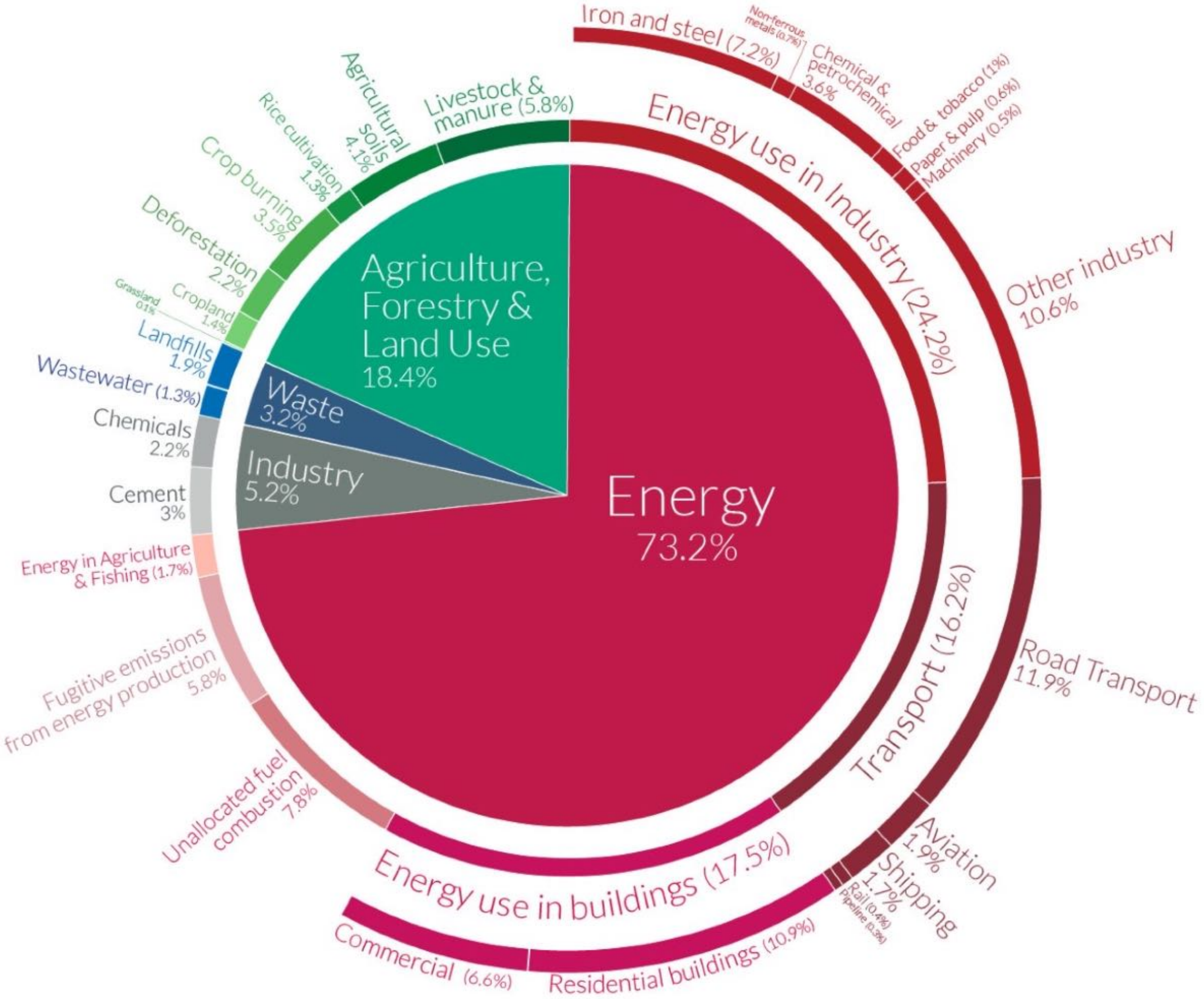
Deep Decarbonization

Module 13


What do we say to the God of Death?

Figure 10: Global Greenhouse Gas Emissions by Sector, 2016[24]



Source: Our World in Data, 2020. Data from Climate Watch, 2020.

CO_2 Emissions from Energy & Everything Else

Stop setting stuff on fire

Not just you and me – everybody, everywhere, forever

Focus on Energy!

$$CO_2 \text{ Emitted} = P \times \frac{\$}{P} \times \frac{E}{\$} \times \frac{CO_2}{E}$$

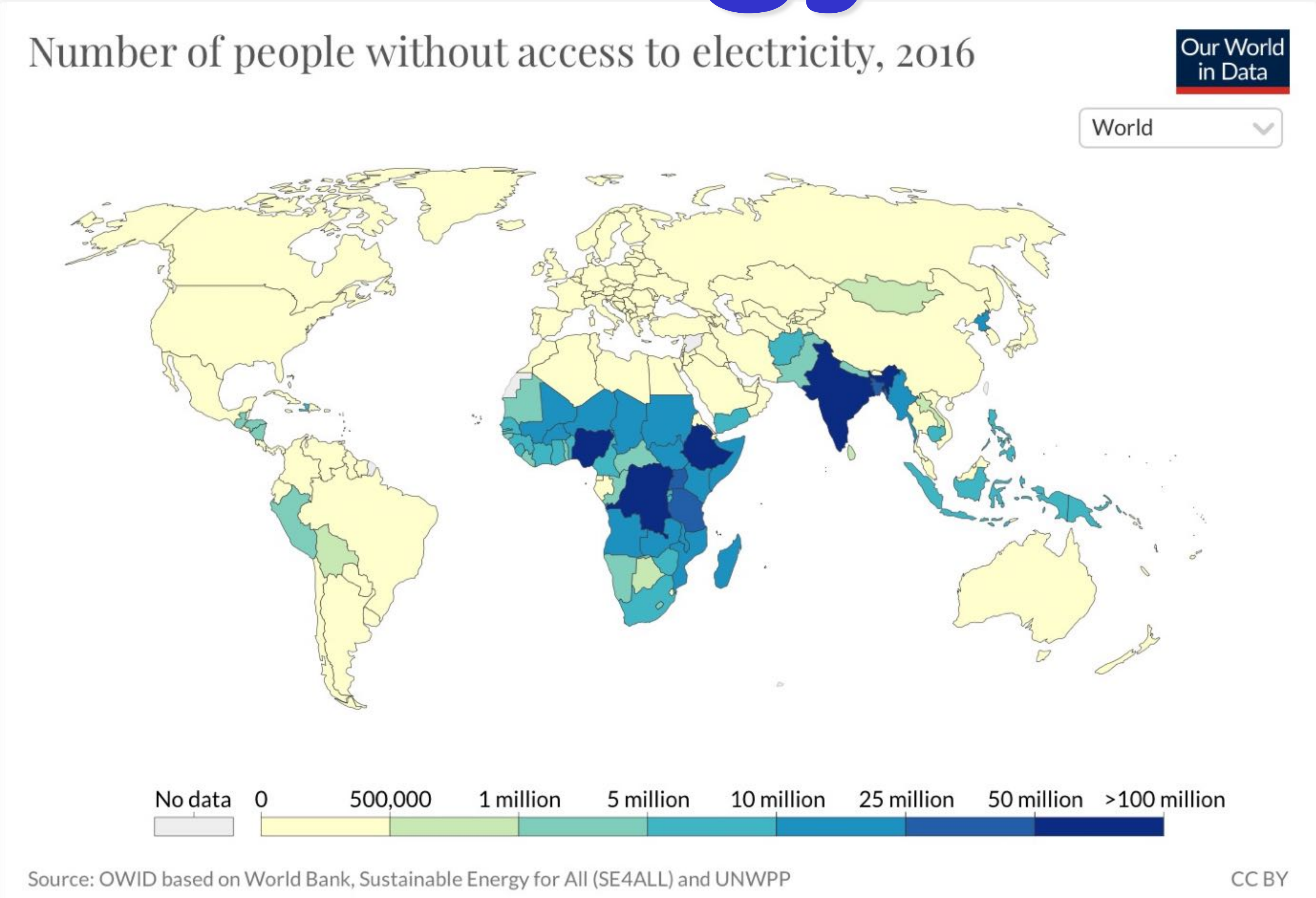
Population — $/person — energy/$ — CO_2 / energy

Kaya Identity

Four factors determine fossil fuel emissions:

- Population
- Economic activity
- Energy efficiency of economy
- Carbon efficiency of energy

Energy Poverty

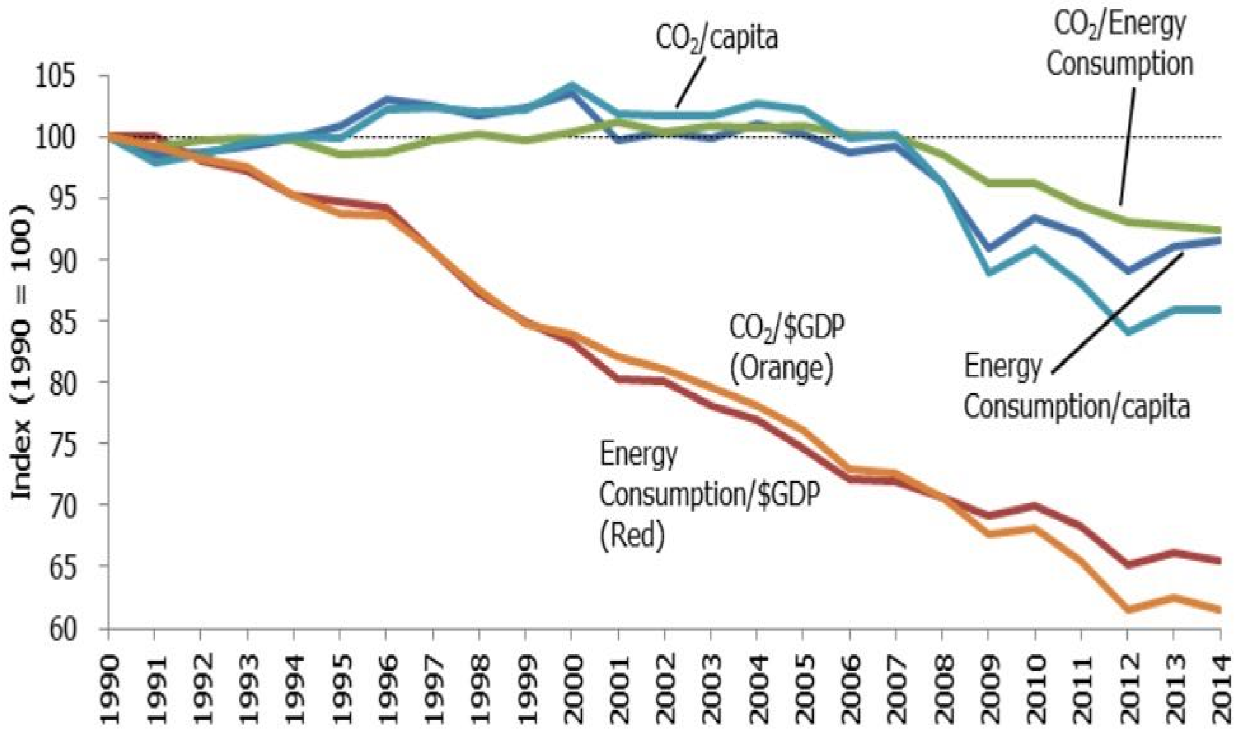


- 330 million people in the US
- 1 billion people with no electricity
- 1 billion with no drinking water
- 2 billion with no toilets
- ~ 1 billion without enough food

Energy Efficiency of the US Economy

$$CO_2 \text{ Emitted} = P \times \frac{\$}{P} \times \frac{E}{\$} \times \frac{CO_2}{E}$$

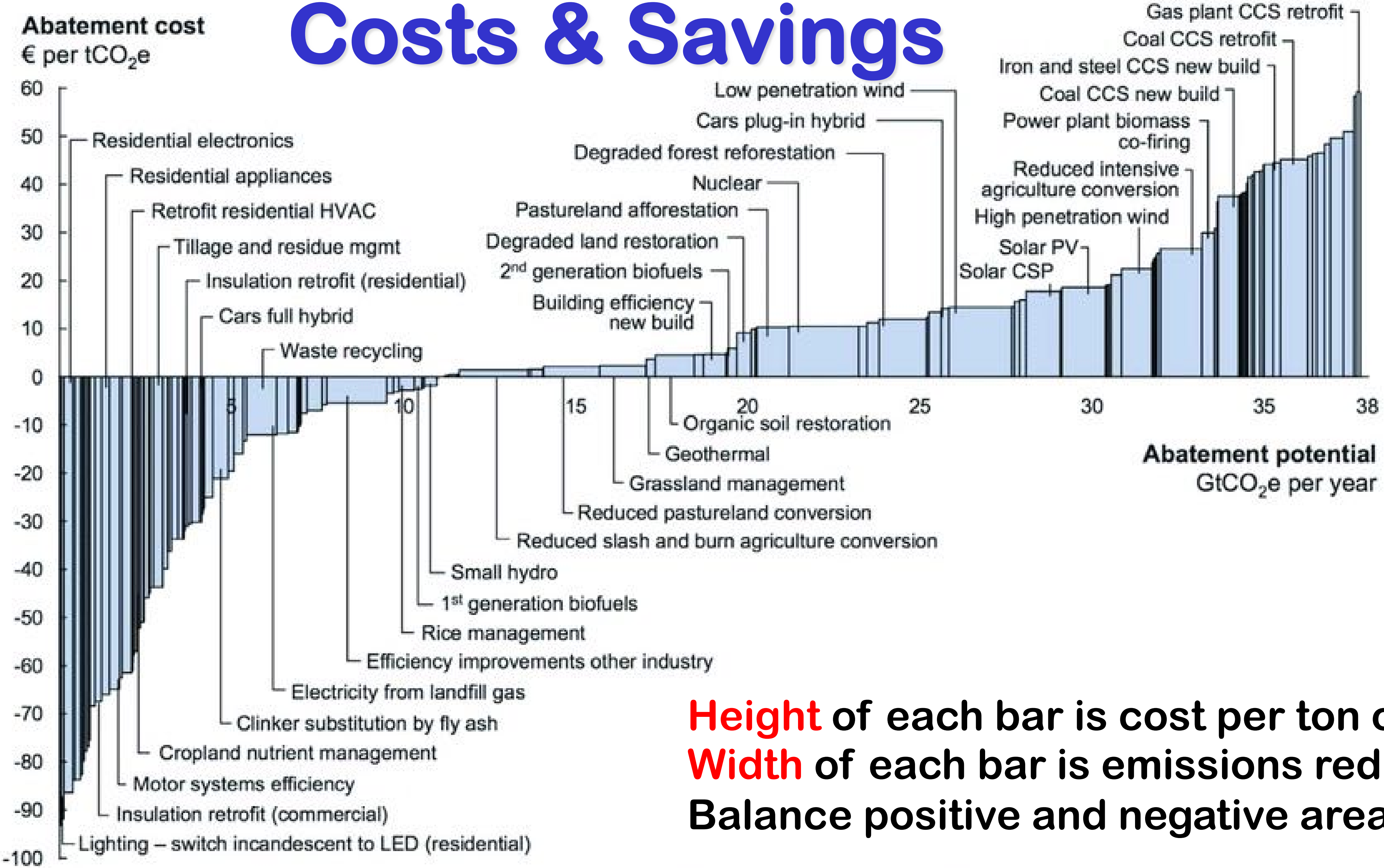
Figure 3-14: U.S. Energy Consumption and Energy-Related CO_2 Emissions Per Capita and Per Dollar GDP



- **Energy per $ of income is down 35% since 1990**
- **CO2 emissions per $ of income is down 40%**

https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Chapter-3-Energy.pdf

Costs & Savings



Height of each bar is cost per ton of CO2
Width of each bar is emissions reduction
Balance positive and negative areas

