purchased only during times of day when demand is highest.

*But how to manage now if marginal generation is coal, not easily dispatchable?*

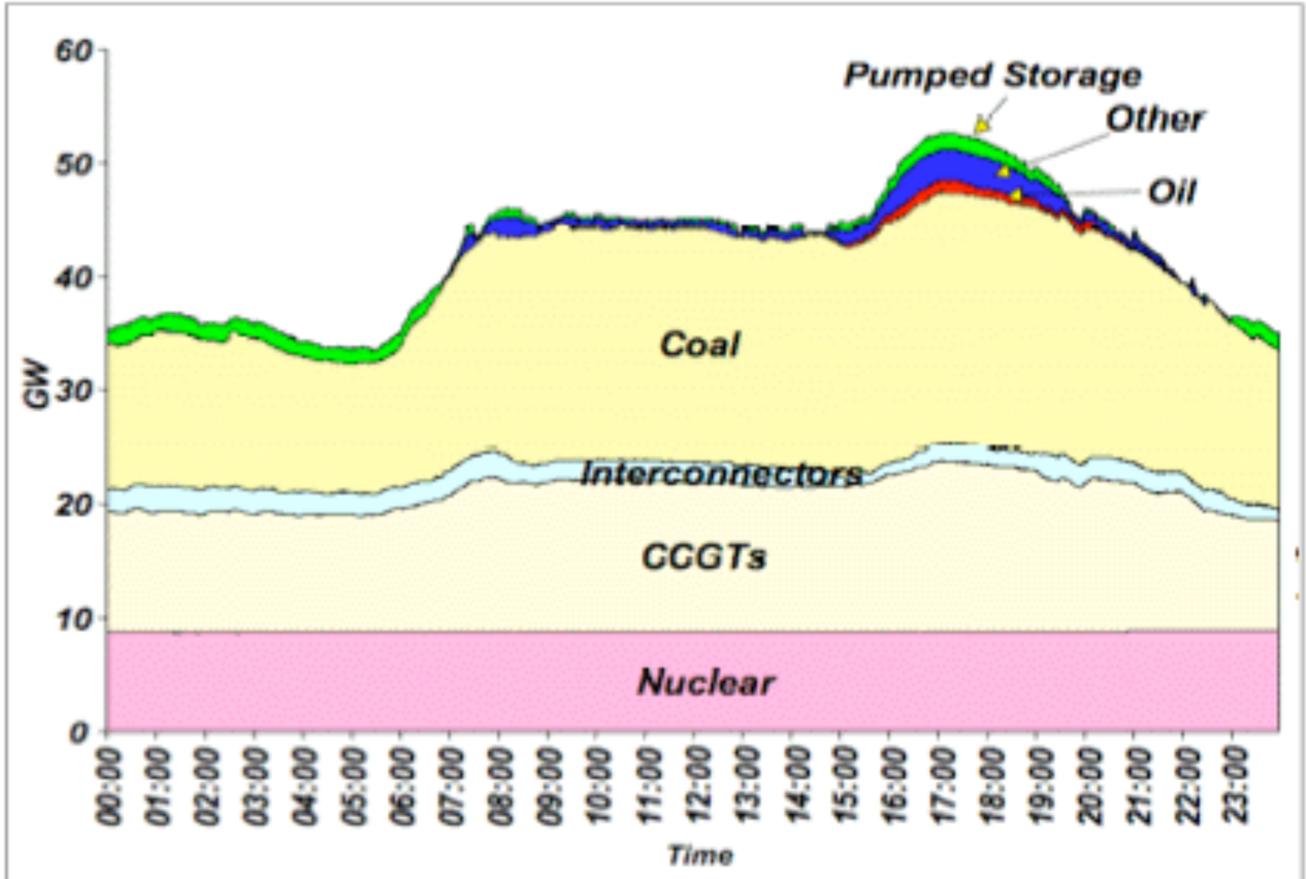



**Figure 11: Generation source for a typical daily demand profile.** ***Courtesy of NGC 2007***

**(CCGT: Combined Cycle Gas Turbines).**

*(figure from the U.K.?)*

# Electricity strategies driven by the diurnal cycle

**Peakers:** buy high cost but fast turn-on generation that can come on just for the peak energy demand period. (*Big complications now that relative costs are flipped.)*

**Peak-shaving:** buy electricity when it's cheap and store it, then sell it back to the grid when it's expensive

**Demand-side management:** sign contracts with customers forcing them to turn off if demand is too high

**Demand-side management:** introduce time-variable pricing for customers to incentivize less use at peak periods, more off-peak

