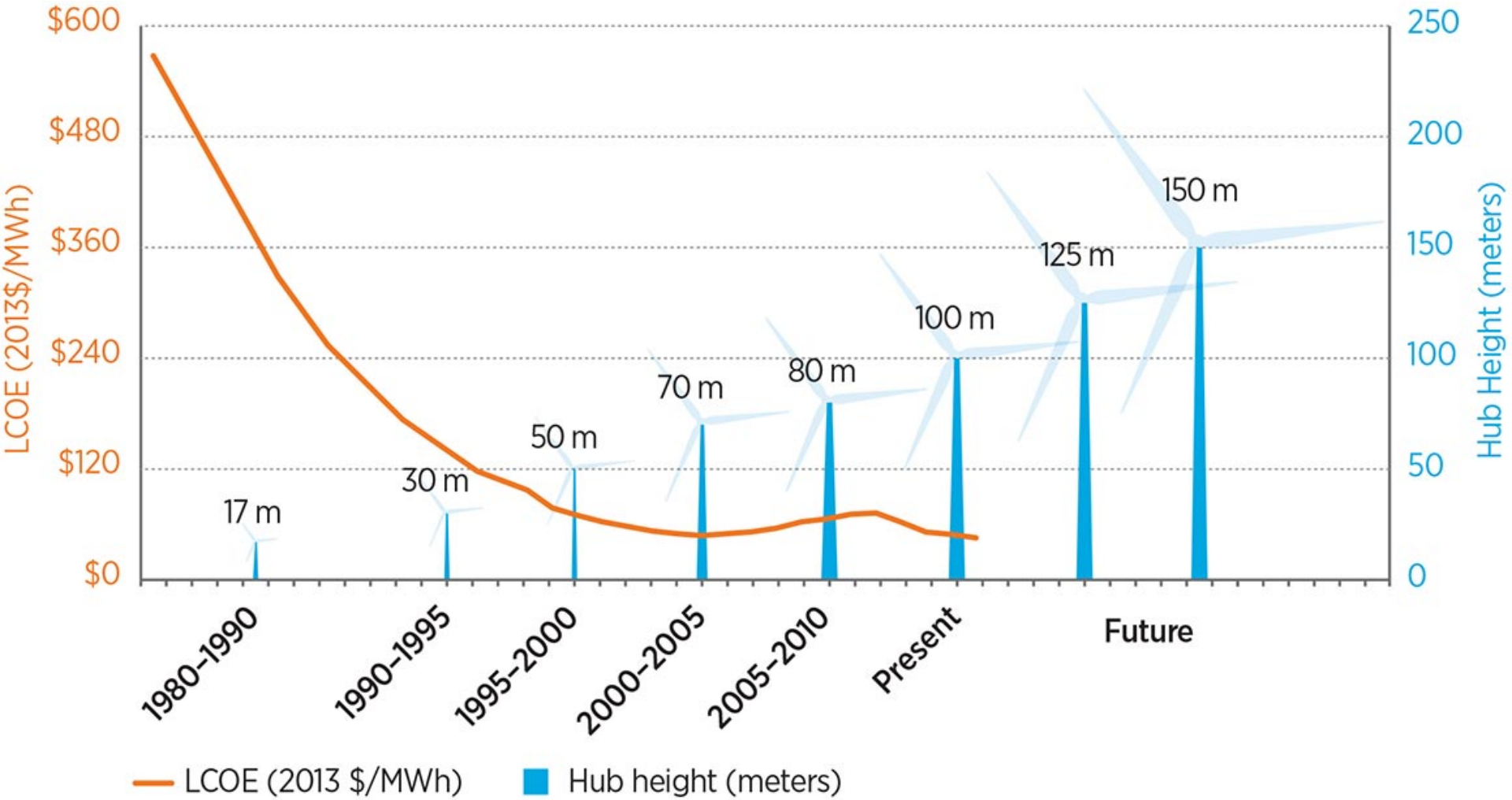
GEOS 24705 / ENST 24705 / ENSC 21100

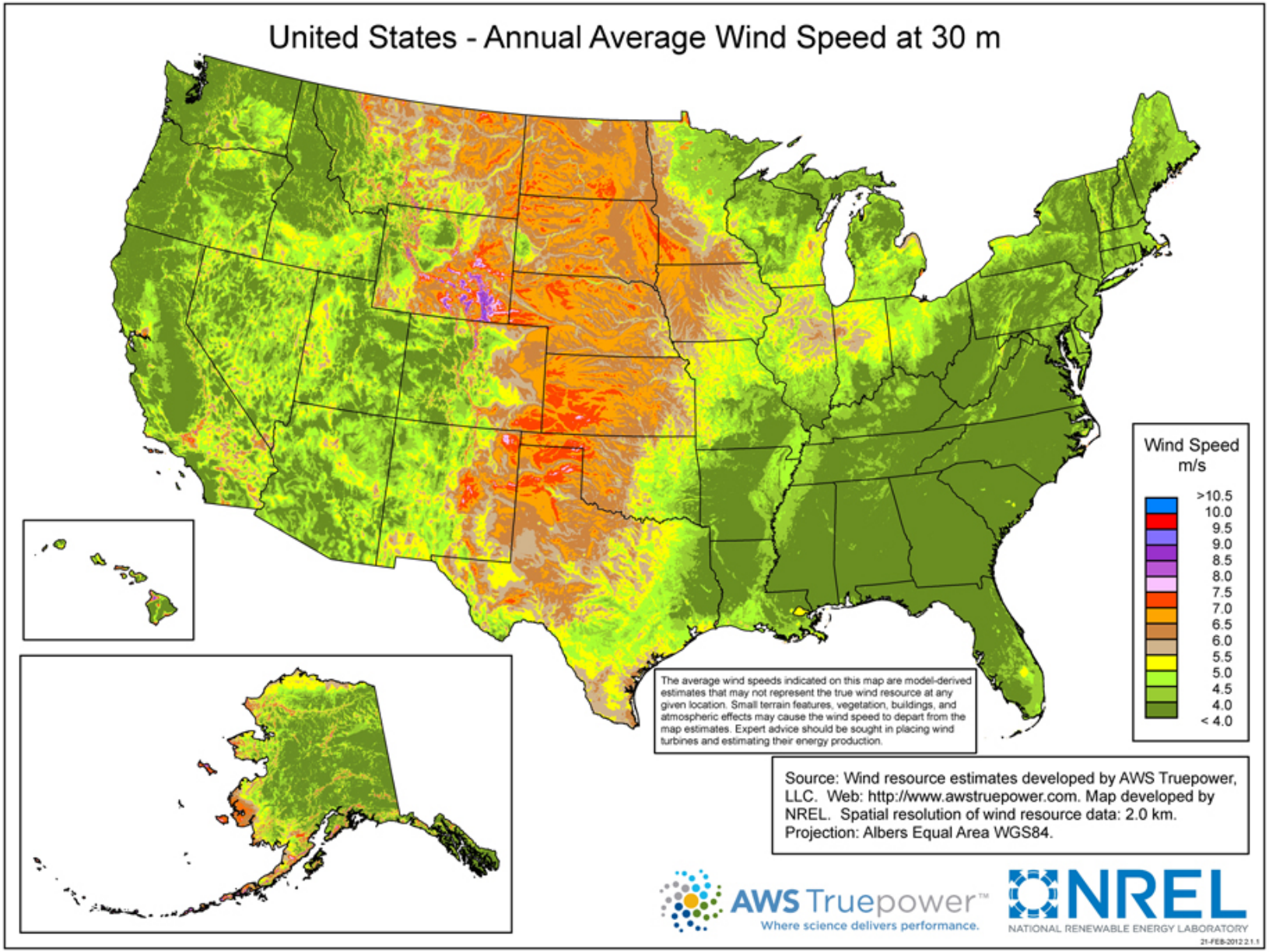
Lecture 16

End of wind, transportation & engines

Wind is increasing now because prices are competitive