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

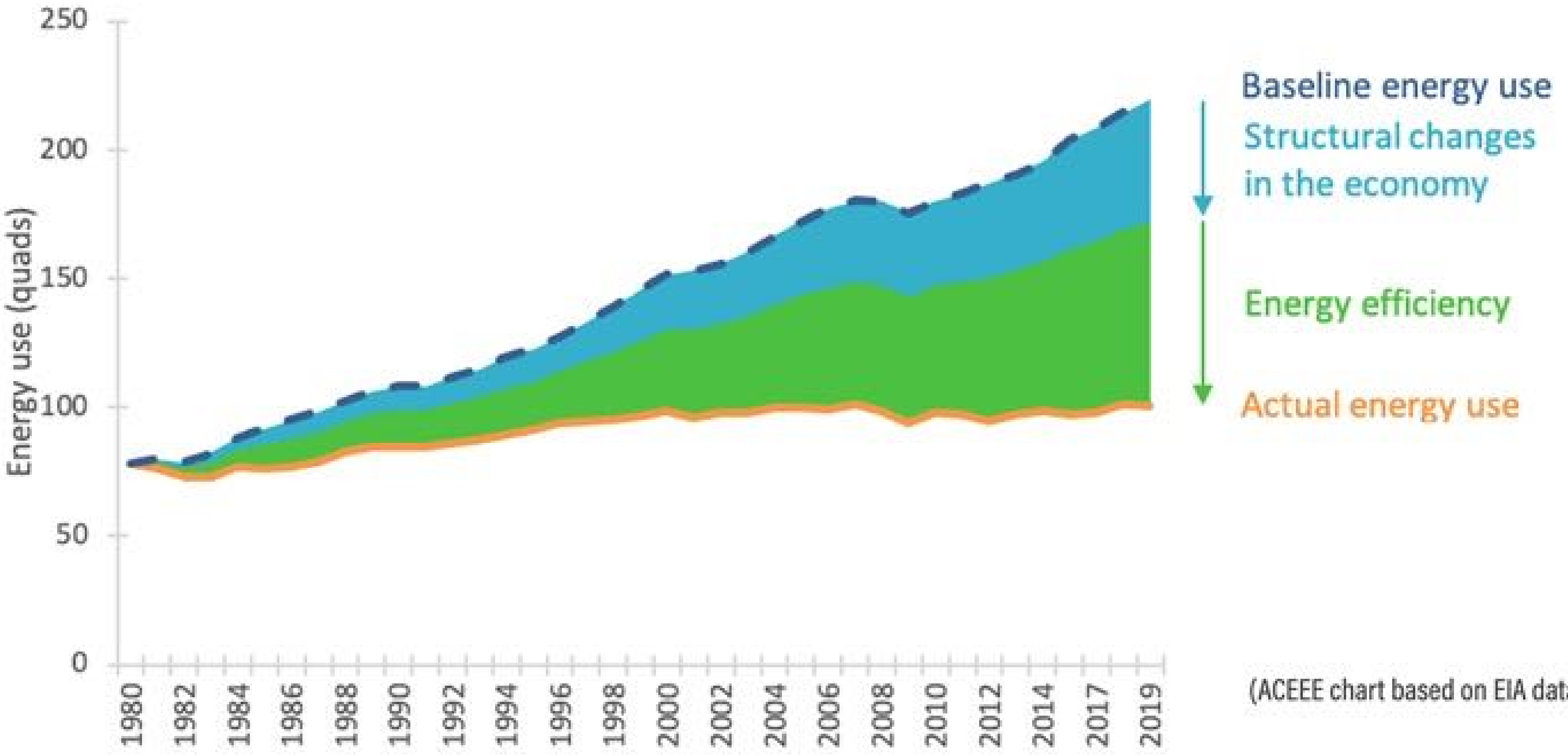
Energy Efficiency

- ***Buildings*** (40%) – envelope design, daylighting, better lights, efficiency standards

- ***Transportation*** (30%) – lighter weight vehicles, public transportation, PHEVs

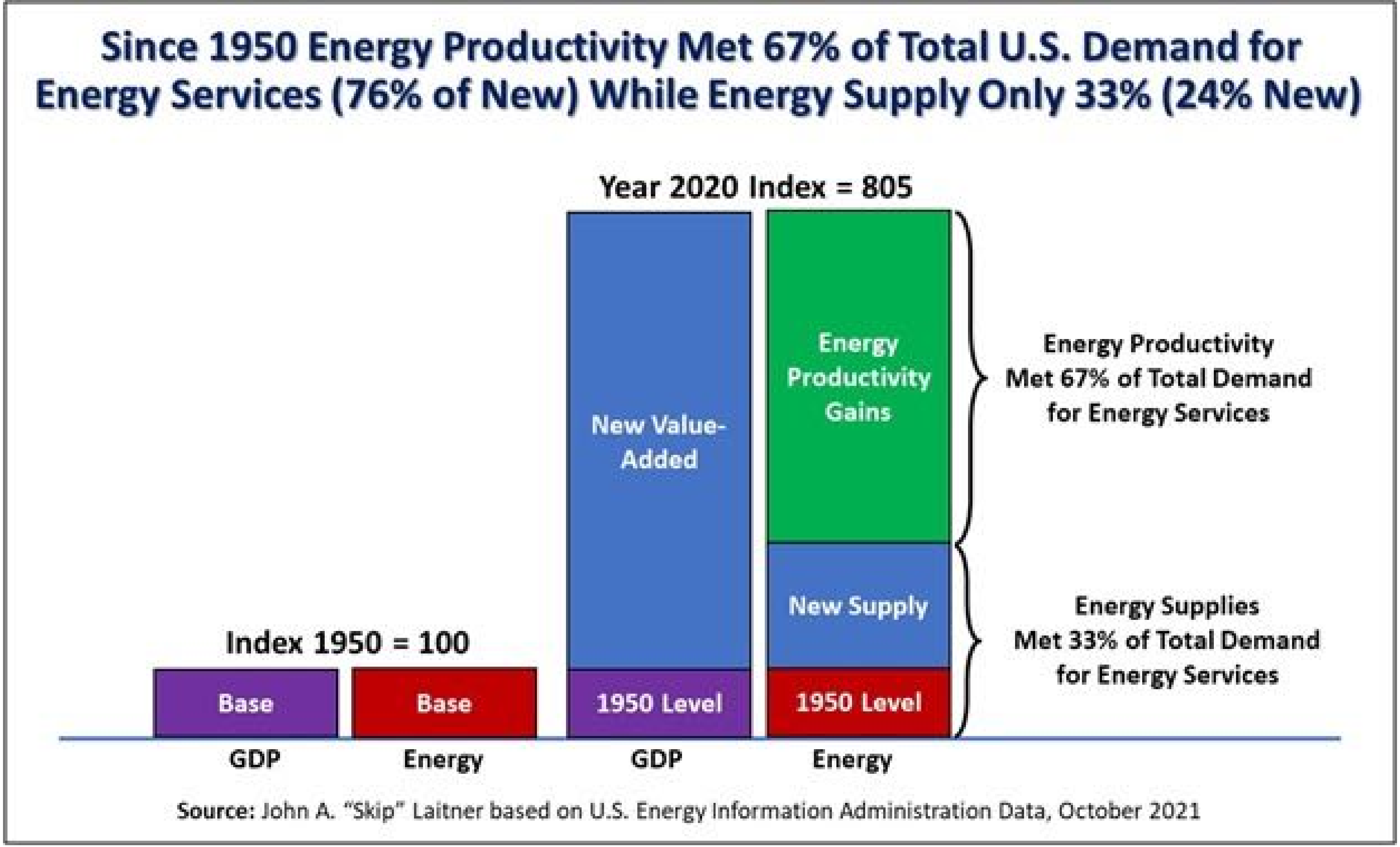
- ***Industry*** (30%) – heat recovery, better motors, CHP

U.S. Energy Consumption

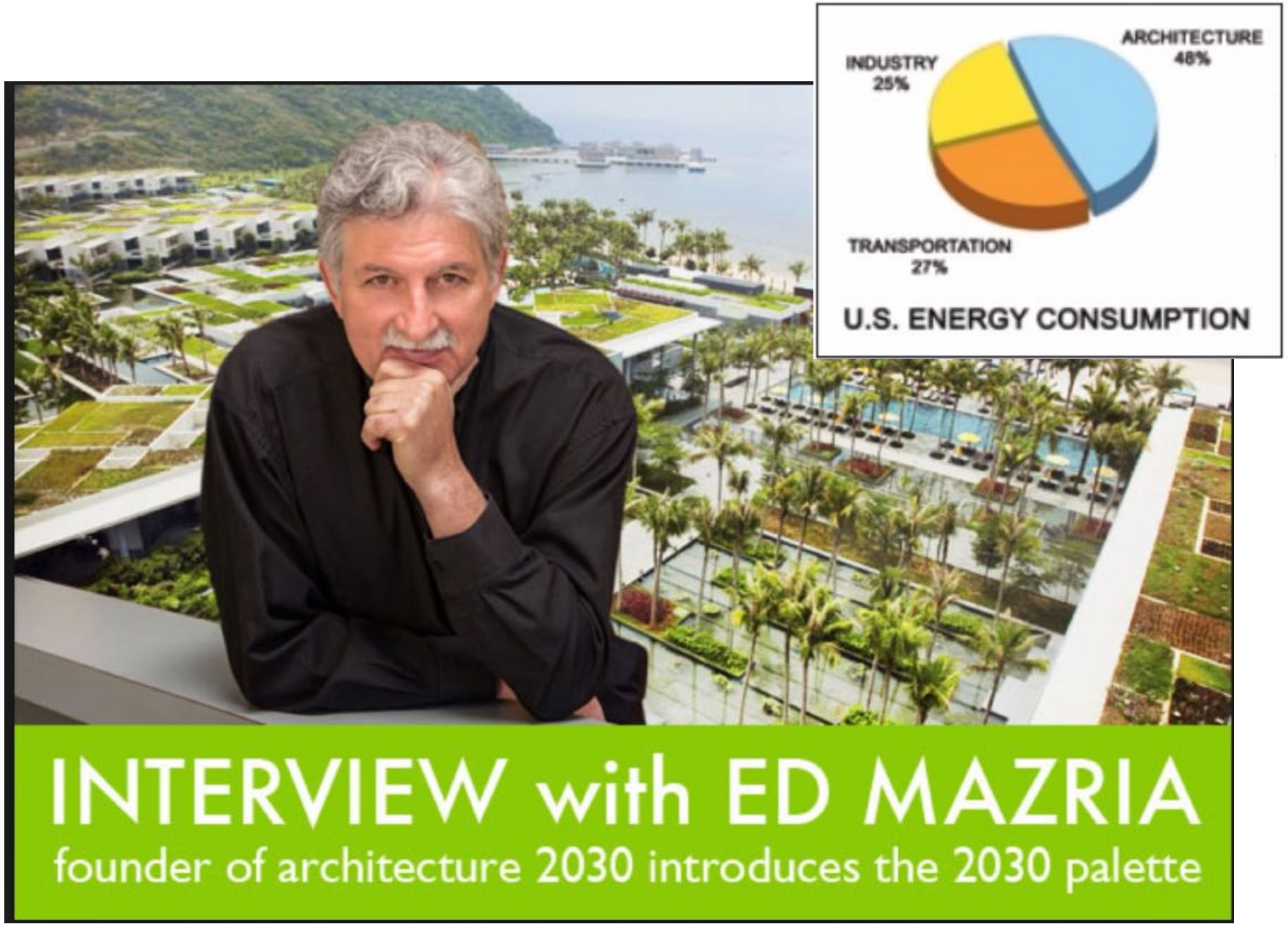


(ACEEE chart based on EIA data)

ACEEE
American Council for an Energy-Efficient Economy


Since 1950 Energy Productivity Met 67% of Total U.S. Demand for Energy Services (76% of New) While Energy Supply Only 33% (24% New)
Year 2020 Index = 805
Index 1950 = 100
Base
Base
1950 Level
New Value-Added
1950 Level
New Supply
Energy Productivity Gains
Energy Productivity Met 67% of Total Demand for Energy Services
Energy Supplies Met 33% of Total Demand for Energy Services
GDP
Energy
GDP
Energy
Source: John A. "Skip" Laitner based on U.S. Energy Information Administration Data, October 2021

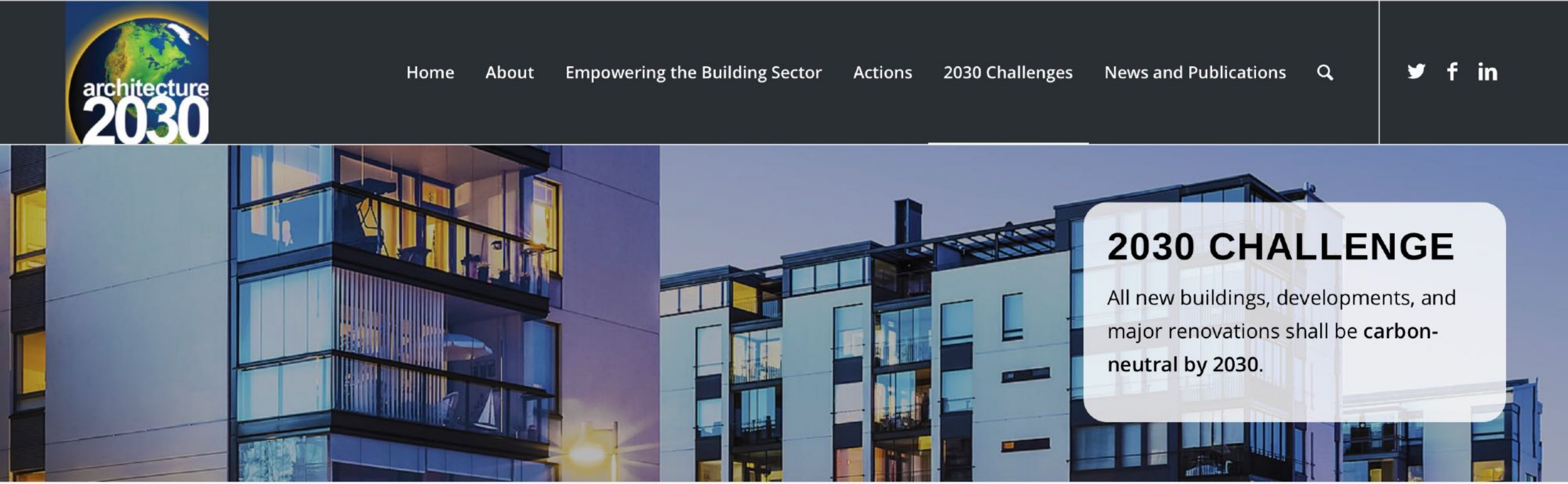
Buildings use a LOT of energy!



In the developed world, our biggest energy need is constructing and operating buildings!

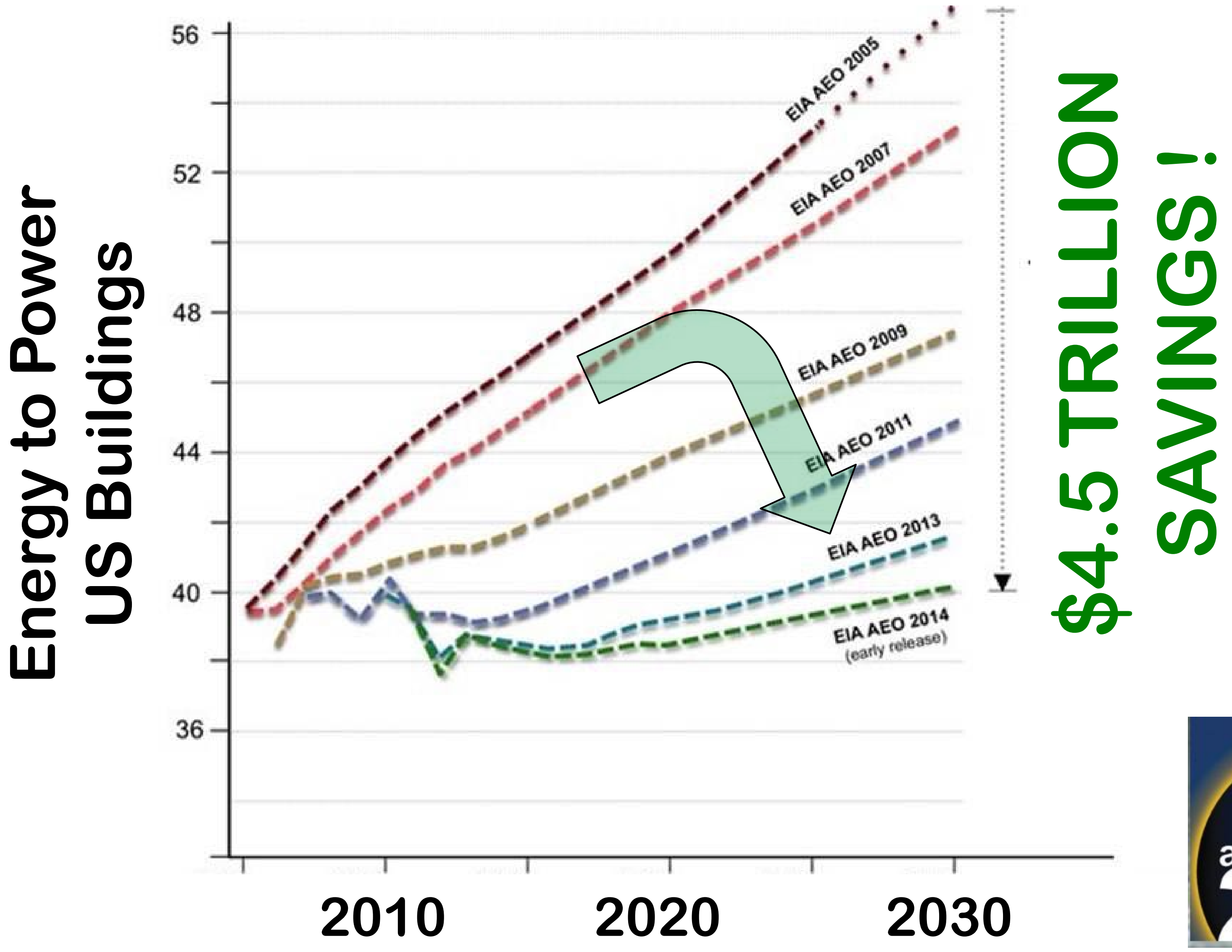
Almost twice as much as transport or industry!

LOTS of room for improvement!



Seventy-three percent (73%) of the 20 largest Architecture / Engineering (A/E) firms, responsible for over $100 billion in construction annually, have now adopted and are implementing the 2030 Challenge. According to a recent poll of design industry leaders by the Design Futures Council, approximately forty percent (40%) of all U.S. architecture firms have adopted the Challenge.