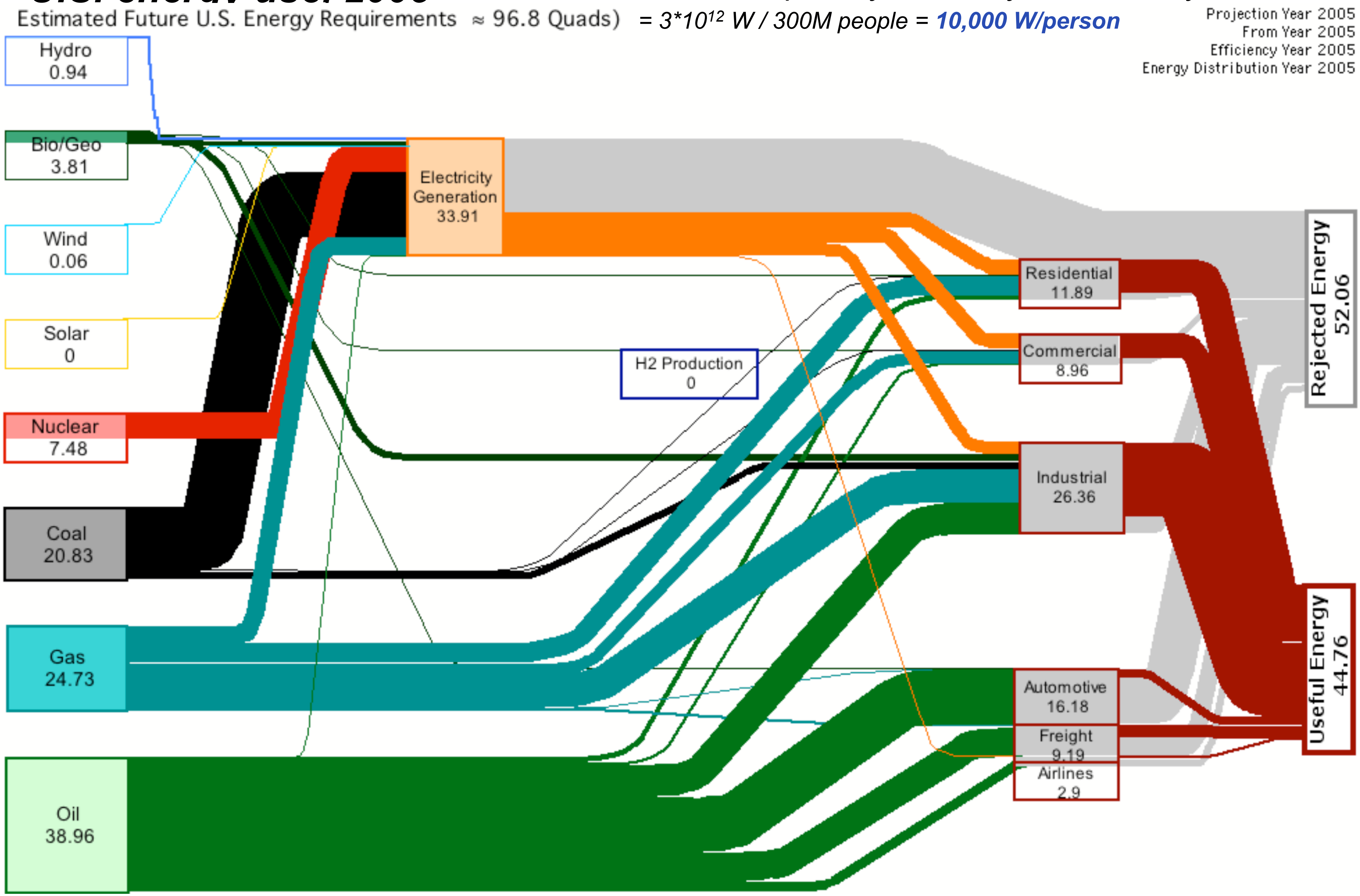
**Load-dumping:** since baseload power can't turn off, sometimes just have to dump it if have too much