Stronger wind allows more revenue per capital & O&M cost



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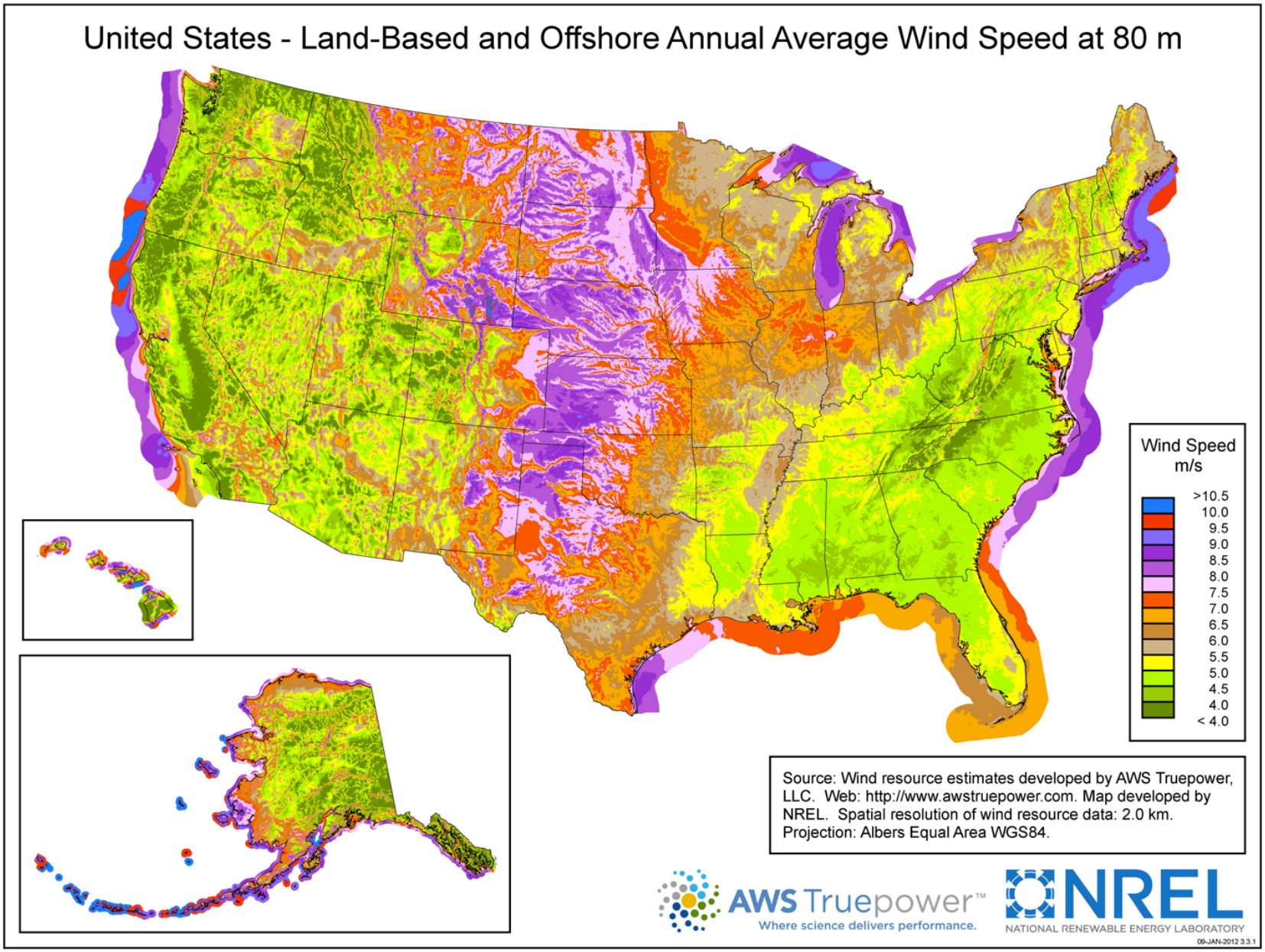
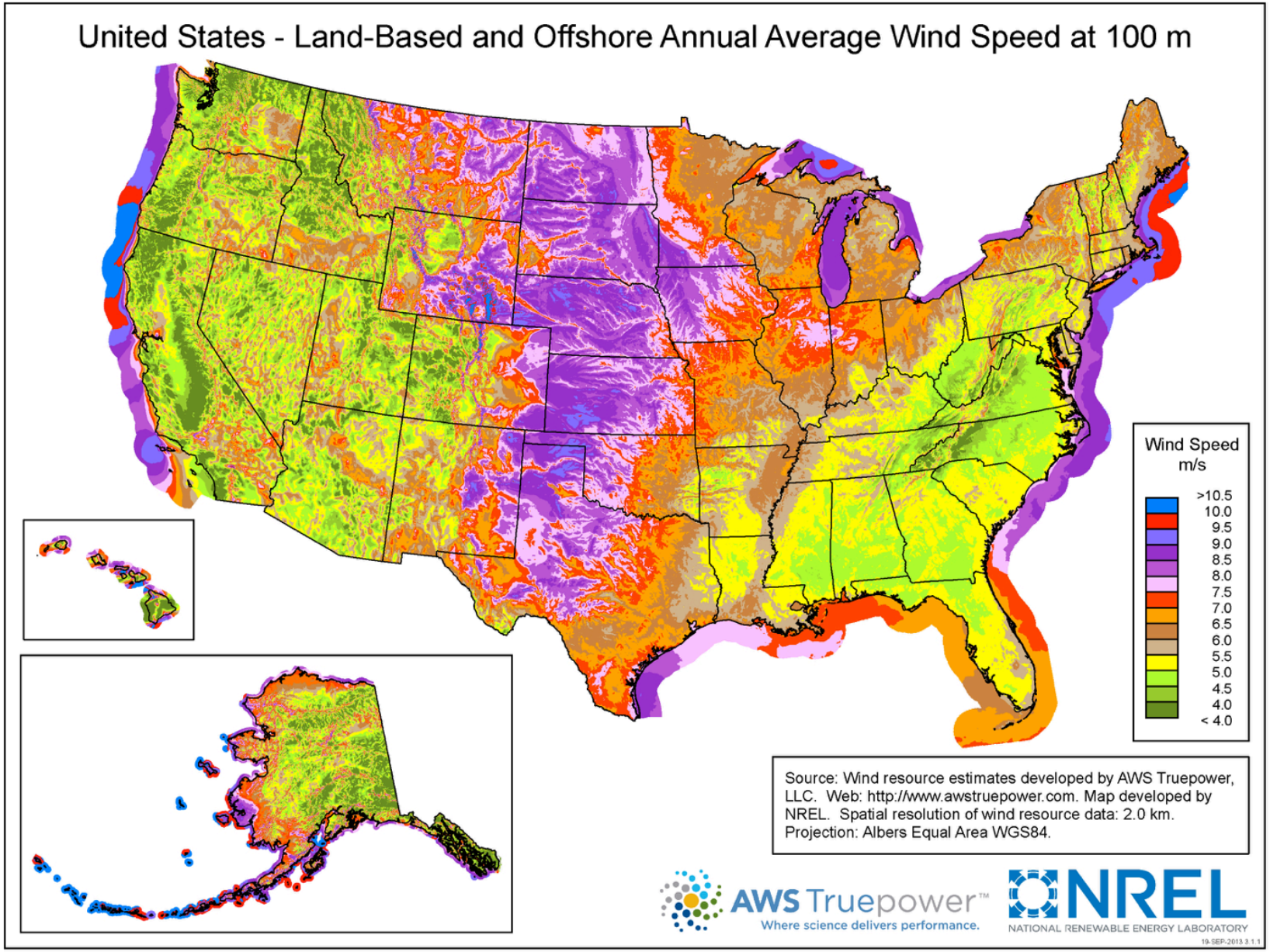