Efficient Architects!



Simple Plan for Deep Decarbonization

1. Clean up electricity
2. Electrify everything

Simple.

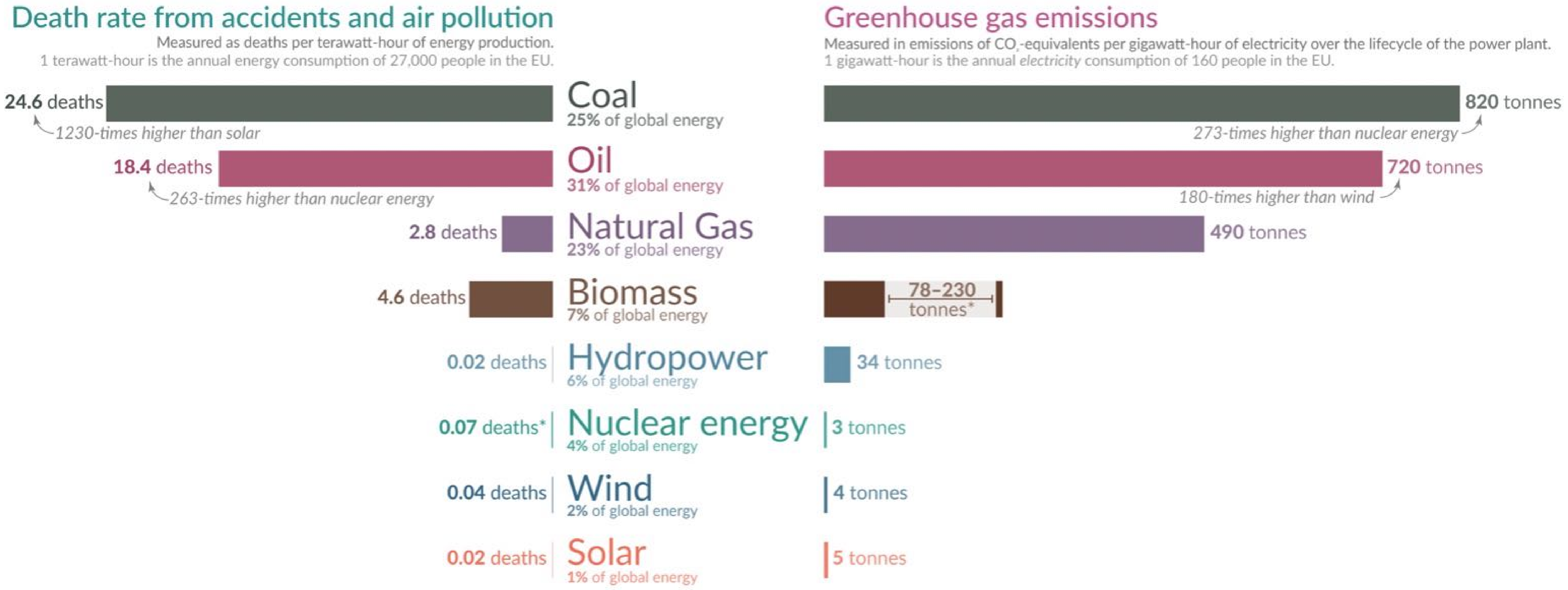
See reading

https://www.vox.com/2016/9/19/12938086/electrify-everything

Clean Up Electricity

What are the safest and cleanest sources of energy?

Our World in Data



*Life-cycle emissions from biomass vary significantly depending on fuel (e.g. crop resides vs. forestry) and the treatment of biogenic sources.

*The death rate for nuclear energy includes deaths from the Fukushima and Chernobyl disasters as well as the deaths from occupational accidents (largely mining and milling).

Energy shares refer to 2019 and are shown in primary energy substitution equivalents to correct for inefficiencies of fossil fuel combustion. Traditional biomass is taken into account.

Data sources: Markandya & Wilkinson (2007); Sovacool et al. (2016); IPCC AR5 (2014); Pehl et al. (2017); BP (2019); Smil (2017).

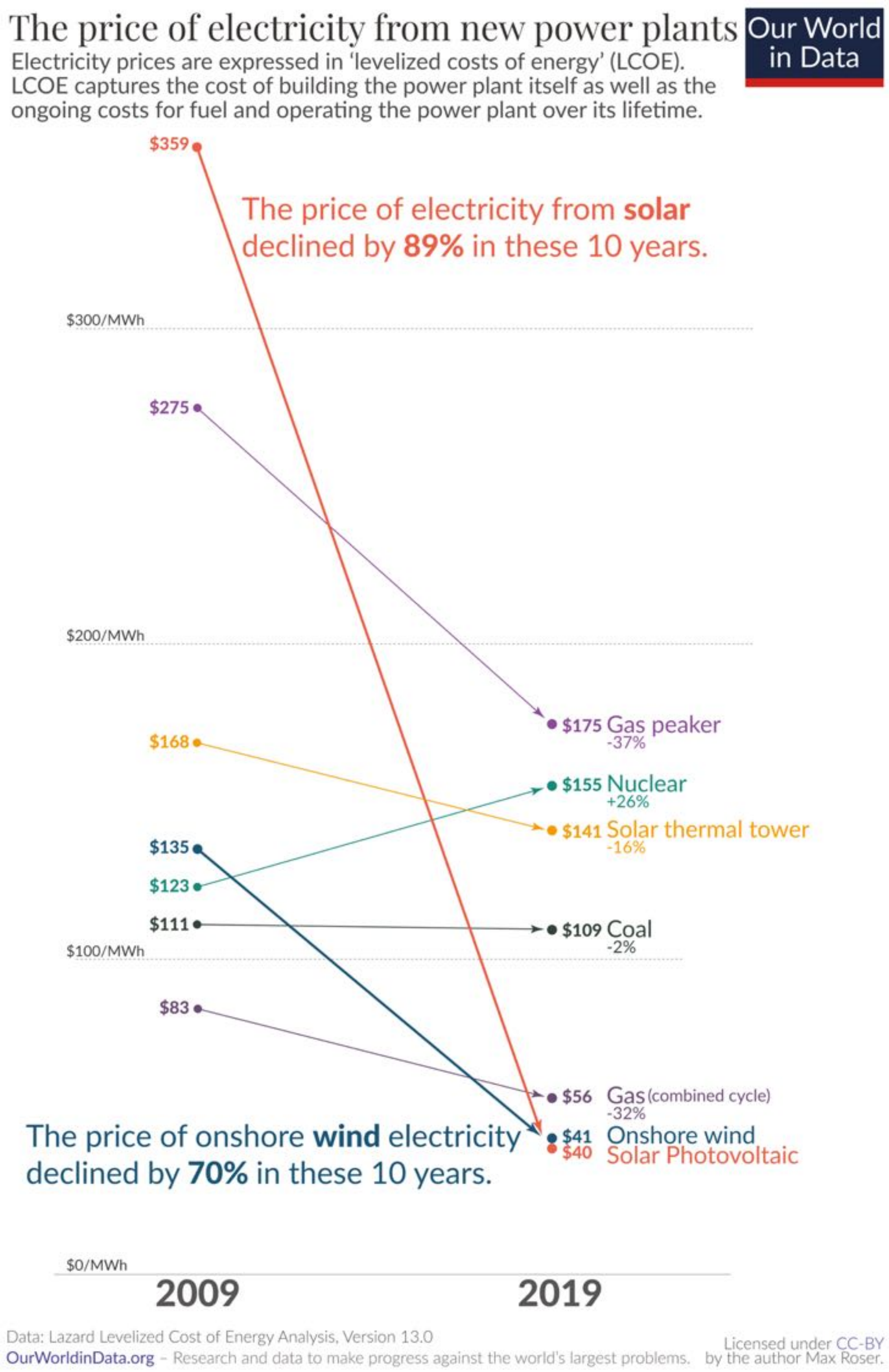
OurWorldinData.org – Research and data to make progress against the world's largest problems.

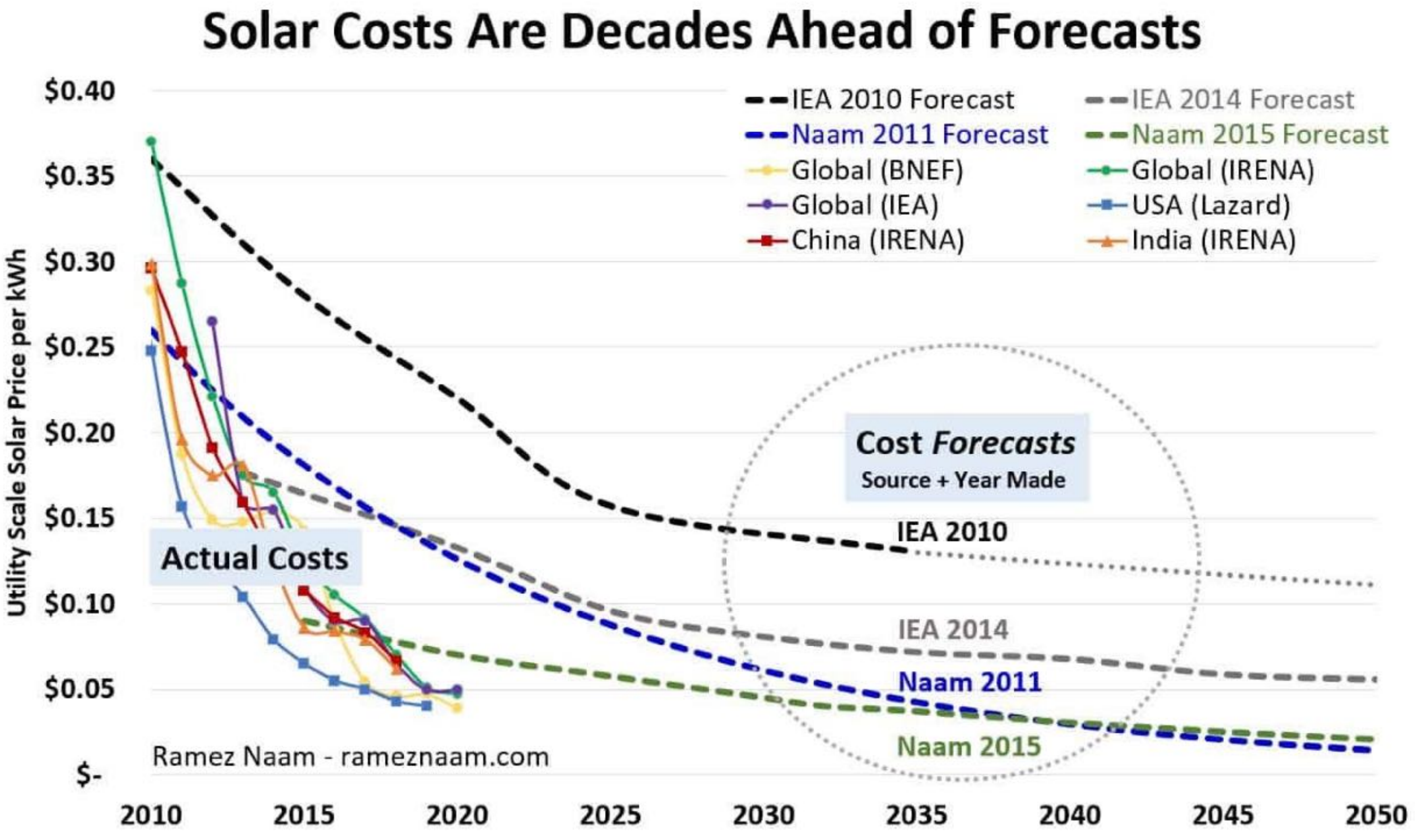
Electricity Sources

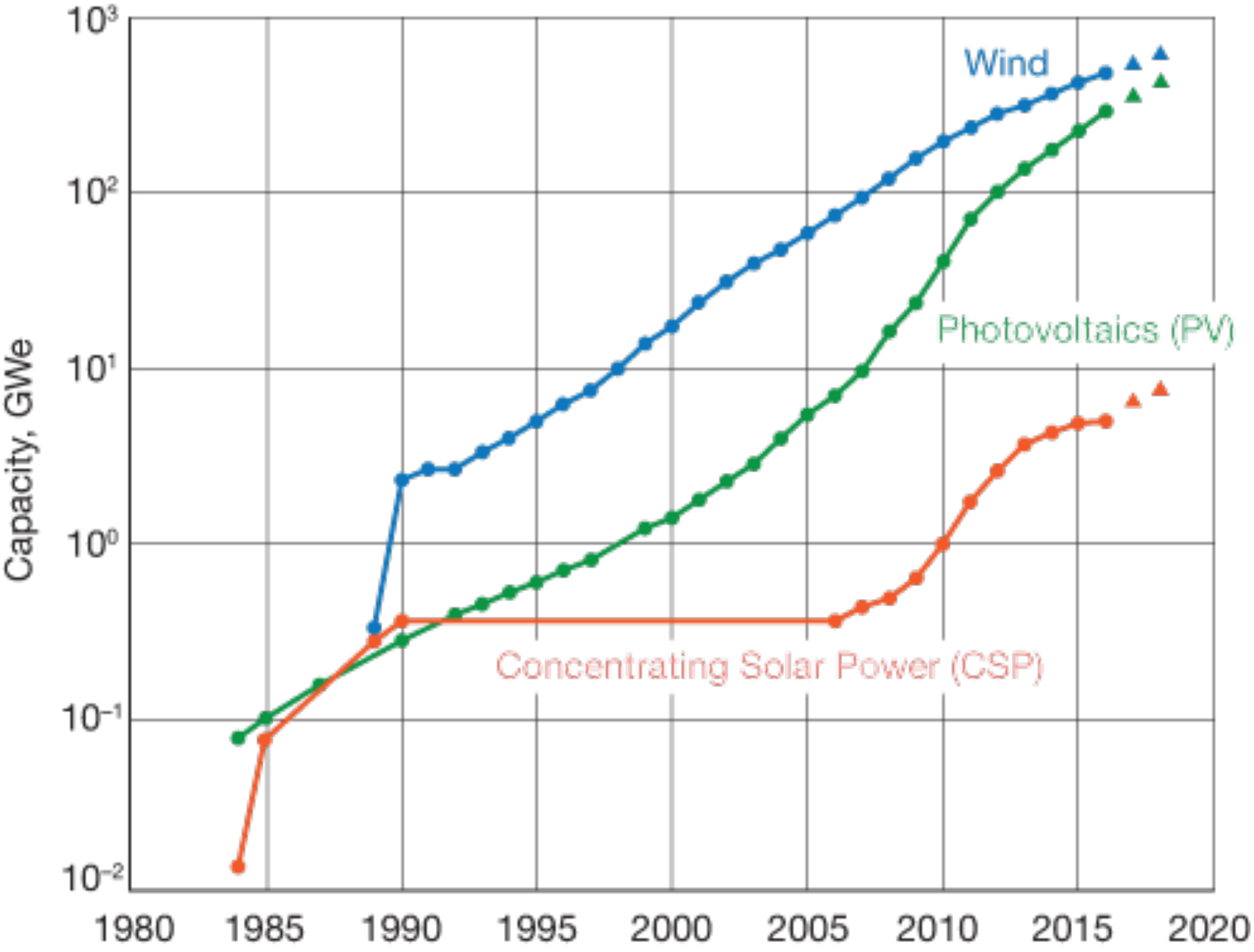
Source	CO2 Emissions (gCO2/kW-hr)	Levelized Cost ($/MW-hr)	Capacity Factor	Advantages	Disadvantages
Coal	820	109	60	Dispatchable	Smoke, Dust
Gas	490	56	50	Dispatchable	CH4 leaks
Biomass	230	110	55	Dispatchable	Forest loss
Solar PV	41	40	29		Daylight only
Geothermal	38	75	70	Dispatchable	Rare
Solar thermal	27	143	33	Evening hours	Cost
Hydro	24	50	44	Dispatchable	Rare
Offshore Wind	12	83	50	High wind	Logistics
Nuclear	12	155	89	Dispatchable	Cost, politics
Onshore Wind	11	38	30		Intermittent

https://ourworldindata.org/cheap-renewables-growth
https://en.wikipedia.org/wiki/Capacity_factor
https://en.wikipedia.org/wiki/Life-cycle_greenhouse_gas_emissions_of_energy_sources
https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/