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

***U.S. energy use, 2005***

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

*= 3*$10^{12}$ W / 300M people =* ***10,000 W/person***



# 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*

**Transportation:** early attempts with steam

Nicolas Cugnot, steam-powered automobile

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

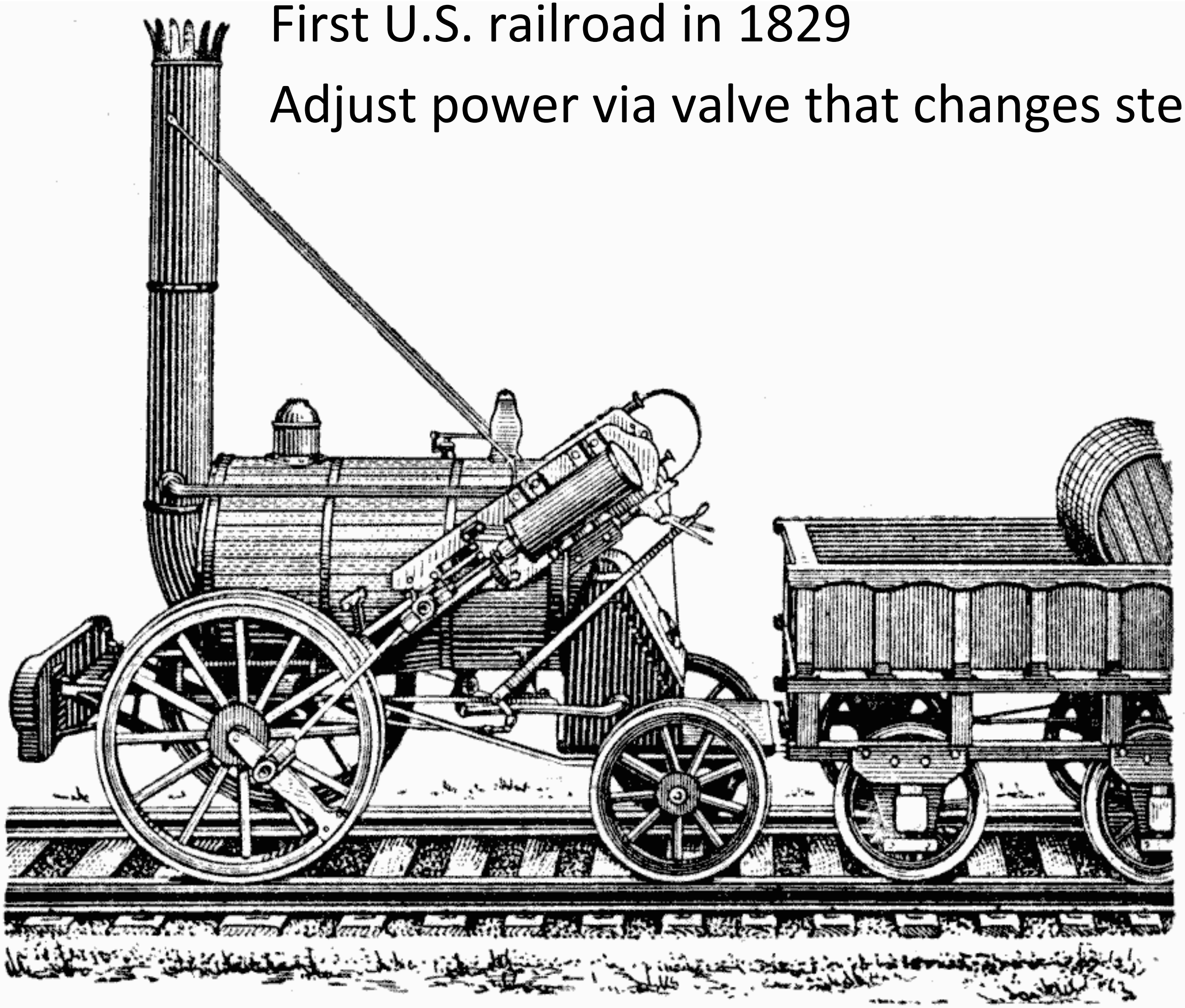
First car accident (1771) *(First fatal accident 1869, also steam)*

**19th century:** steam used mainly 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..

**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

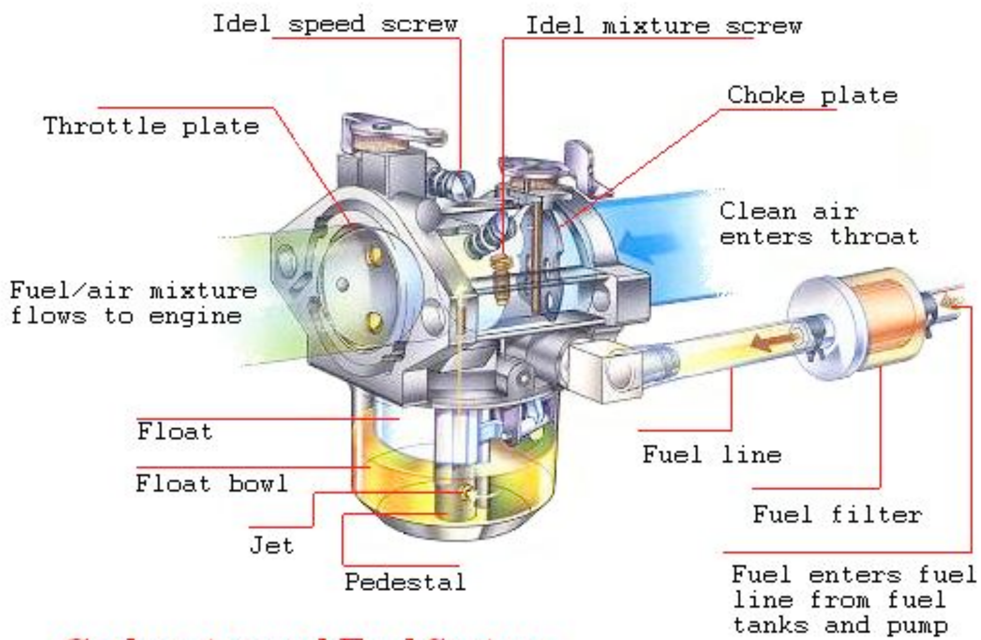
# Obstacles to liquid fuel

- 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.”

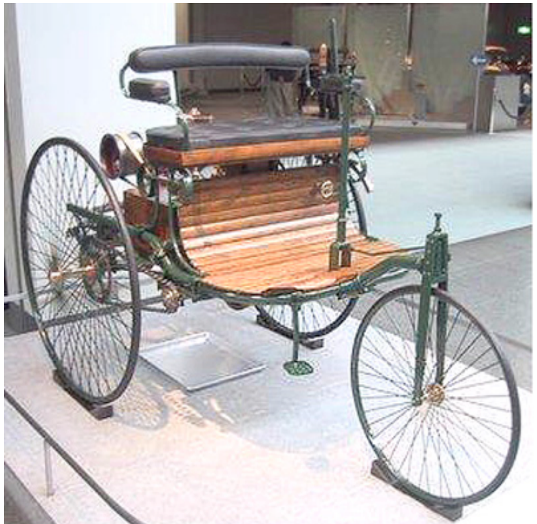
# Internal combustion engine history:
## development in German-speaking countries

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.