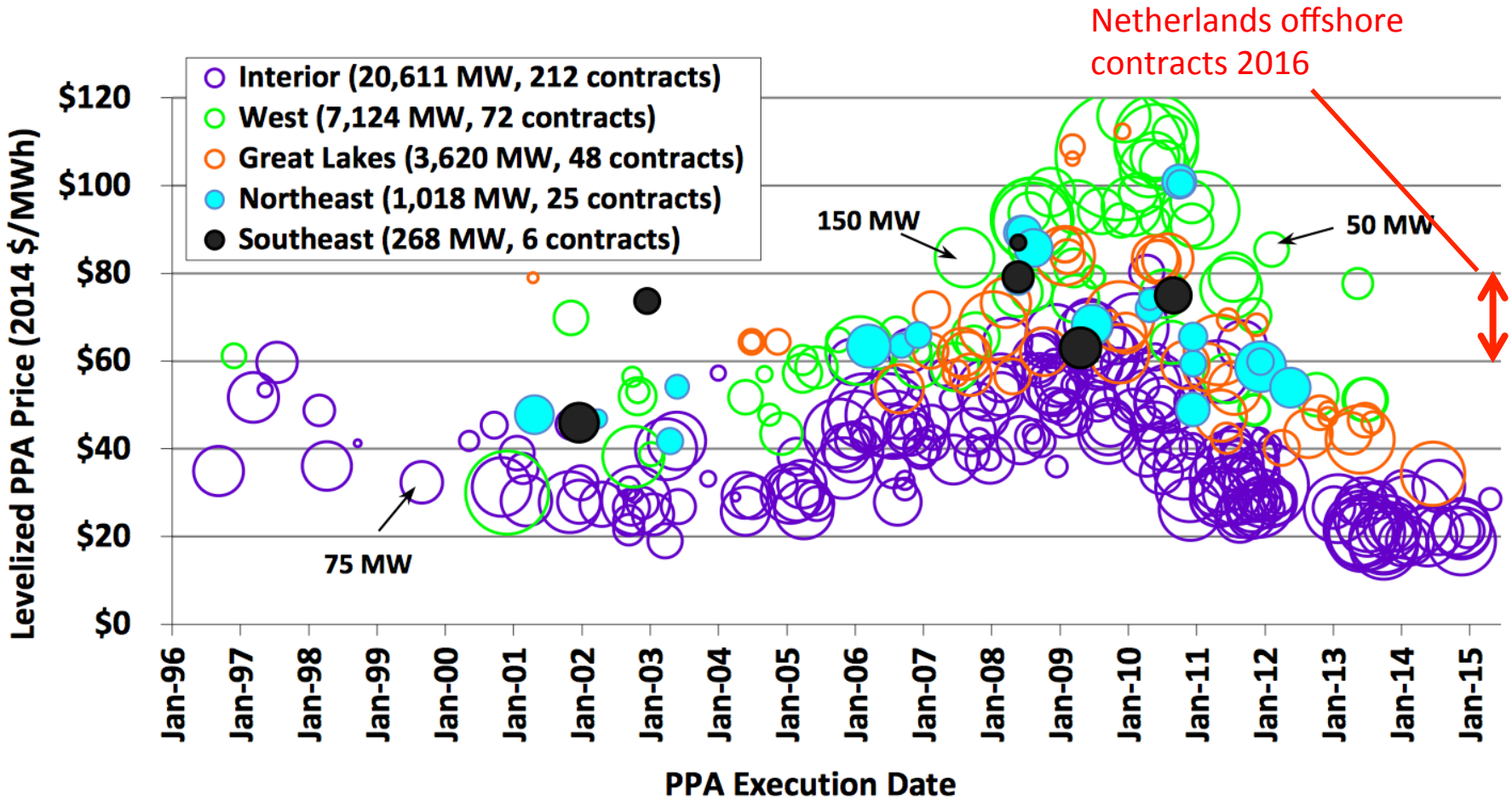
Stronger wind allows more revenue per capital & O&M cost