Energy Market Transformation





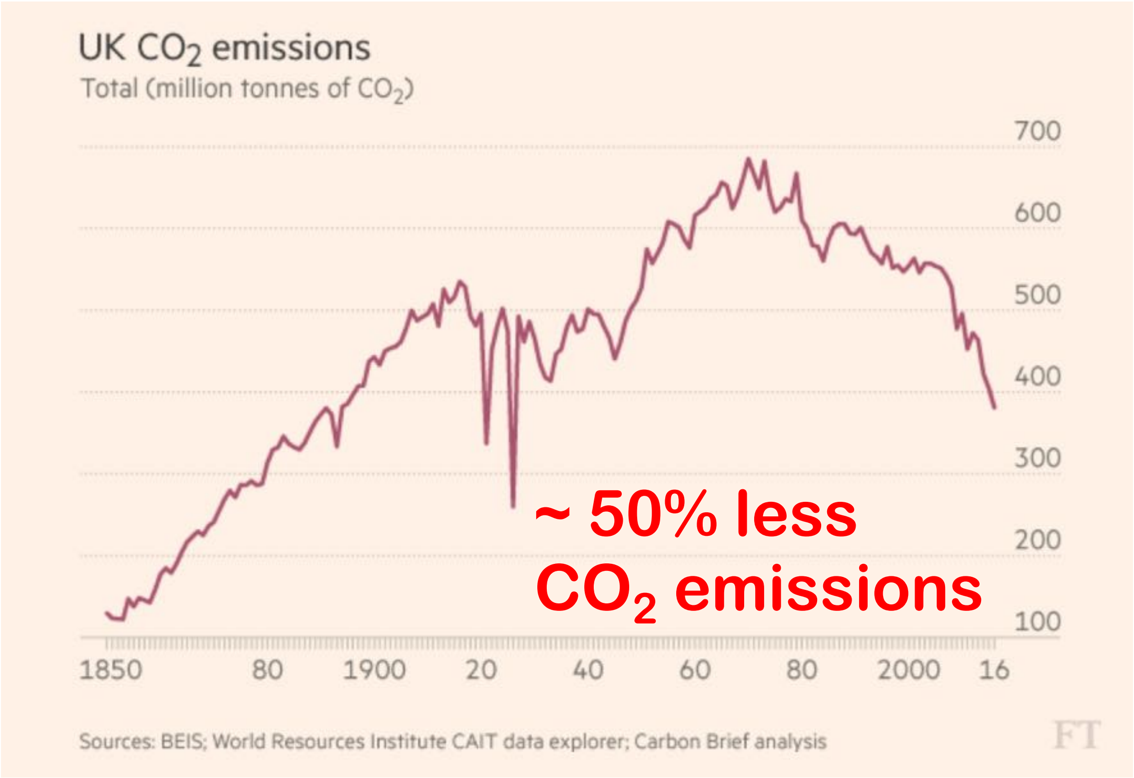


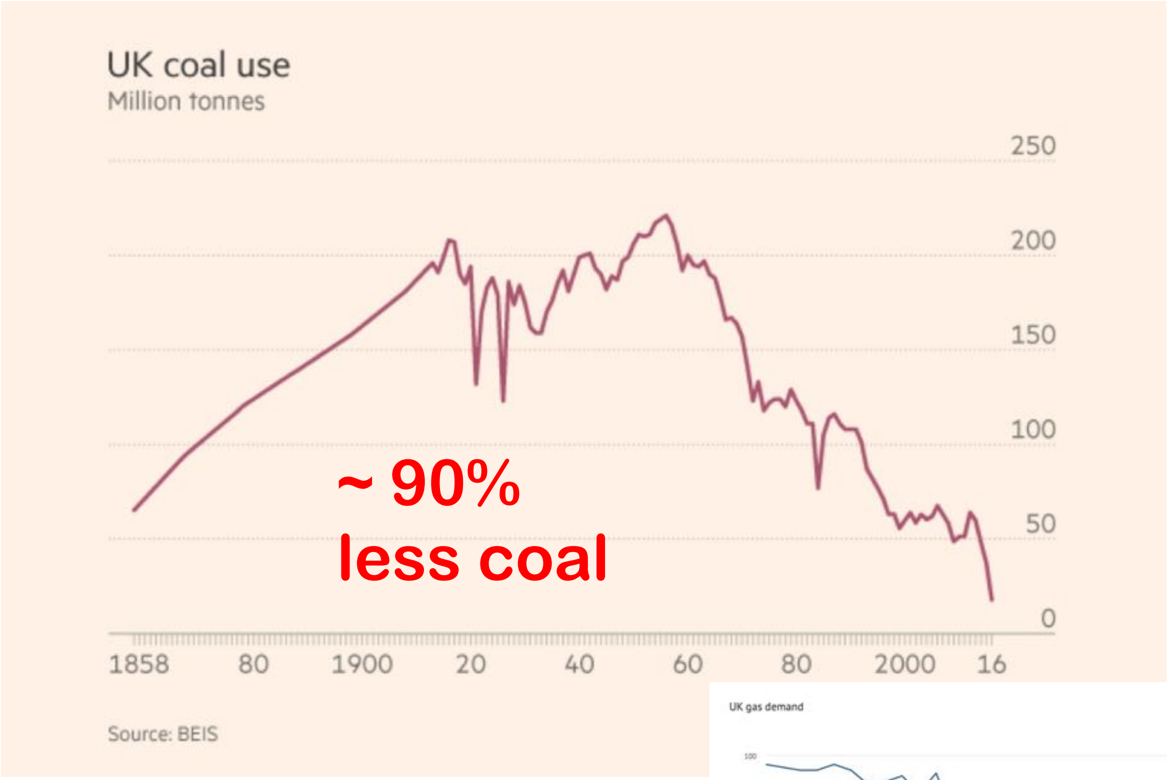
Exponential Growth of Renewable Electricity

Recent Xcel bids in CO for wind and solar <u>with battery storage</u>: 2-4 cents/kWh

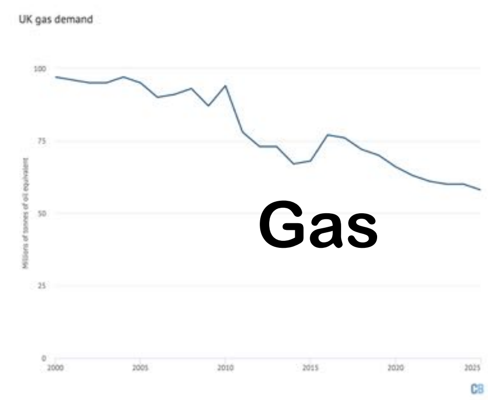
UK "Invented" Coal

$$\text{CO}_2\ \text{Emitted} = P \times \frac{\$}{P} \times \frac{E}{\$} \times \frac{CO_2}{E}$$

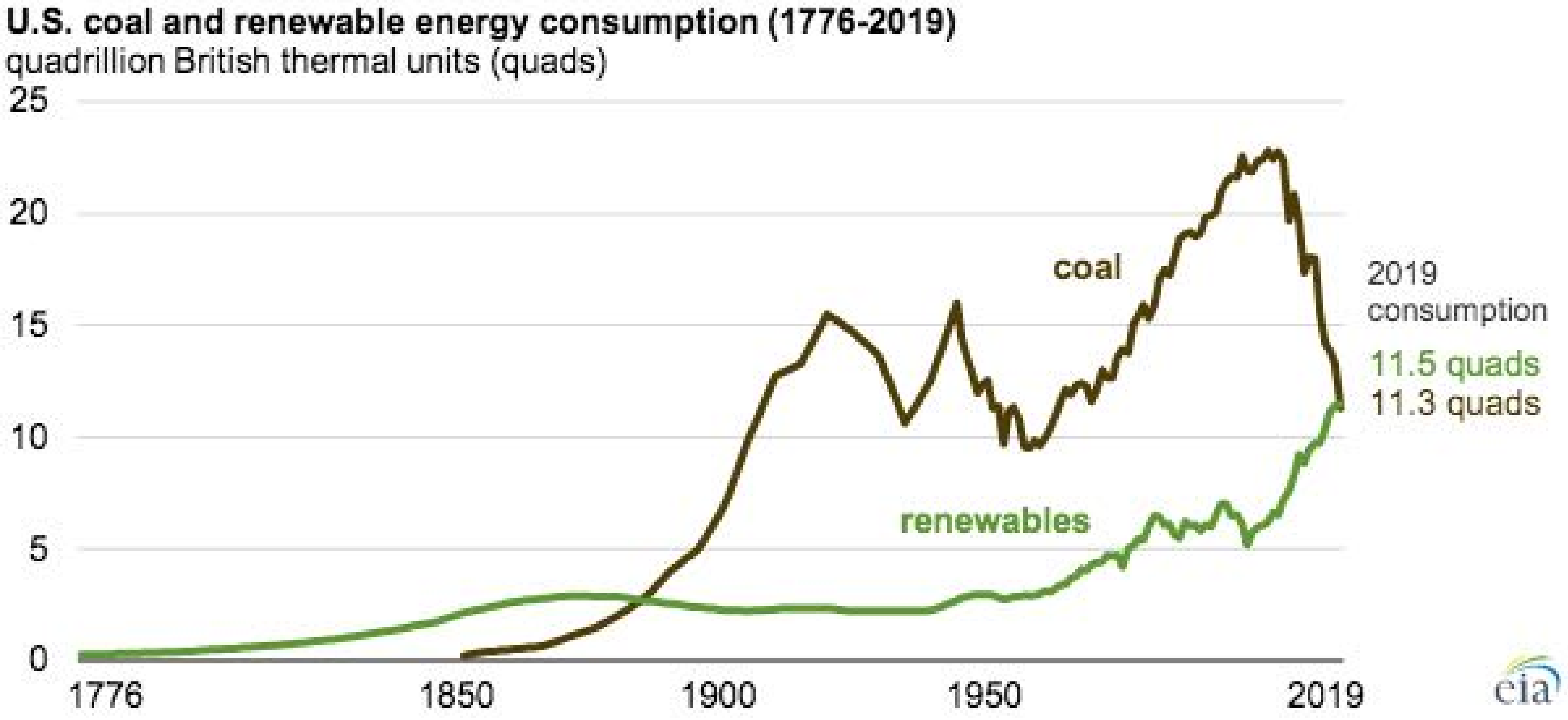




Now emits less CO_2 than in Victorian times!



Renewables Overtake Coal



UTILITY DIVE Home Events Library Jobs Viewpoints Topics

FEATURE

Renewable plus storage bids in Xcel Colorado solicitation could set low-price benchmark

CO Excel Auction

Median price for delivered wind+storage was 2.1 ¢/kW-hr

< 1/2 cost of existing coal!

Jan 16, 2018

The Two Fastest-Growing Jobs*

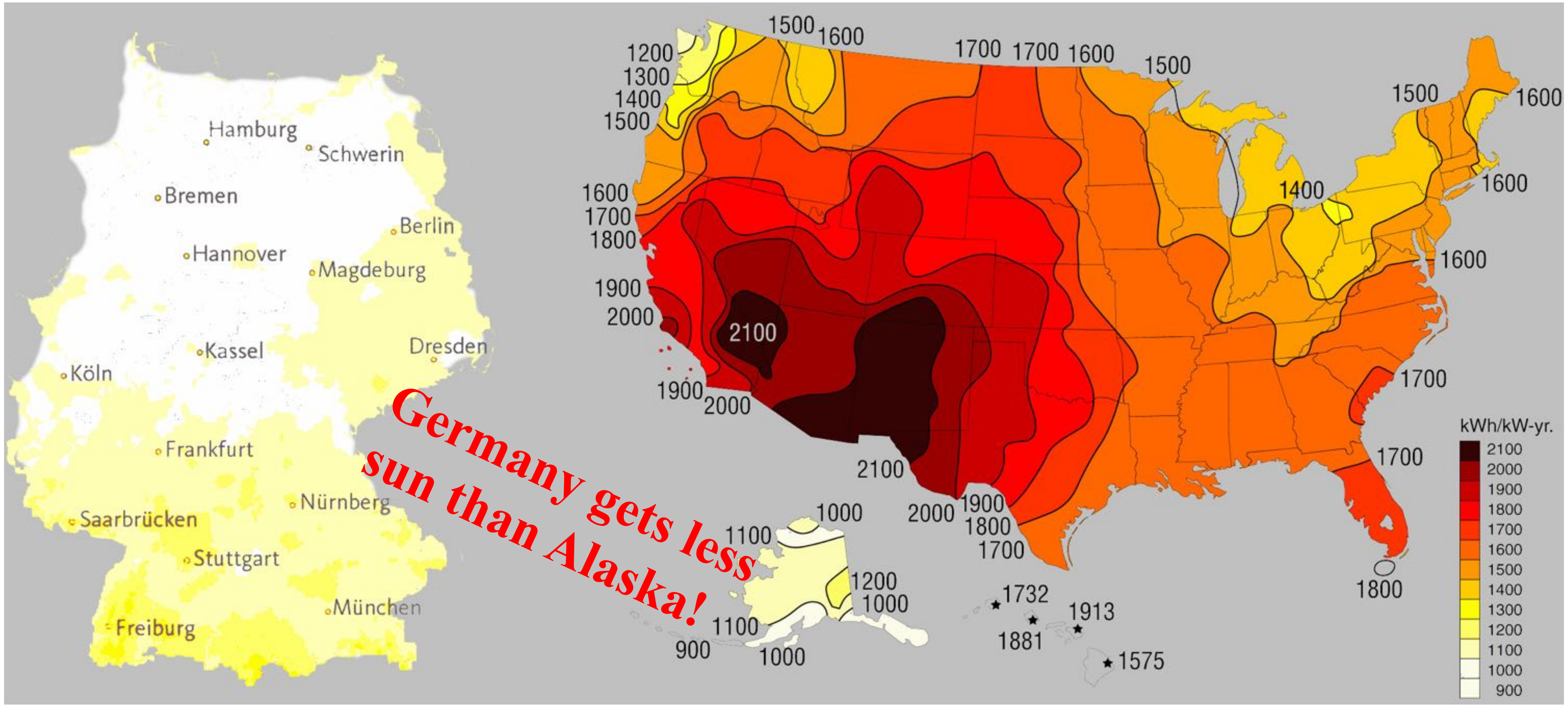
1. Solar PV installer
   Median salary: $39,000

2. Wind turbine technician
   Median salary: $54,000

*U.S. Bureau of Labor Statistics

Utility Scale PV

Solar Resources



German electricity

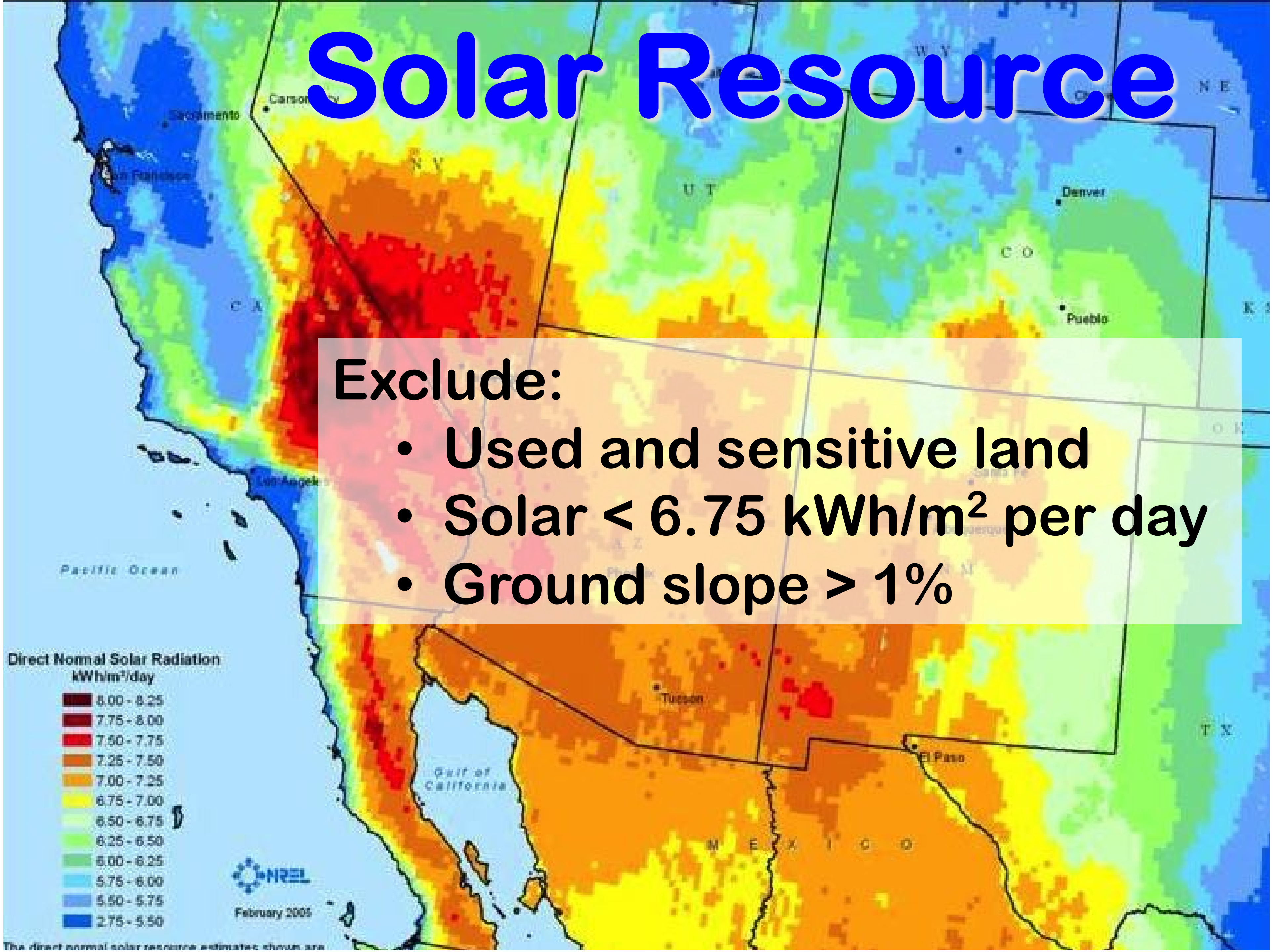
- 4% wind & solar in 2000
- 32% wind & solar in 2016