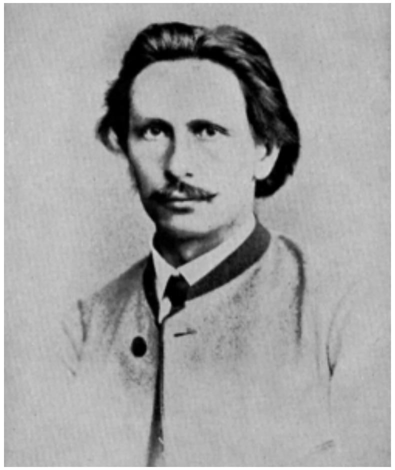
1885: Karl Benz builds 3-wheeled automobile with 4-stroke engine, 2/3 hp
*patent 1886. also patents: spark ignition, sparkplug, carburetor, clutch, gear shift, radiator*

*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!" '

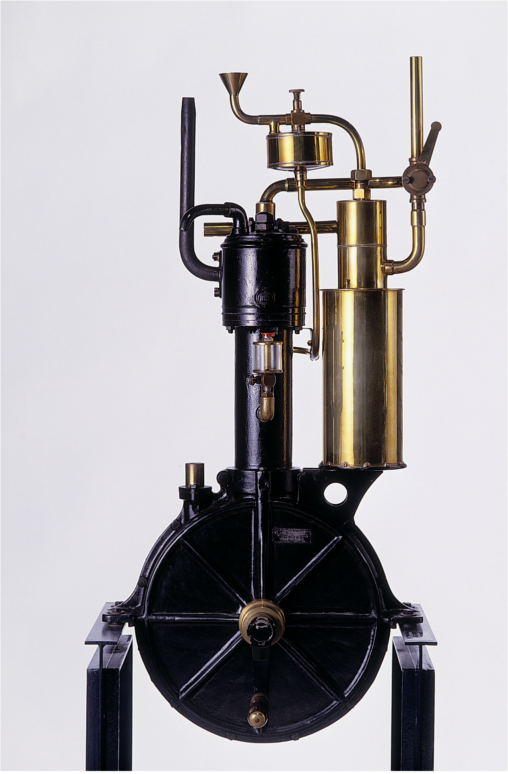
----- *Jason Torchinsky, Jalopnik*

*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.*

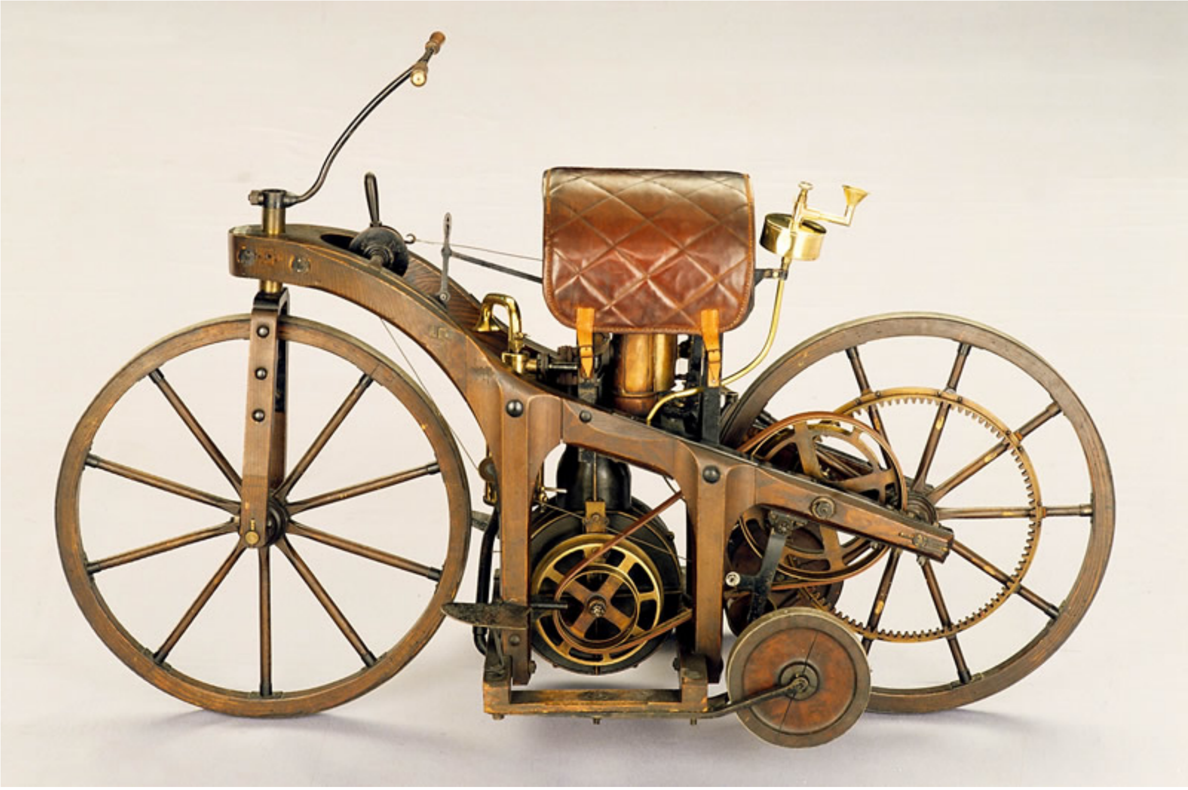
**Internal combustion engine history:**
multiple developments in German-speaking countries