PPA value gives clue about levelized cost

.. must cover cost to generator inclusive of subsidies

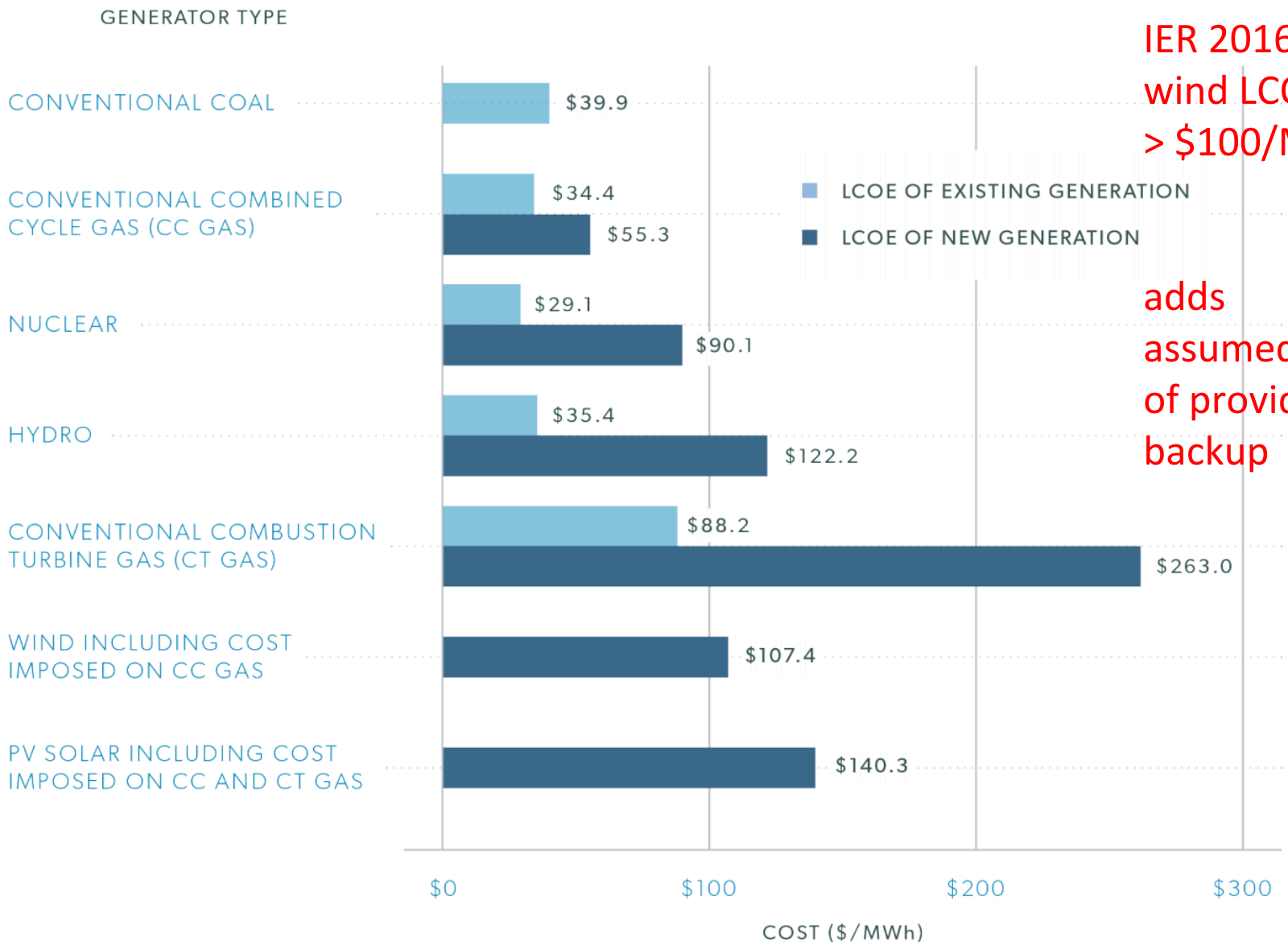
U.S. Block Island
$240/MWh



PPA is "power purchase agreement"
guaranteed price provided in long-term contract