US vs Germany

Solar Resource

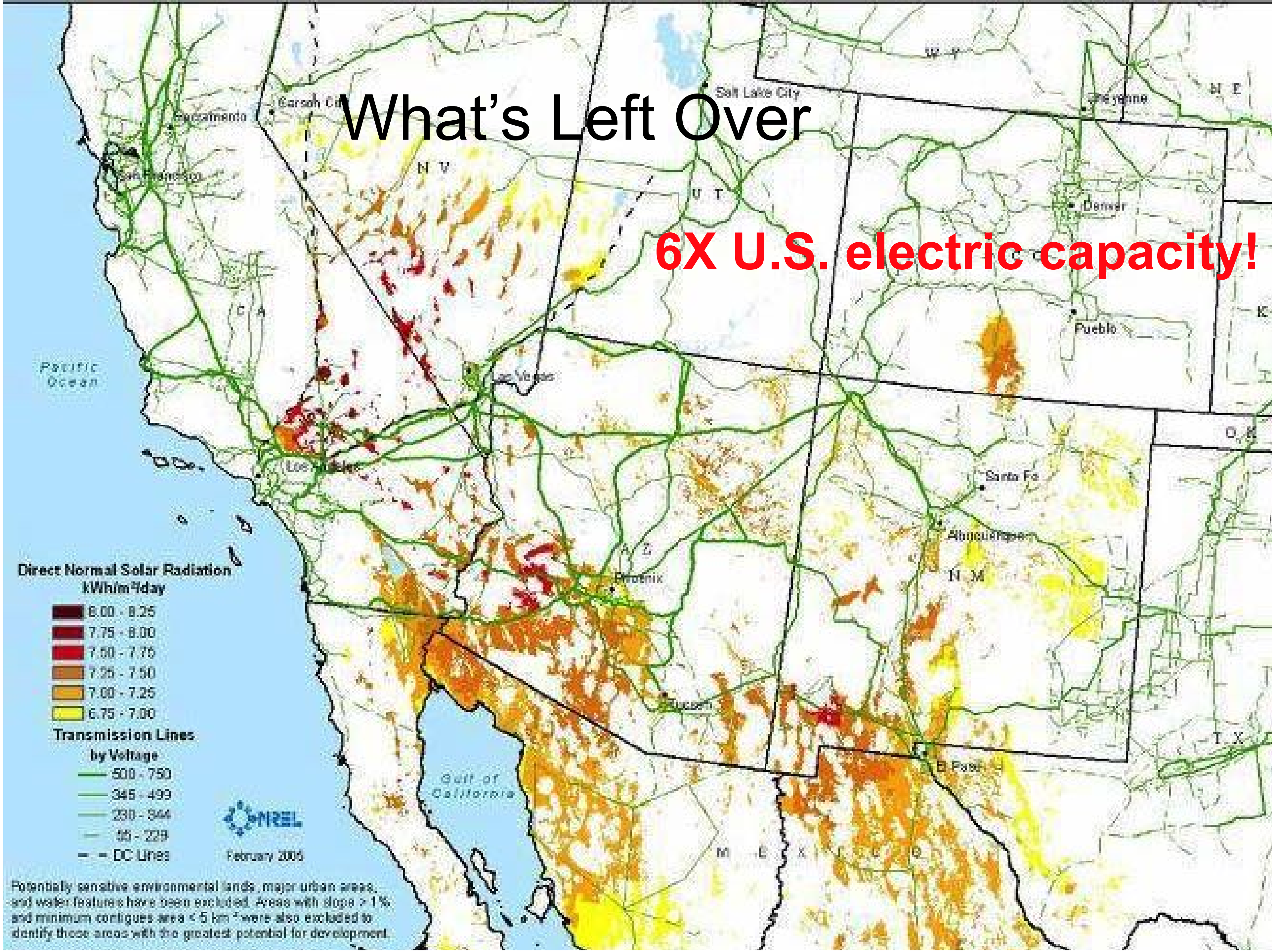
Exclude:

- Used and sensitive land
- Solar < 6.75 kWh/m^2 per day
- Ground slope > 1%



What’s Left Over

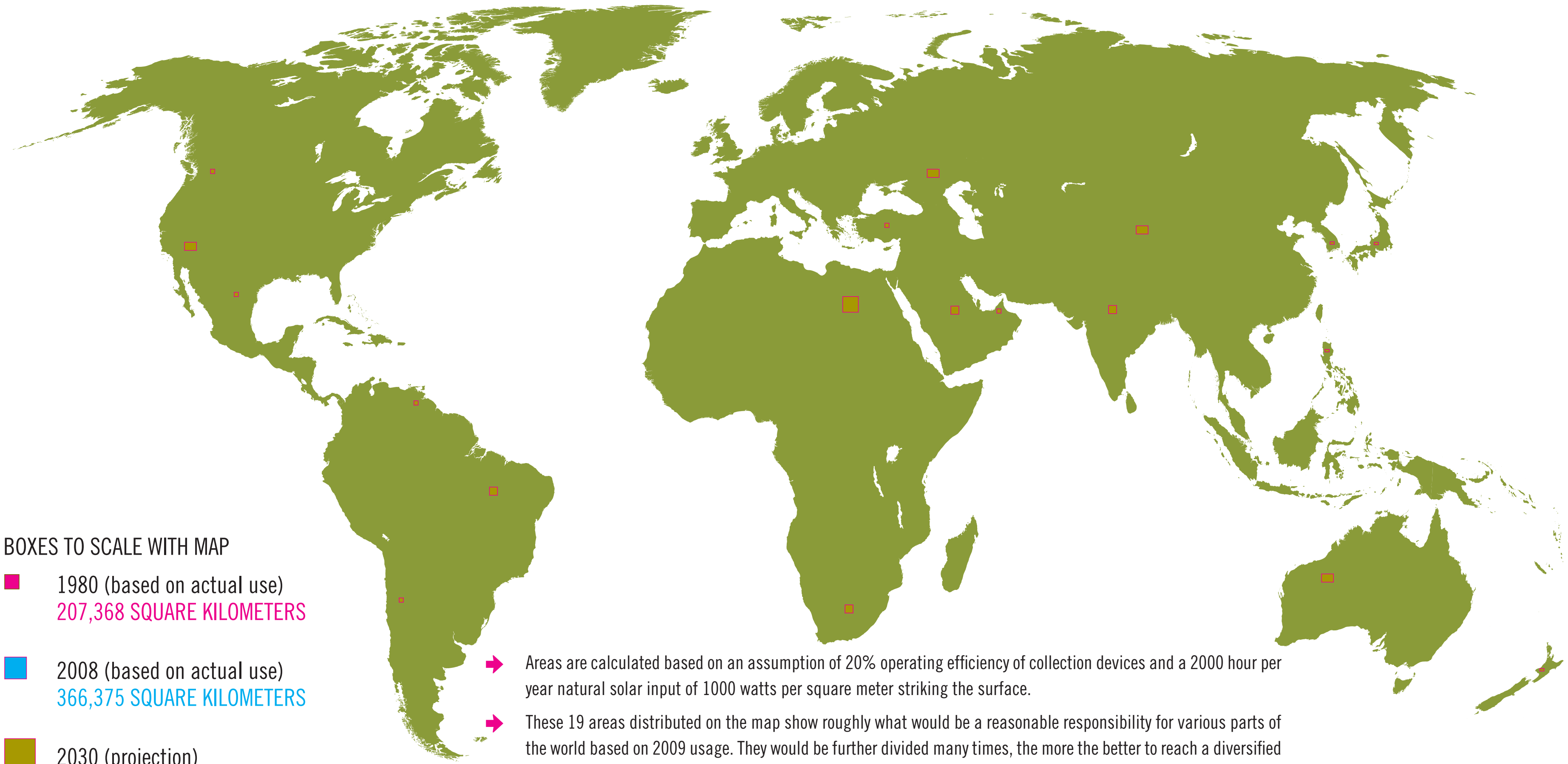
6X U.S. electric capacity!



SURFACE AREA REQUIRED TO POWER THE WORLD

WITH ZERO CARBON EMISSIONS AND WITH SOLAR ALONE

www.landartgenerator.org



BOXES TO SCALE WITH MAP

1980 (based on actual use)
207,368 SQUARE KILOMETERS

2008 (based on actual use)
366,375 SQUARE KILOMETERS

2030 (projection)
496,805 SQUARE KILOMETERS

Required area that would be needed in the year 2030 is shown as one large square in the key above and also as distributed around the world relative to use and available sunlight.

- Areas are calculated based on an assumption of 20% operating efficiency of collection devices and a 2000 hour per year natural solar input of 1000 watts per square meter striking the surface.
- These 19 areas distributed on the map show roughly what would be a reasonable responsibility for various parts of the world based on 2009 usage. They would be further divided many times, the more the better to reach a diversified infrastructure that localizes use as much as possible.
- The large square in the Saharan Desert (1/4 of the overall 2030 required area) would power all of Europe and North Africa. Though very large, it is 18 times less than the total area of that desert.
- The definition of "power" covers the fuel required to run all electrical consumption, all machinery, and all forms of transportation. It is based on the US Department of Energy statistics of worldwide Btu consumption and estimates the 2030 usage (678 quadrillion Btu) to be 44% greater than that of 2008.
- Area calculations do not include magenta border lines.

land art generator initiative

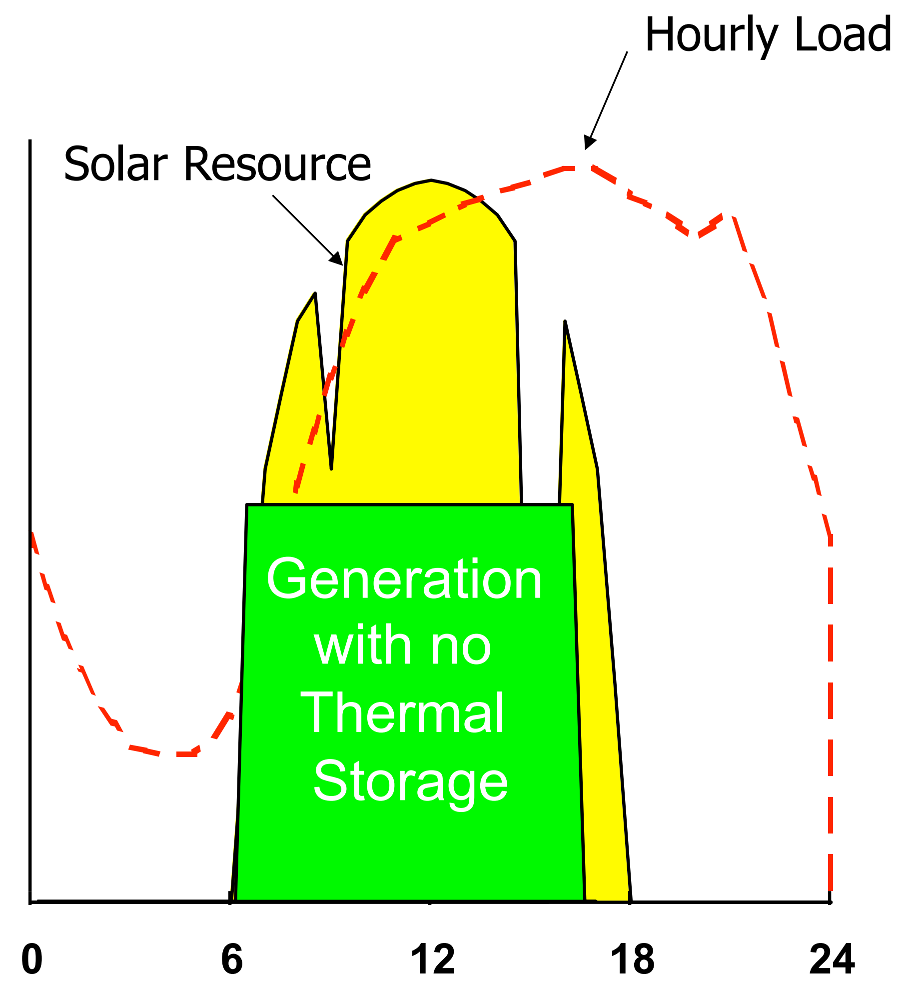

Concentrating Solar Power
(CSP)

354 MW Solar Electric Generating Systems (SEGS)

CSP’s BIG ATTRACTION:

STORAGE!

CSP with Thermal Energy Storage
Meets Utility Demands for Power



CSP with Thermal Energy Storage
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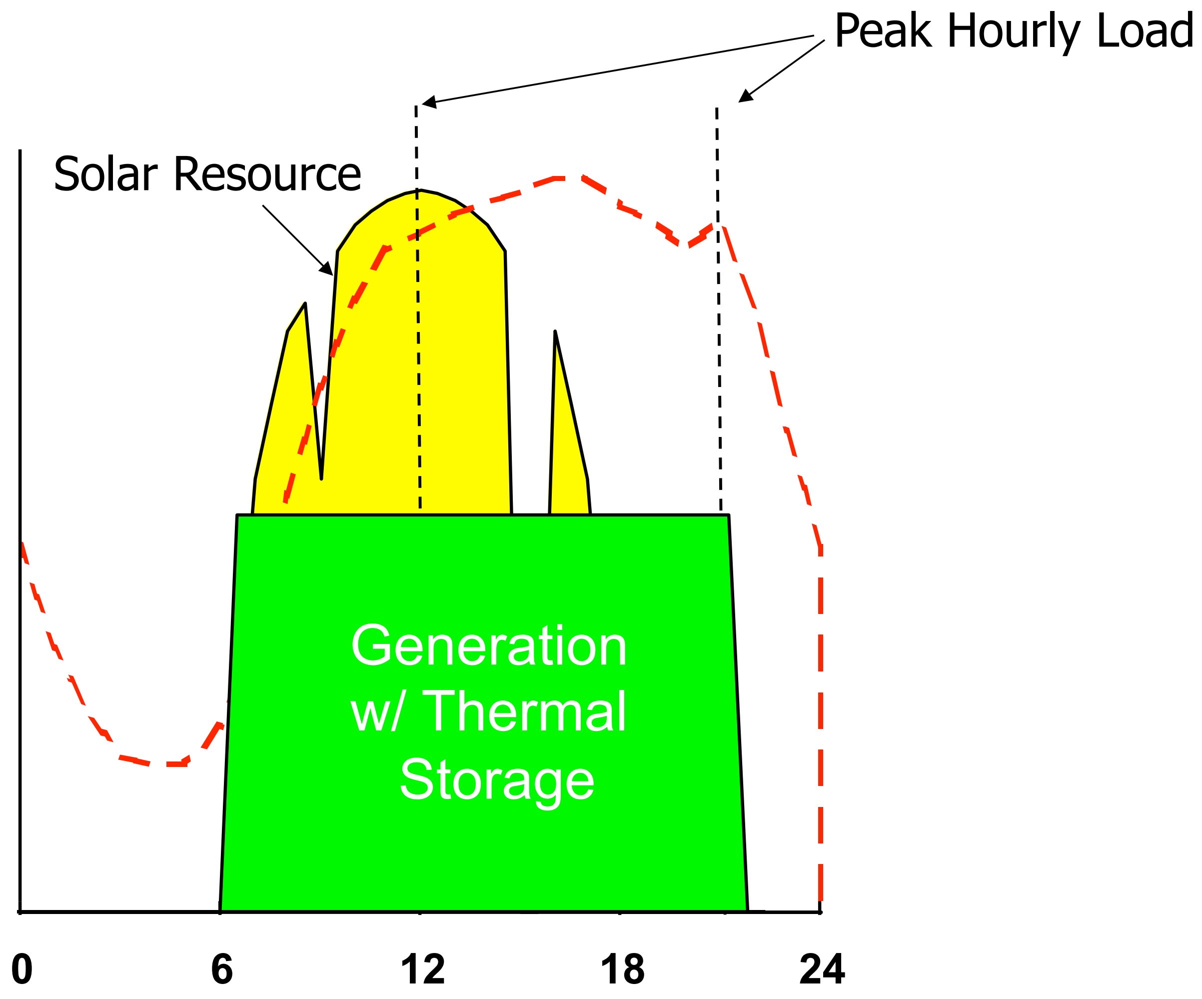
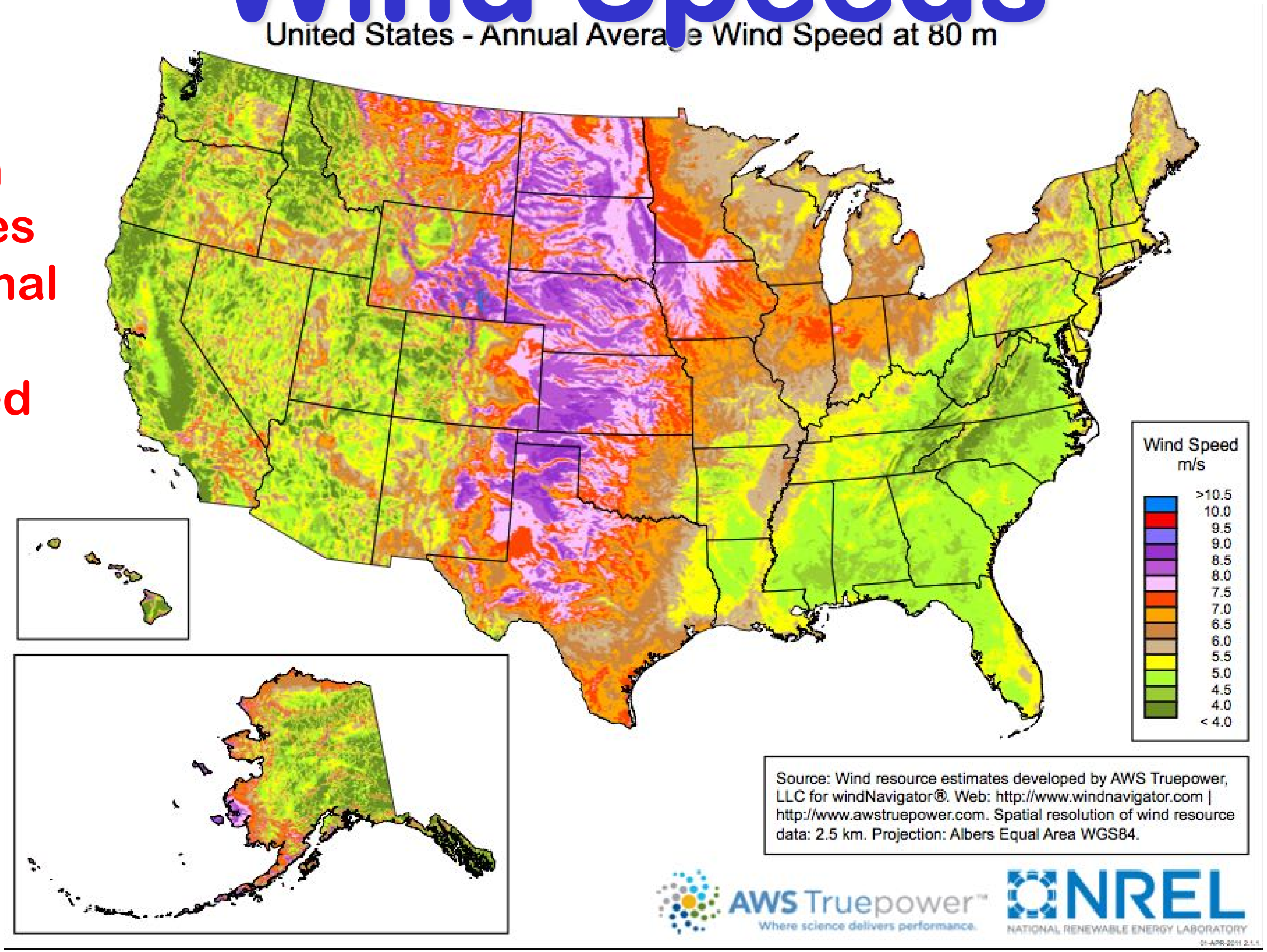