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)*



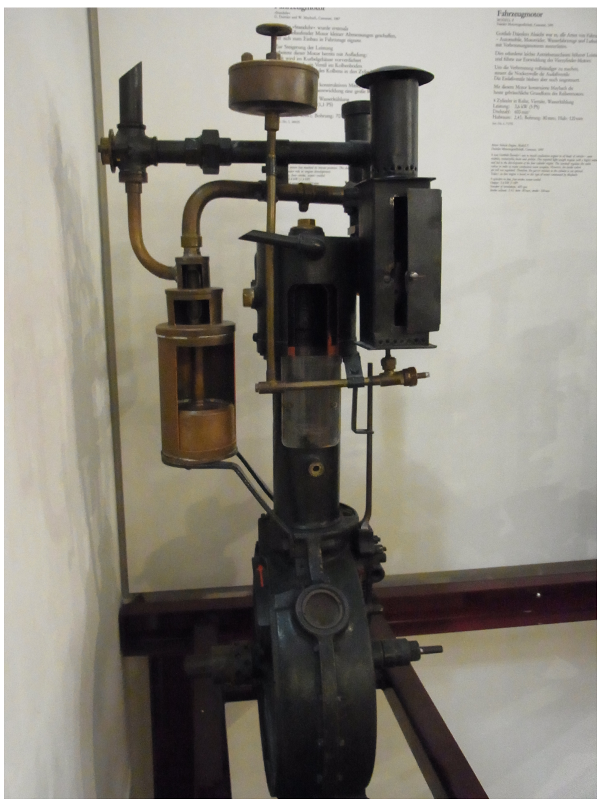
# Internal combustion engine history:

## multiple developments in German-speaking countries

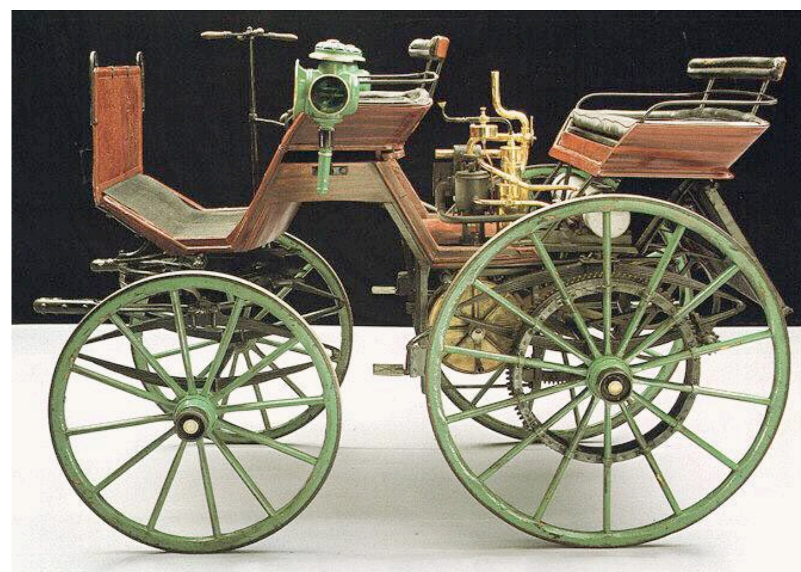
1885: Daimler & Maybach develop advanced 4-stroke engine, attach it to motorcycle

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*

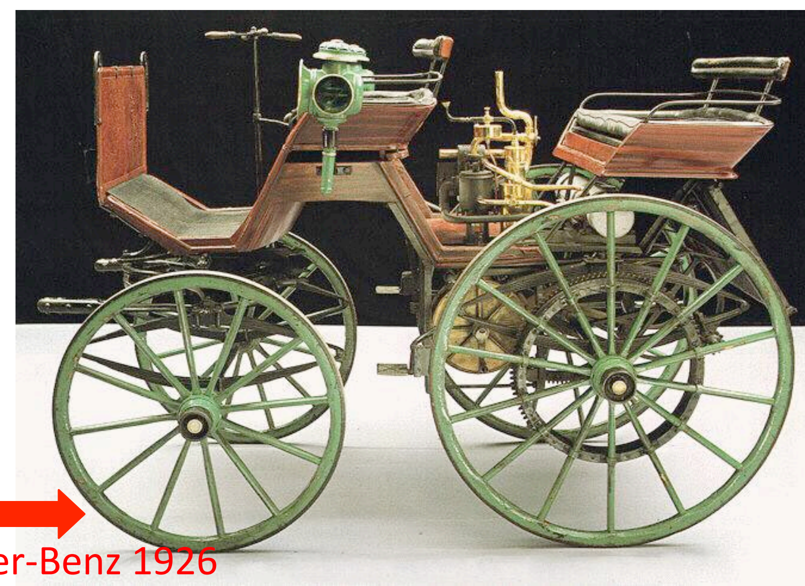
1885: Daimler & Maybach develop advanced 4-stroke engine, attach it to motorcycle