Levelized cost: devil is in the details

affected by assumptions about financing rates, regulations, fuel costs



IER 2016:
wind LCOE is
> $100/MWh

adds
assumed cost
of providing
backup

Levelized cost: devil is in the details

affected by assumptions about financing rates, regulations, fuel costs

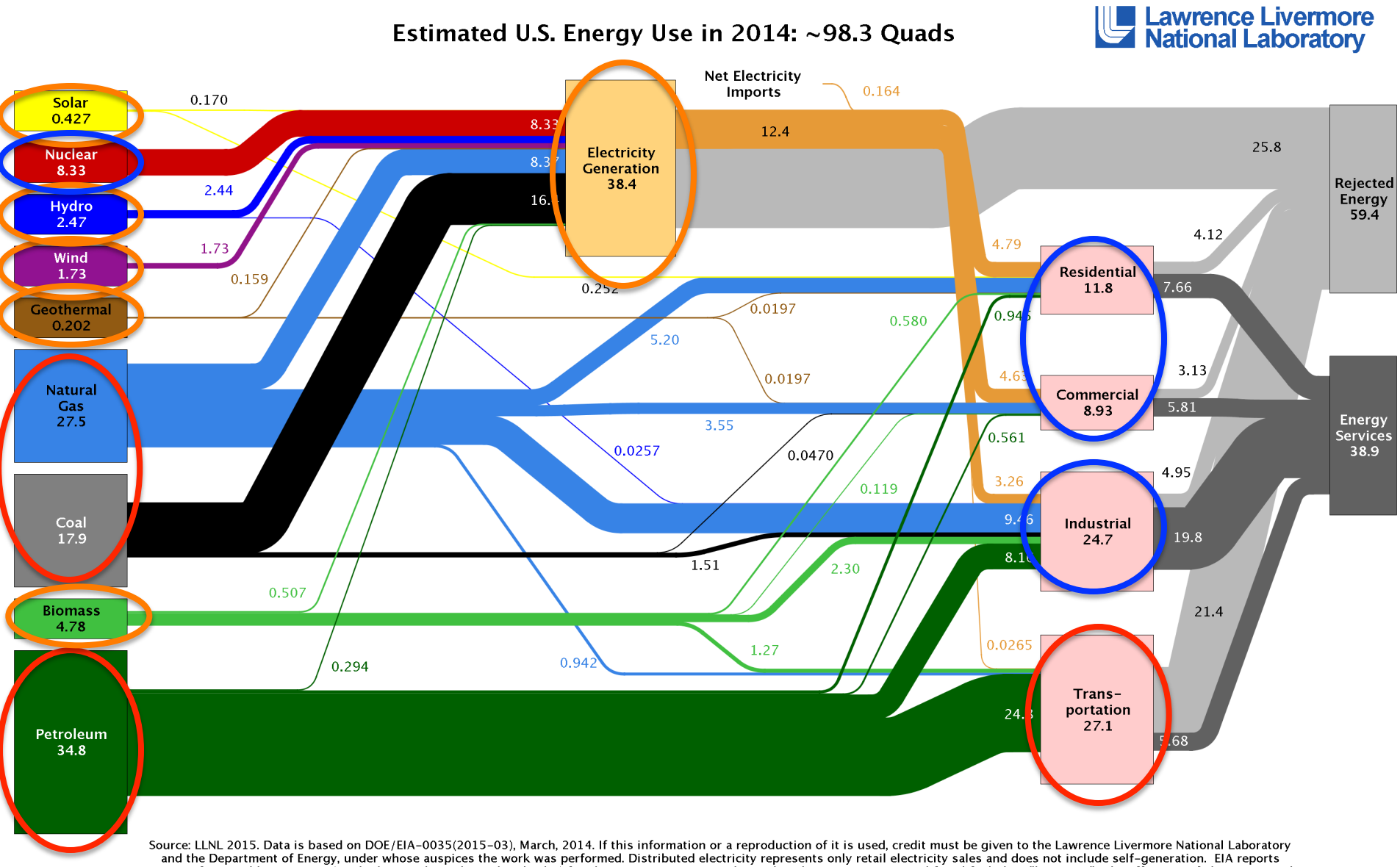
EIA forecast (not current): wind LCOE is < $40/MWh

Table 1a. Estimated levelized cost of electricity (capacity-weighted average[1]) for new generation resouces entering service in 2022 (2017 $/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[2]	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS[3]	NB	NB	NB	NB	NB	NB	NA	NB
Coal with 90% CCS[3]	NB	NB	NB	NB	NB	NB	NA	NB
Conventional CC	87	13.0	1.5	32.8	1.0	48.3	NA	48.3
Advanced CC	87	15.5	1.3	30.3	1.1	48.1	NA	48.1
Advanced CC with CCS	NB	NB	NB	NB	NB	NB	NA	NB
Conventional CT	NB	NB	NB	NB	NB	NB	NA	NB
Advanced CT	30	22.7	2.6	51.3	2.9	79.5	NA	79.5
Advanced nuclear	90	67.0	12.9	9.3	0.9	90.1	NA	90.1
Geothermal	91	28.3	13.5	0.0	1.3	43.1	-2.8	40.3
Biomass	83	40.3	15.4	45.0	1.5	102.2	NA	102.2
Non-dispatchable technologies								
Wind, onshore	43	33.0	12.7	0.0	2.4	48.0	-11.1	37.0
Wind, offshore	45	102.6	20.0	0.0	2.0	124.6	-18.5	106.2
Solar PV[4]	33	48.2	7.5	0.0	3.3	59.1	-12.5	46.5
Solar thermal	NB	NB	NB	NB	NB	NB	NB	NB
Hydroelectric[5]	65	56.7	14.0	1.3	1.8	73.9	NA	73.9