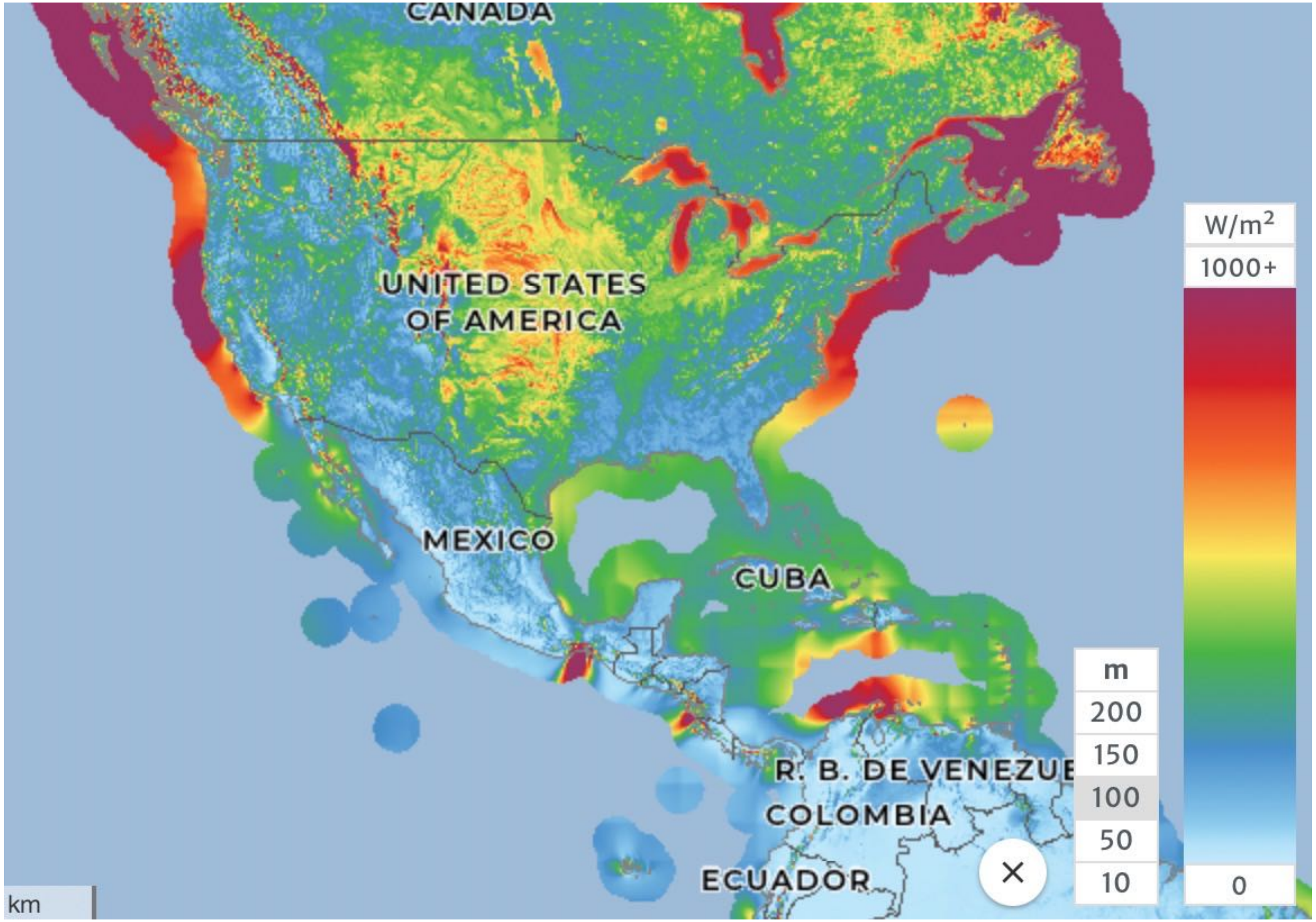
BrightSource 392 MW Ivanpah, California

Wind Speeds

Energy from wind turbines is proportional to the wind speed cubed



Wind *Energy*

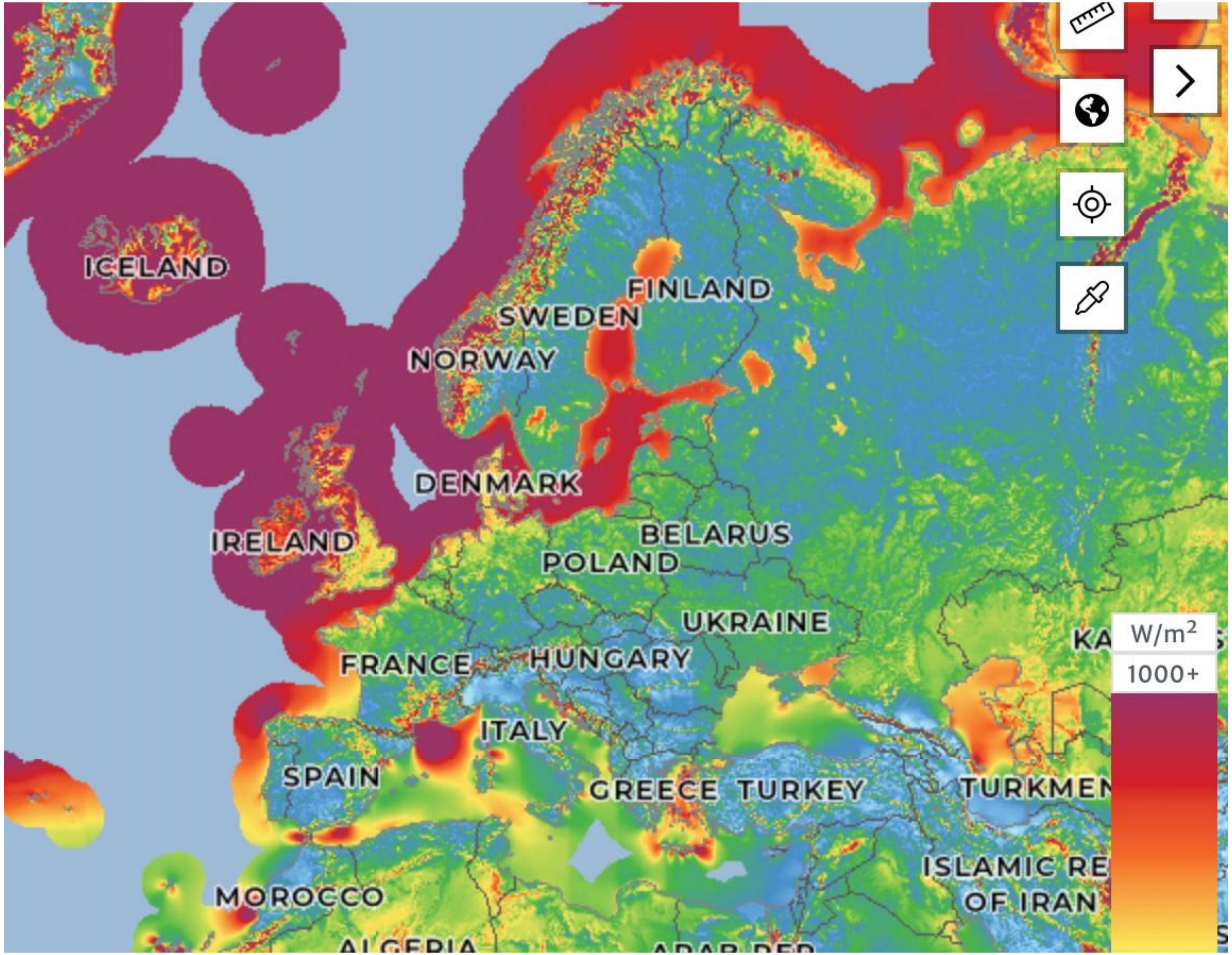


Offshore east and west coast *much* better than Great Plains!

New extremely tall offshore turbines with capacity factors > 65% (higher than gas or coal)

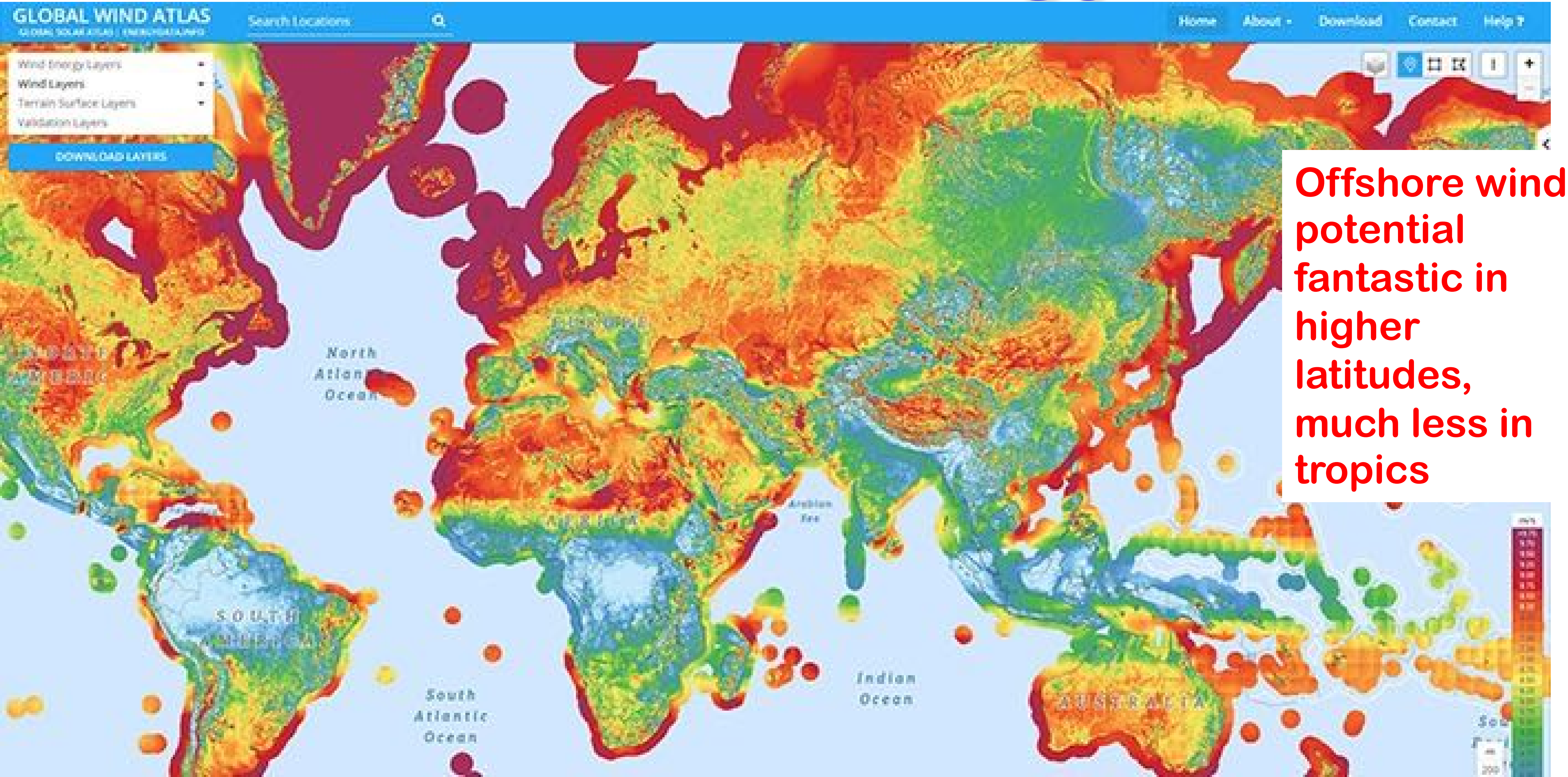
Also that's where the electricity demand is greatest

Wind *Energy*



Phenomenal energy availability off NW Europe!