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

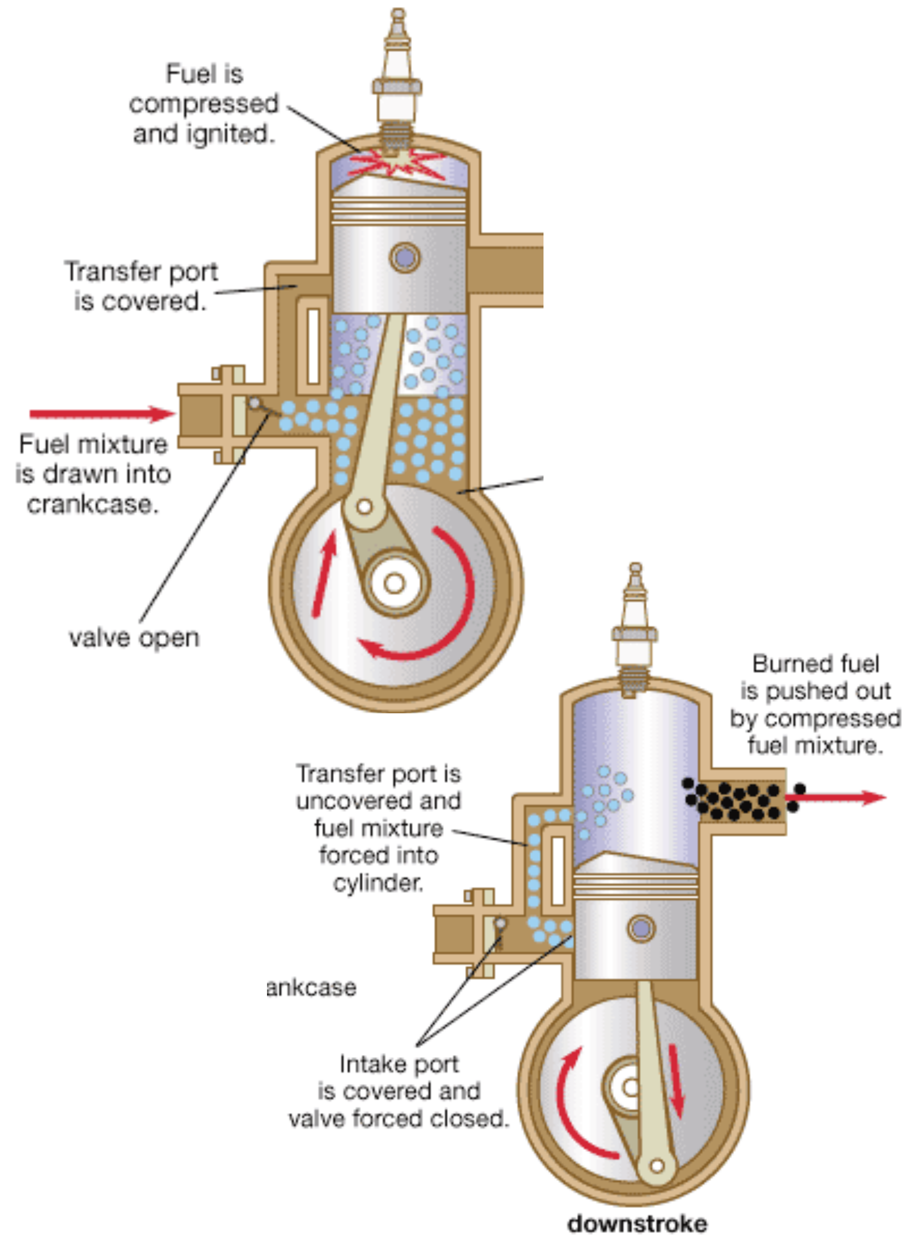
**Second stroke:**

Fuel/air is ignited

Piston driven down

Exhaust gas leaves cylinder

Fuel/air mixture enters cylinder