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

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

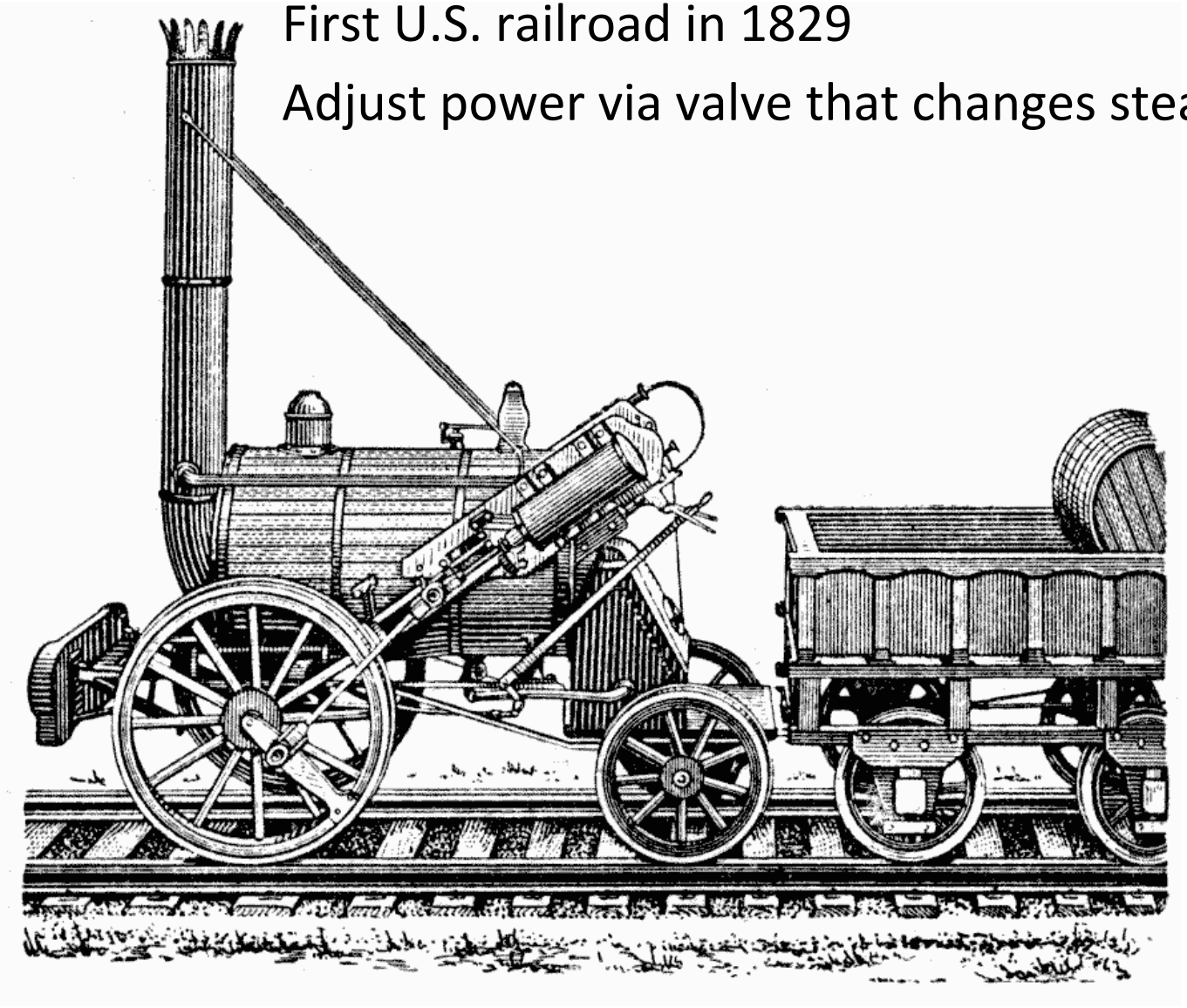
Uses: things that need to be mobile, where power-to-mass matters

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

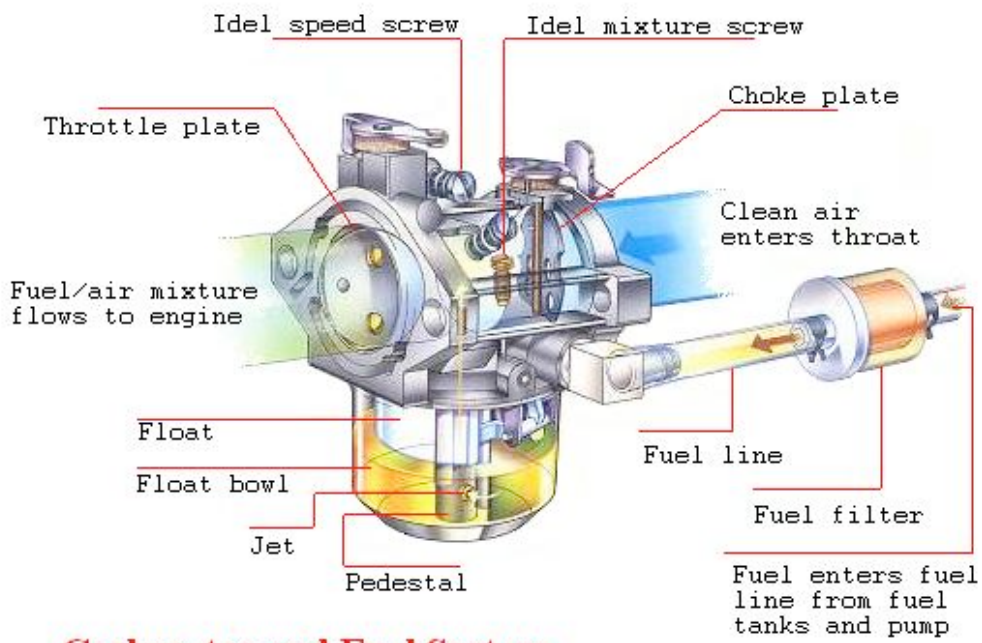
Obstacles to liquid fuel

- 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

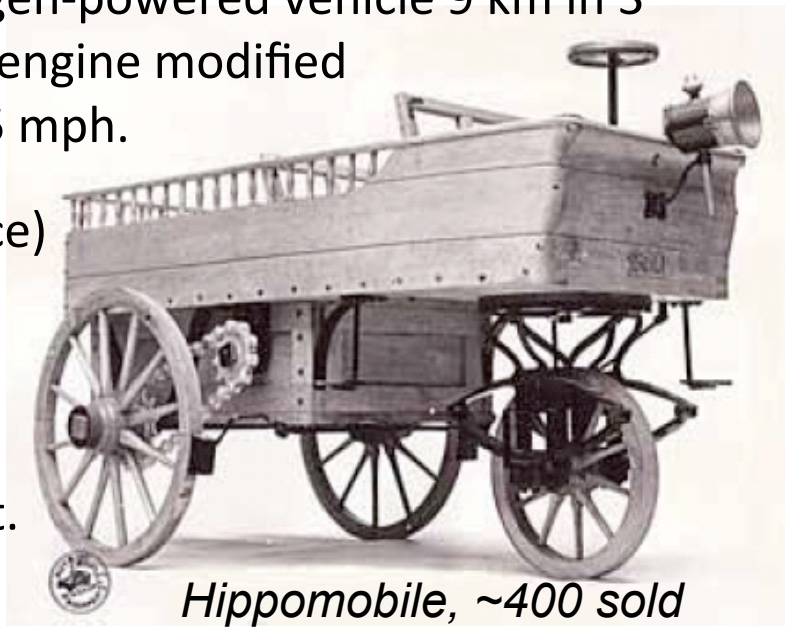
1690: Denis Papin (France) designs *(but doesn't build)* an internal combustion engine driven by gunpowder. Gives up and invents steam engine instead *(against design but no build, later built by Newcomen).*

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."