Wind *Energy*

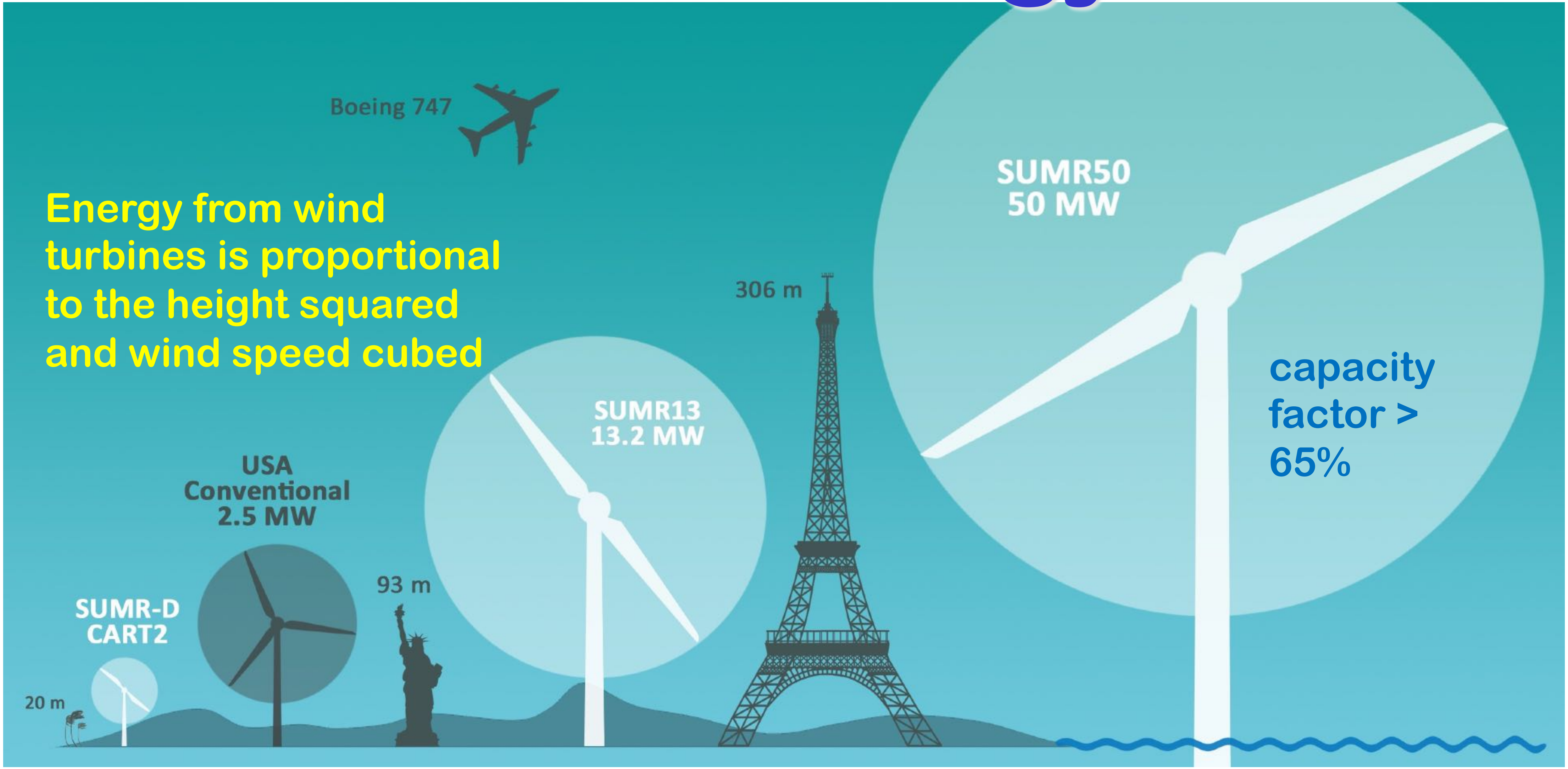


Offshore wind potential fantastic in higher latitudes, much less in tropics

Wind Energy

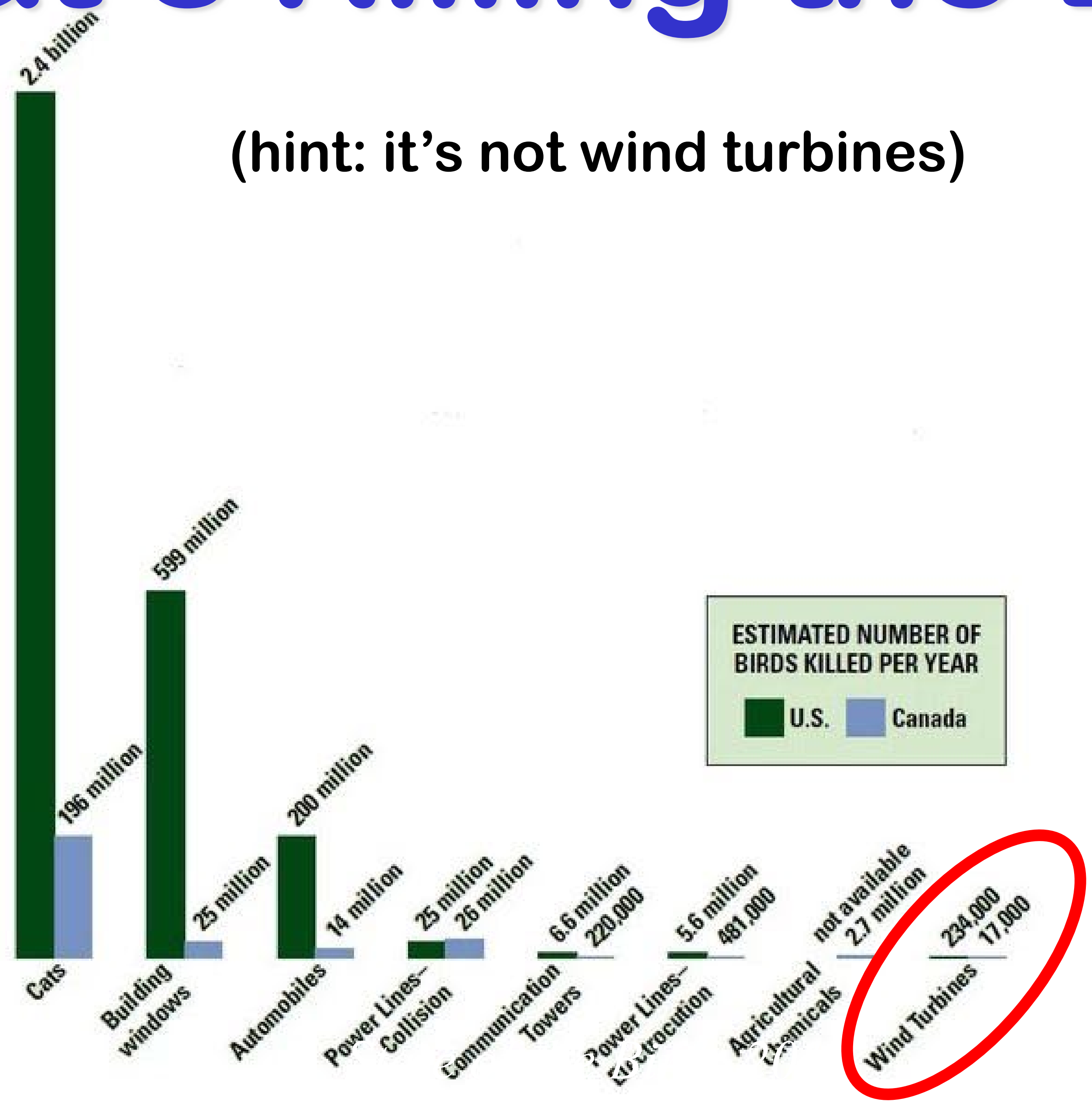
Energy from wind turbines is proportional to the height squared and wind speed cubed

capacity factor > 65%



What's Killing the Birds?

(hint: it's not wind turbines)



Advocacy

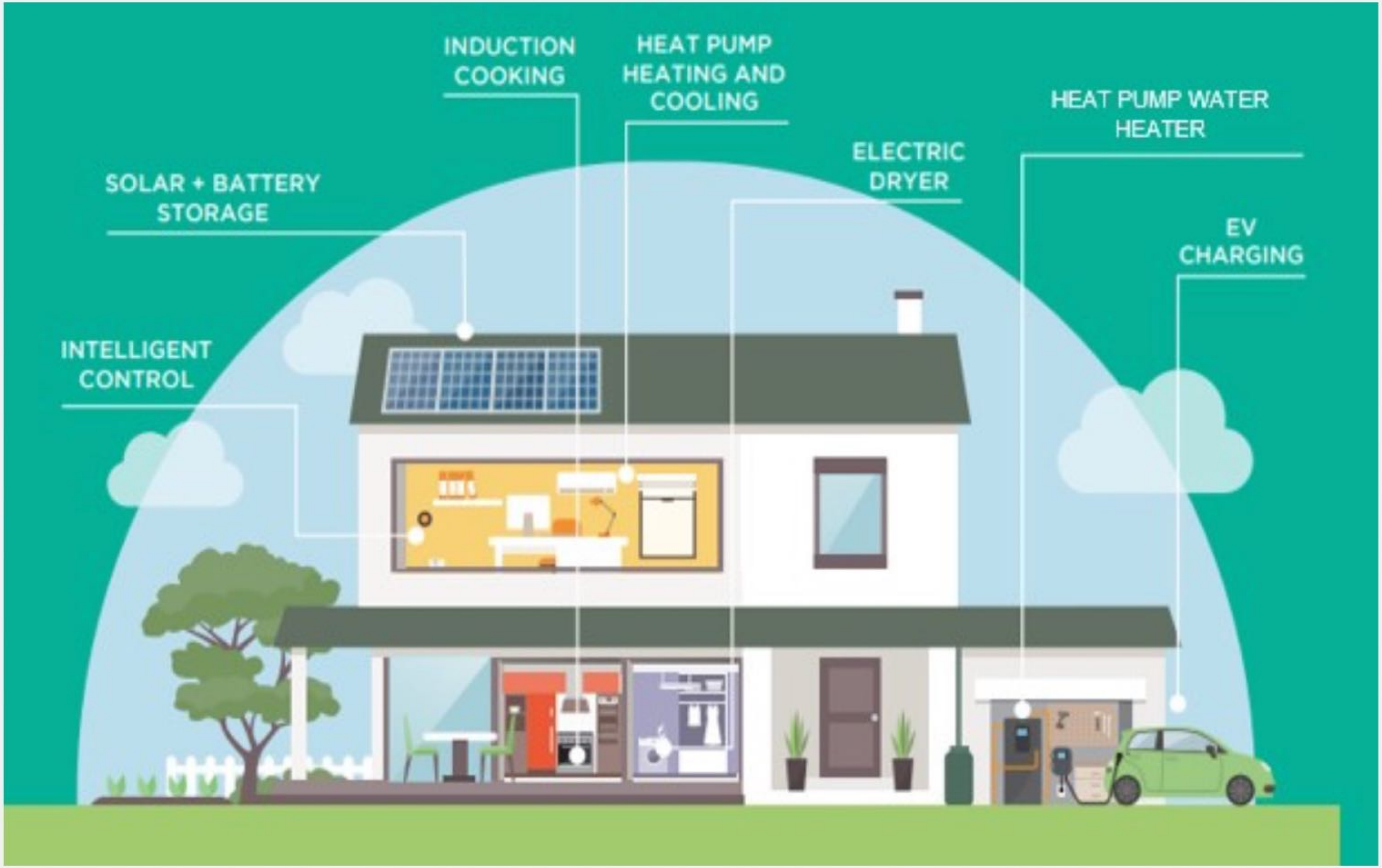
Audubon's Position on Wind Power

Snow Geese and Greater White-fronted Geese. Photo: Greg Latza

Audubon strongly supports properly sited wind power as a renewable energy source that helps reduce the threat posed to birds and people by climate change. However, we also advocate that wind power facilities should be planned, sited, and operated in ways that minimize harm to birds and other wildlife, and we advocate that wildlife agencies should ensure strong enforcement of the laws that protect birds and other wildlife.

Electrify Everything

ELECTRIFY EVERYTHING



Electrification = Efficiency!

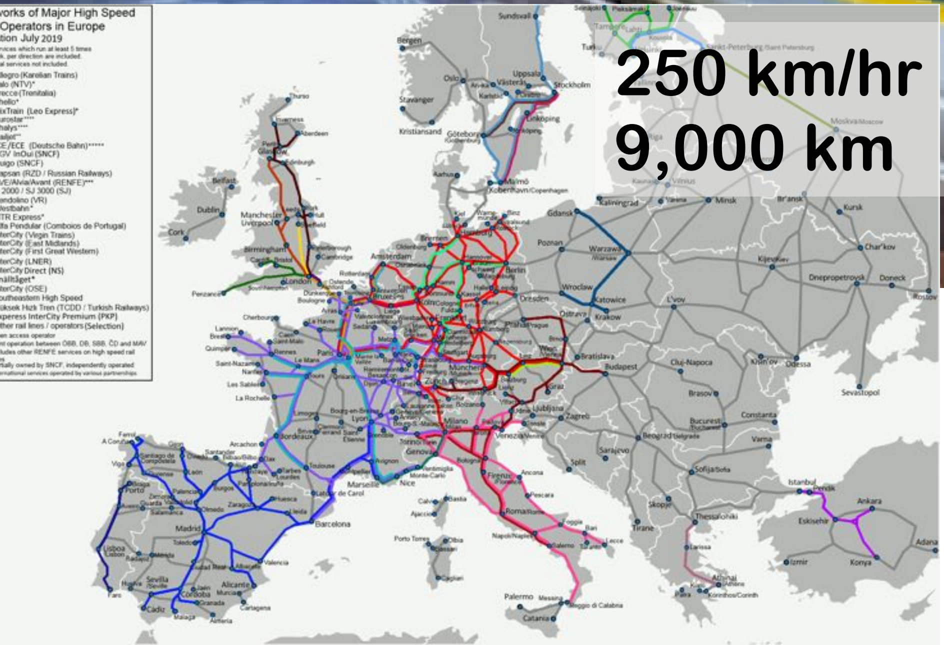
Large-scale electrification would cut primary energy consumption in the US by about 55%

- 10% of our energy is used to mine & distribute fuels!
- Wind & Solar waste less energy through mechanical conversions than fossil-powered generators – save 15%
- Electrifying transportation saves another 15%
- Electrifying buildings saves another 10%

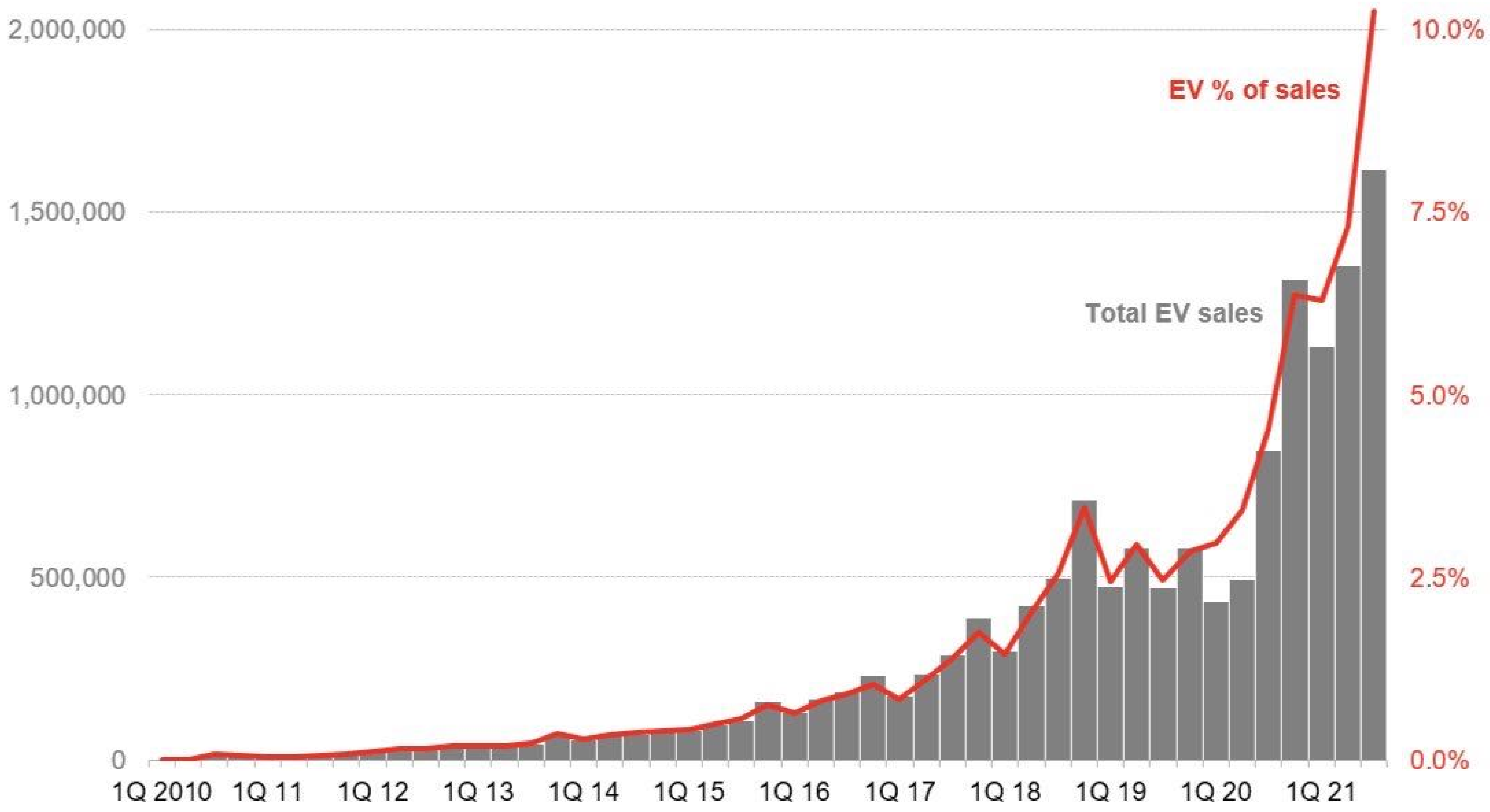
These savings are BEFORE “traditional” efficiency measures like insulation, lighting, etc

https://www.vox.com/energy-and-environment/21349200/climate-change-fossil-fuels-rewiring-america-electrify