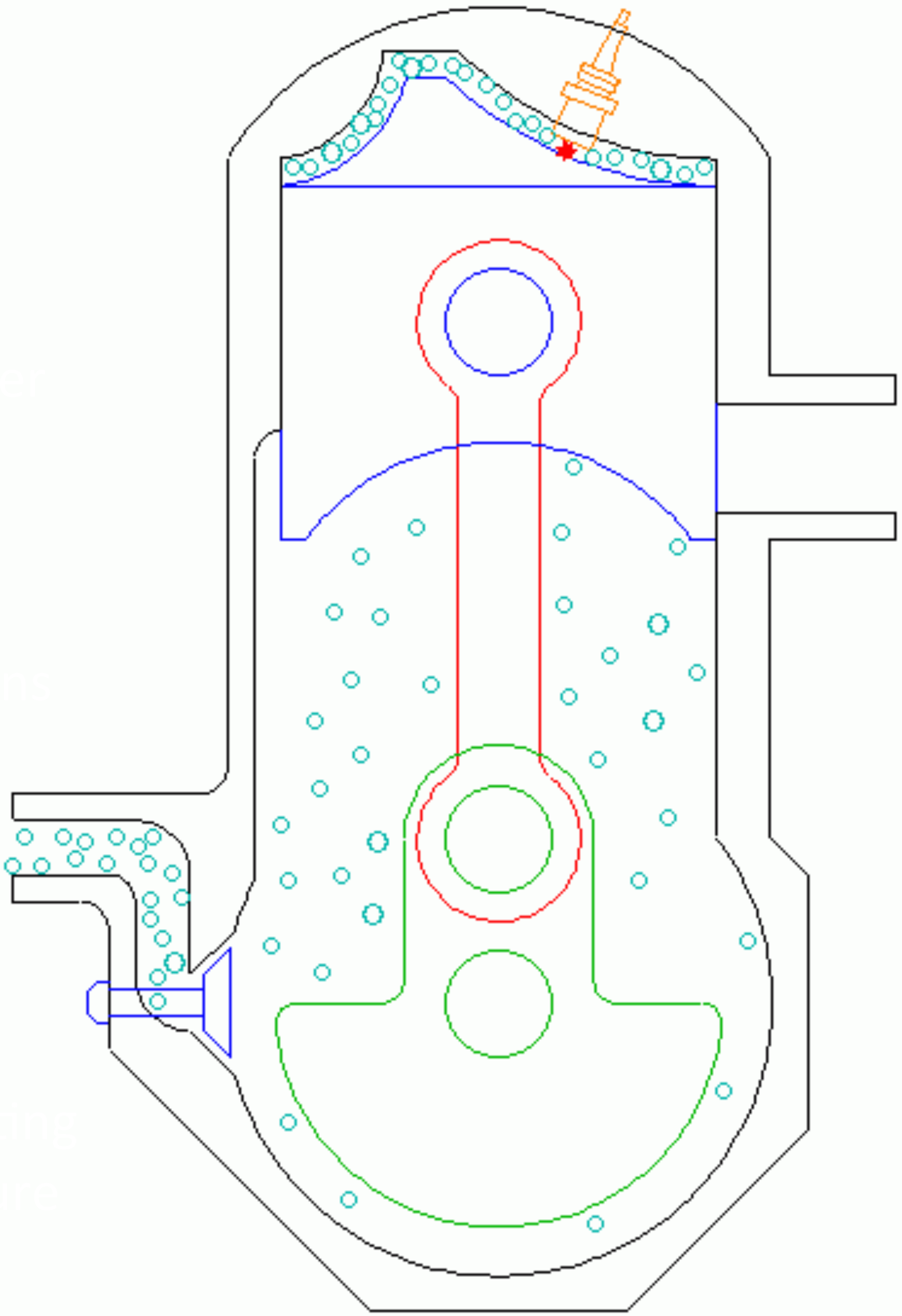


# Two-stroke engine

Simple, cheap

**Advantages:**

**Disadvantages:**



# Two-stroke engine

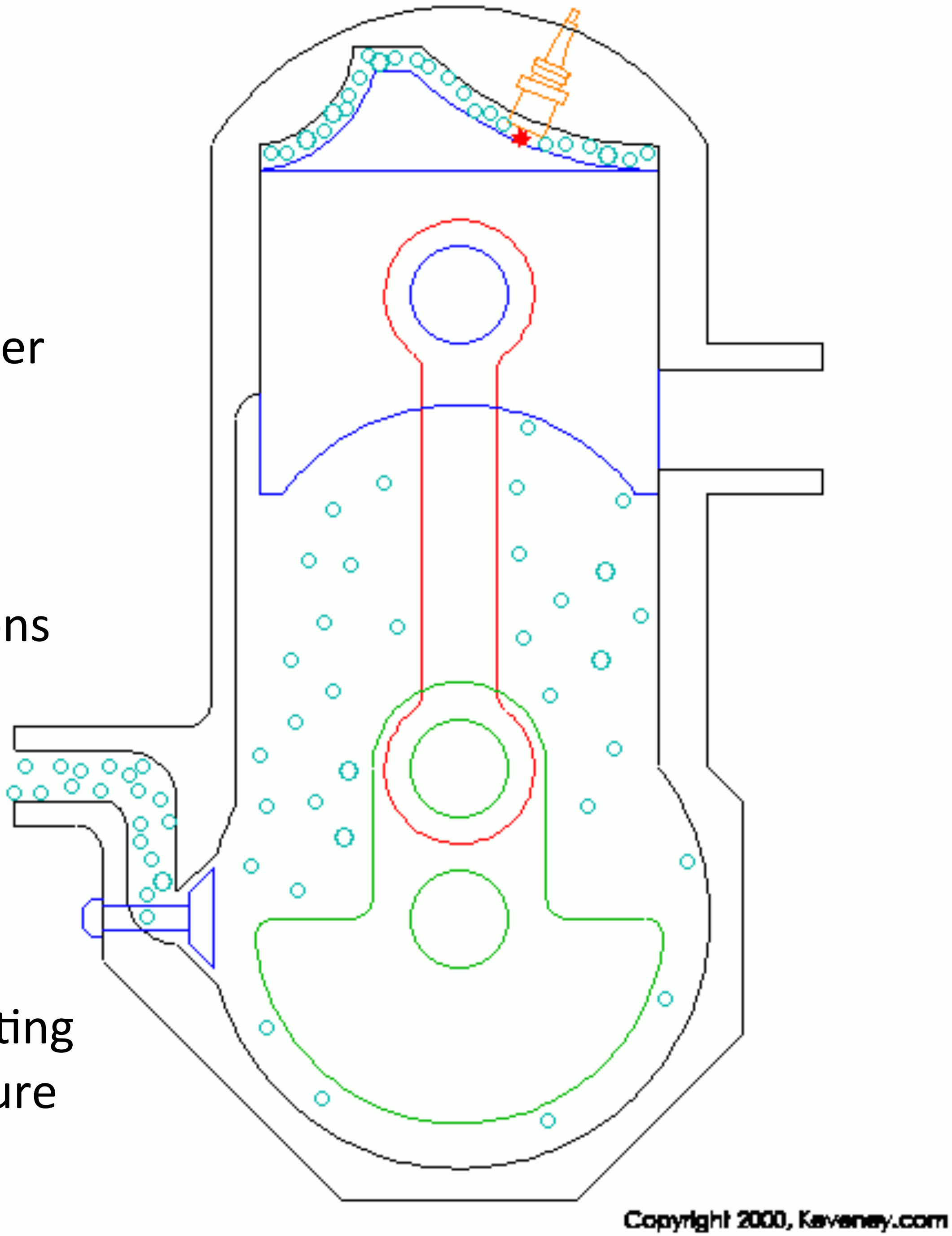