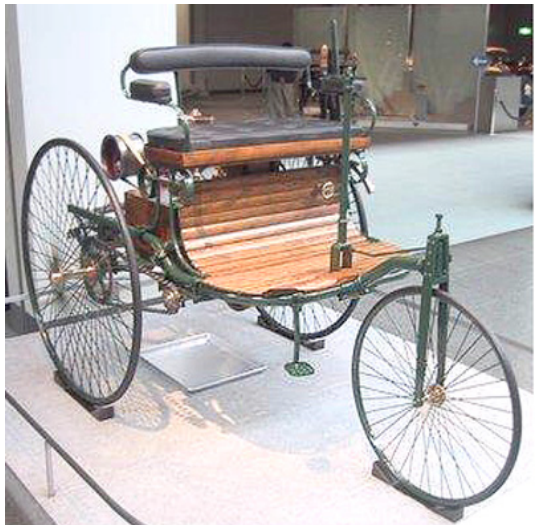
Internal combustion engine history:
development in German-speaking countries

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.

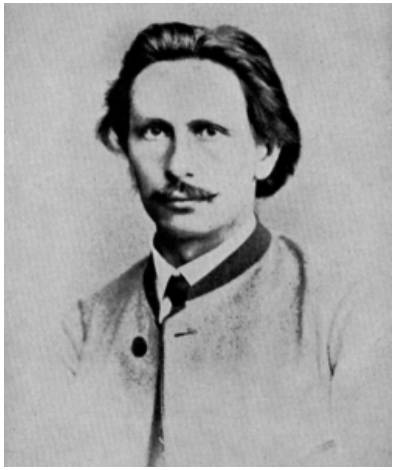
1885: Karl Benz builds 3-wheeled automobile with 4-stroke engine, 2/3 hp
patent 1886. also patents: spark ignition, sparkplug, carburetor, clutch, gear shift, radiator

Benz Patent Motorwagen 1885 – gas or petrol use



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

Karl Benz



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!" '

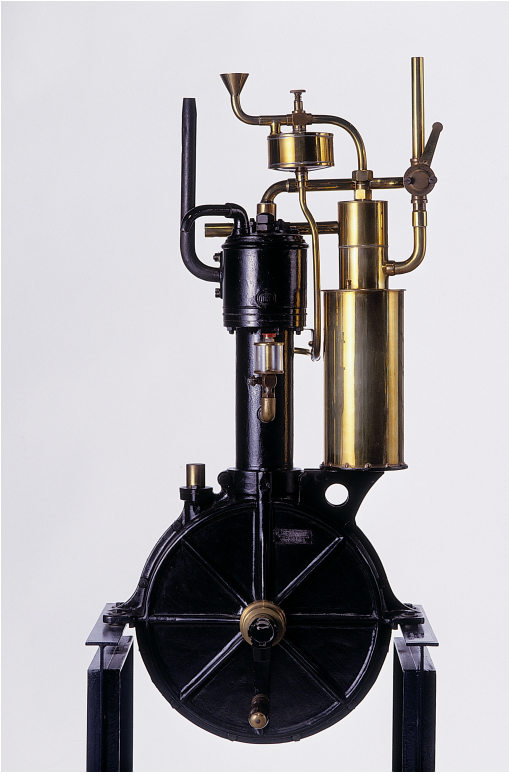
----- *Jason Torchinsky, Jalopnik*

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.

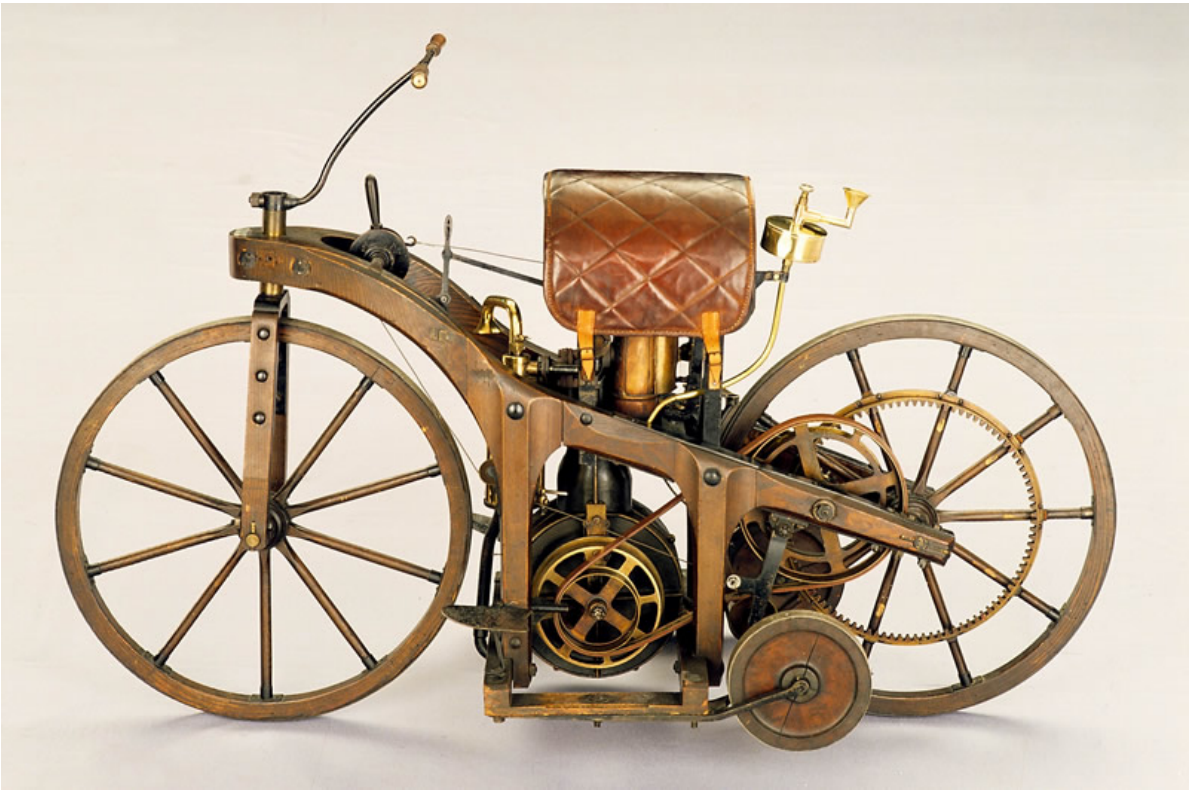
Multiple developments in German-speaking countries