## Simple, cheap

**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*

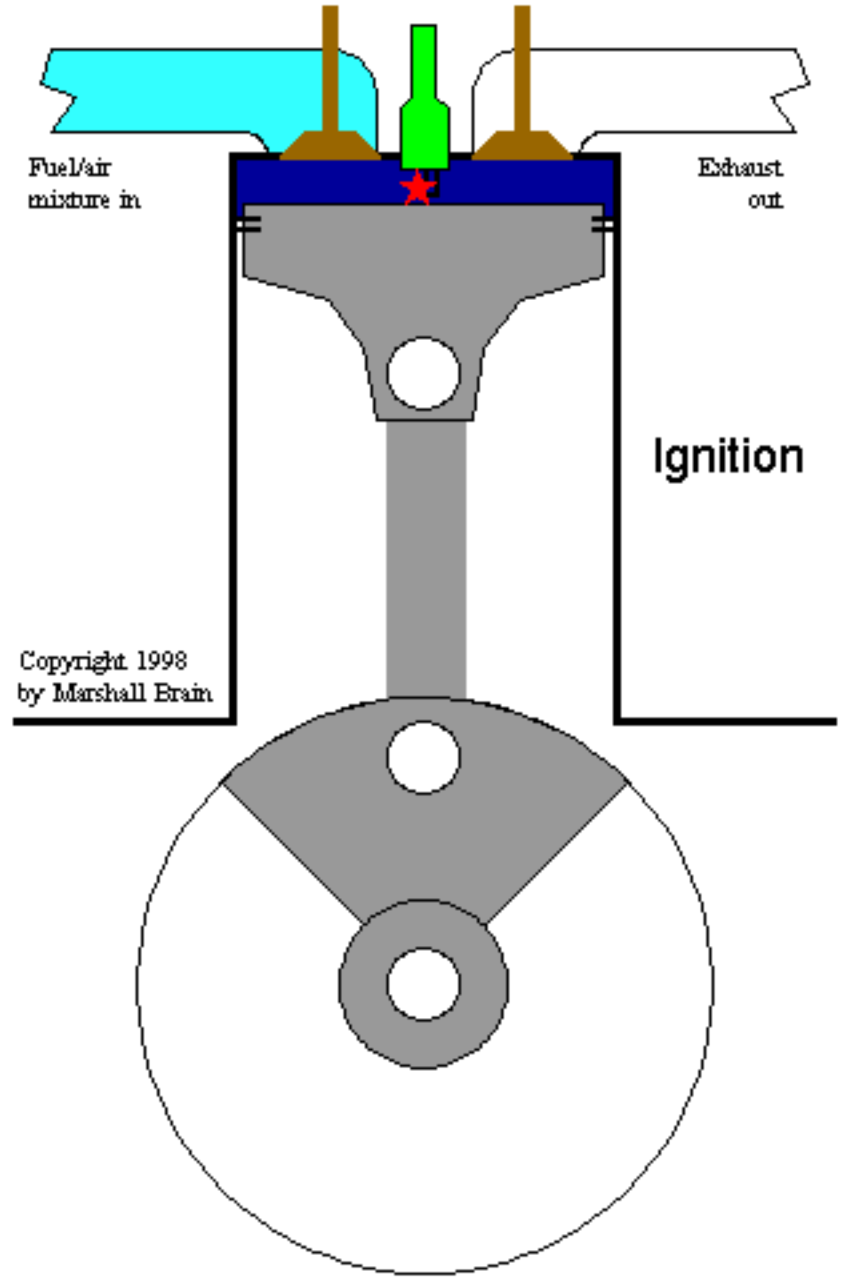


**Four-stroke engine:** Otto cycle
driver of most transportation

**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