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)



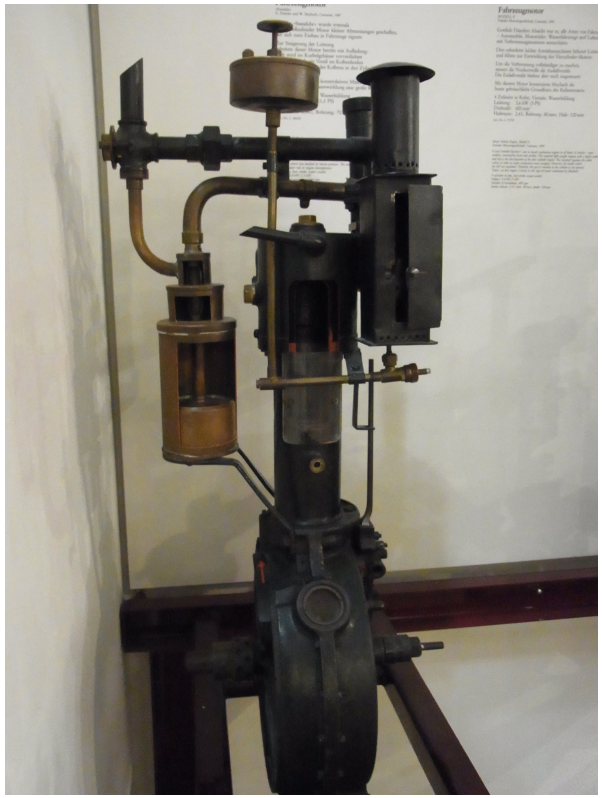
Multiple developments in German-speaking countries

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

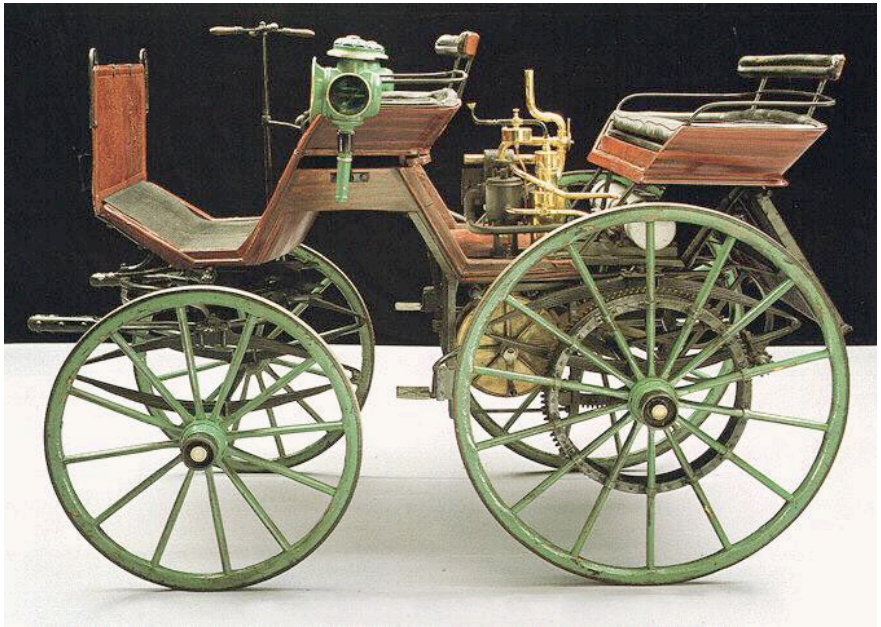
1886-1889: Daimler & Maybach makes 4-wheeled automobile

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

Daimler-Maybach engine, 1887
(at Deutsches Museum)



Daimler-Maybach automobile, 1886 *(VintageWeb)*



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

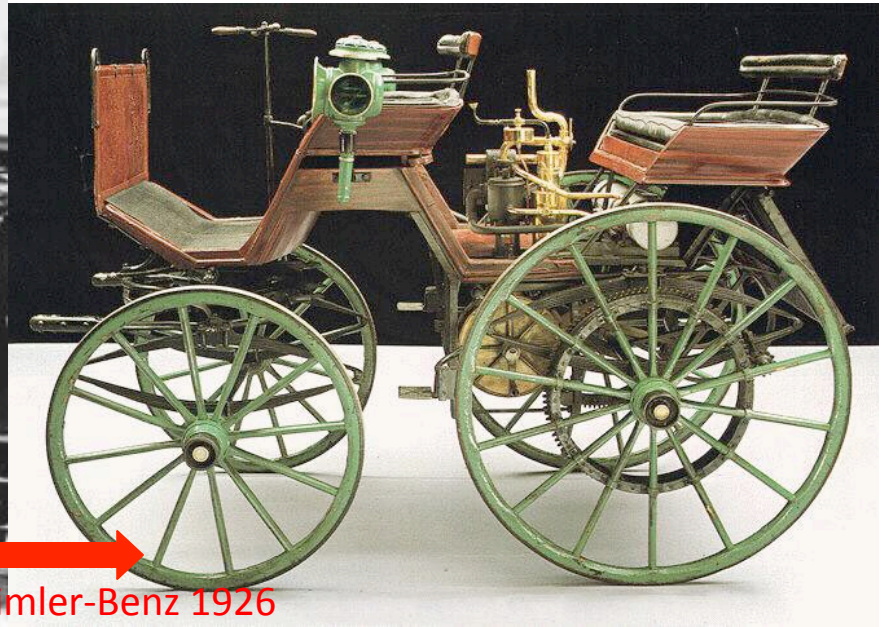
1885: Daimler & Maybach develop advanced 4-stroke engine, attach it to motorcycle

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)*