Electrify Transportation

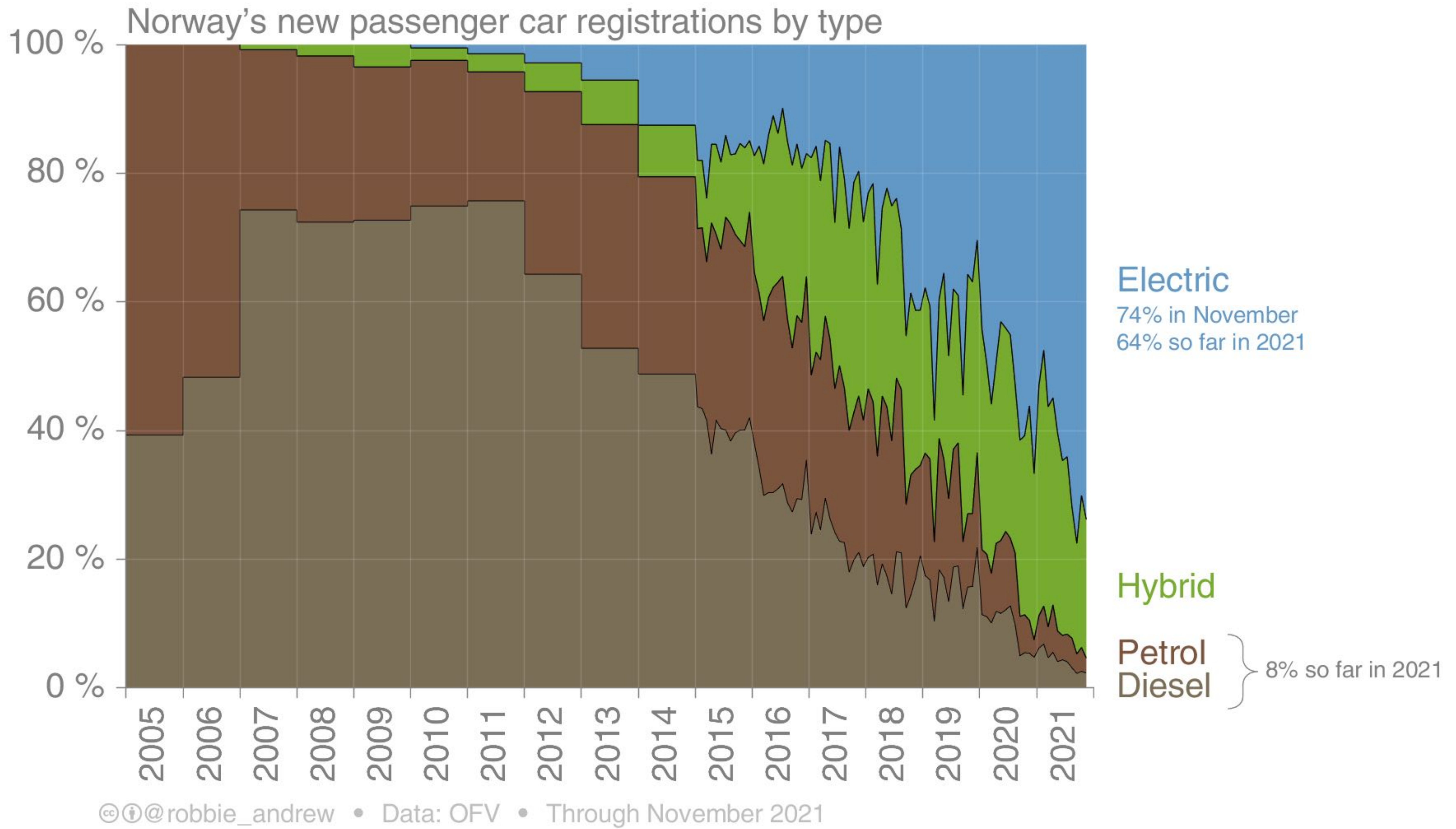


Quarterly electric passenger vehicle sales and % of total sales



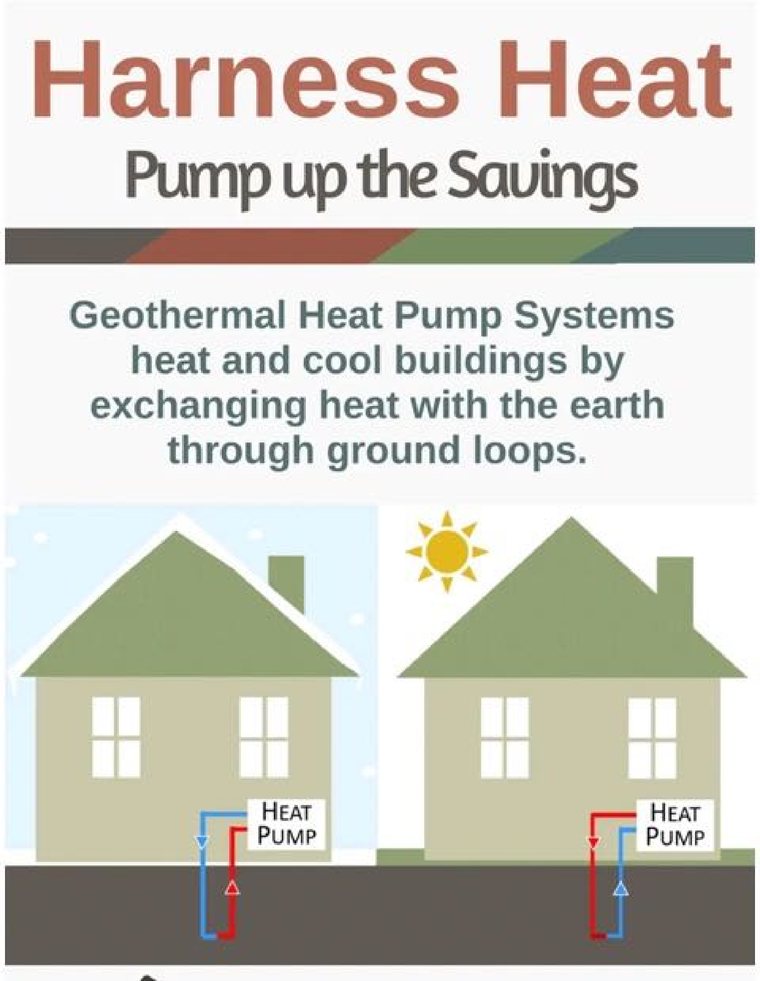
Source: *Bloomberg Intelligence, BloombergNEF, Rystad Energy. Note: Includes plug-in hybrids.*

BloombergNEF


Norway's new passenger car registrations by type
100 %
80 %
60 %
40 %
20 %
0 %
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Electric
74% in November
64% so far in 2021
Hybrid
Petrol
Diesel
8% so far in 2021
@robbie_andrew • Data: OFV • Through November 2021

Electrify Heating

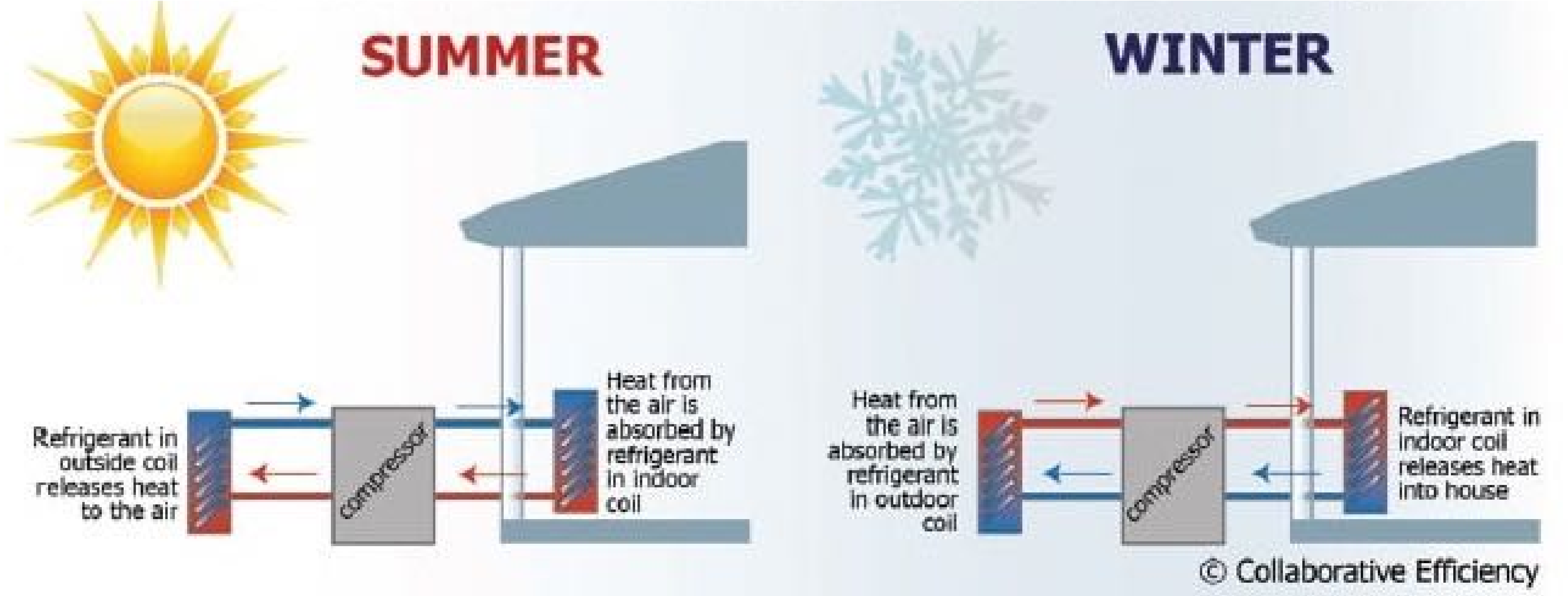
p system. Robert Brecha, CC BY-ND



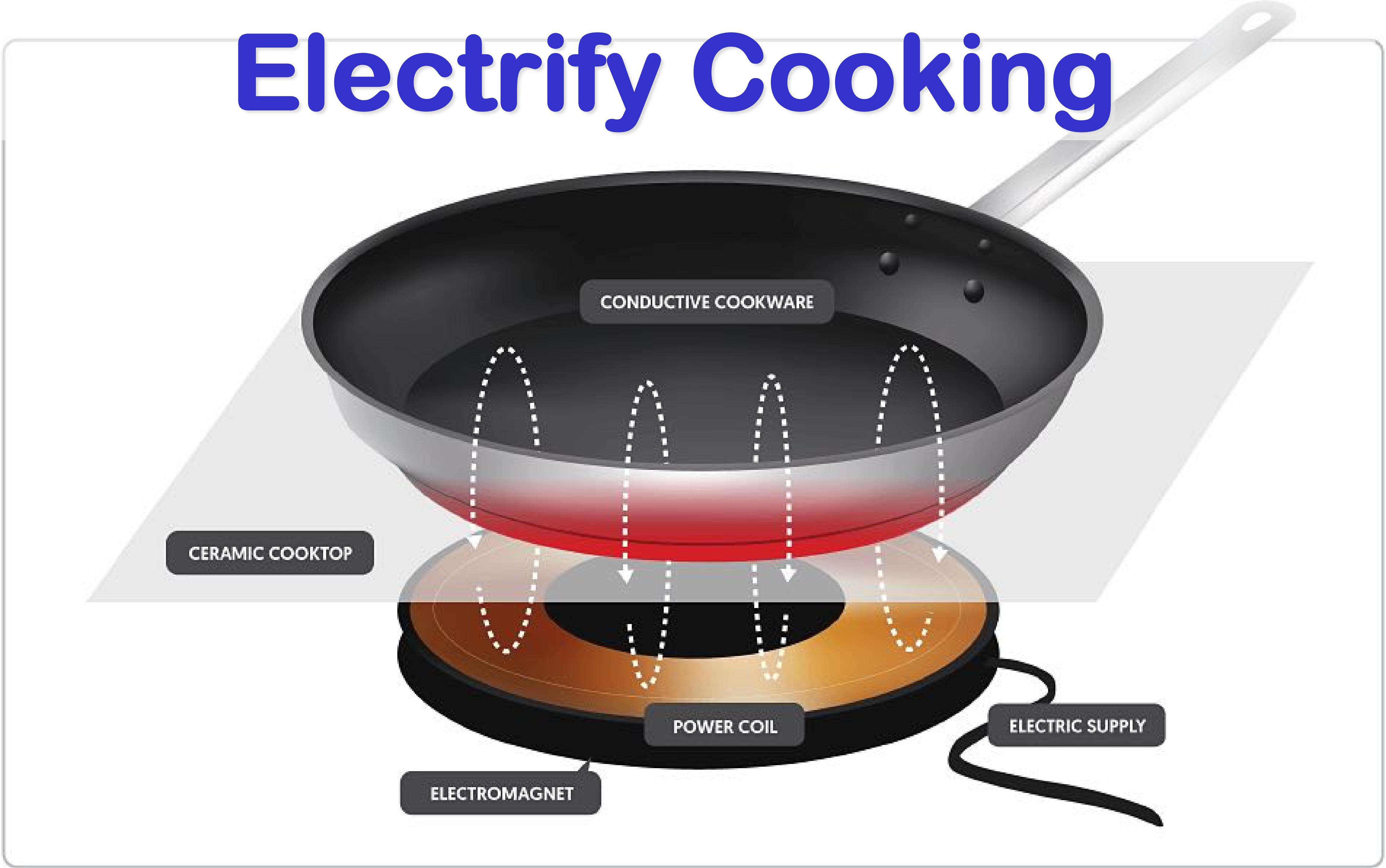
Electrification Myth-Busting: Heat Pumps Are Ready for Cold Climates Today

When paired with better building standards and rooftop solar, the electrification of homes pencils out economically even in regions with the harshest winters.

JUSTIN GERDES | APRIL 15, 2019



Electrify Cooking



Electrify Industry

Almost half of fuel consumed for energy can be electrified with technology available today.

Share of total estimated fuel consumption for energy, 2017, %

	Share (%)	Examples of processes	Technology status
Other (potential not assessed[1])	19		
Very-high-temperature heat (>1,000°C)	32	Melting in glass furnace, reheating of slab in hot strip mill, and calcination of limestone for cement production	Research or pilot phase
High-temperature heat (400–1,000°C)	16	Steam reforming and cracking in the petrochemical industry	Available today
Medium-temperature heat (100–400°C)	18	Drying, evaporation, distillation, and activation	Available today
Low-temperature heat (≤100°C)	15	Washing, rinsing, and food preparation	Available today

Note: Current electricity consumption and energy consumption as feedstock are excluded. Sectors included are chemicals and petrochemicals, iron and steel, nonmetallic minerals, nonferrous metals, food and tobacco, transport equipment, machinery, textile and leather, wood and wood products, paper pulp and print, mining, industrial feedstock, and other industrial nonenergy use. Industrial energy consumption for which the source data do not specify a sector (nonspecified industrial energy consumption) is attributed to other industrial sectors and uses.

[1]Includes heating, ventilation, and air-conditioning; transportation; and refrigeration.

Source: Expert interviews; *Heat and cooling demand and market perspective*, JRC Scientific and Policy Reports, European Commission, 2012, publications.jrc.ec.europa.eu; "Manufacturing energy and carbon footprints (2014 MECS)," US Office of Energy Efficiency & Renewable energy, September 2018, energy.gov; *World energy balances 2019*, IEA, September 2019, iea.org; McKinsey analysis

McKinsey & Company

Heavy manufacturing uses energy differently than other parts of the economy

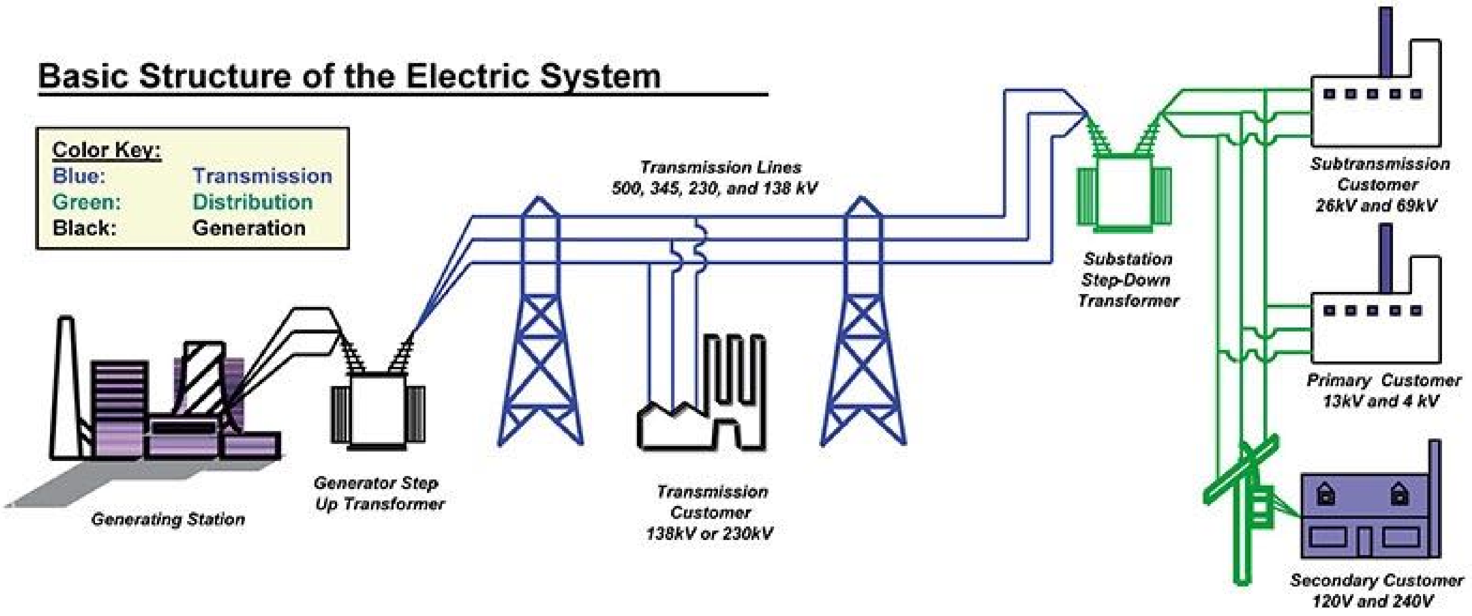
Some processes (e.g., steel and aluminum) require very high temperatures that are hard to get from electricity

Altogether, the really hard part is about the last 5% of energy-related CO_2 emissions

Grid Integration

Grid Integration

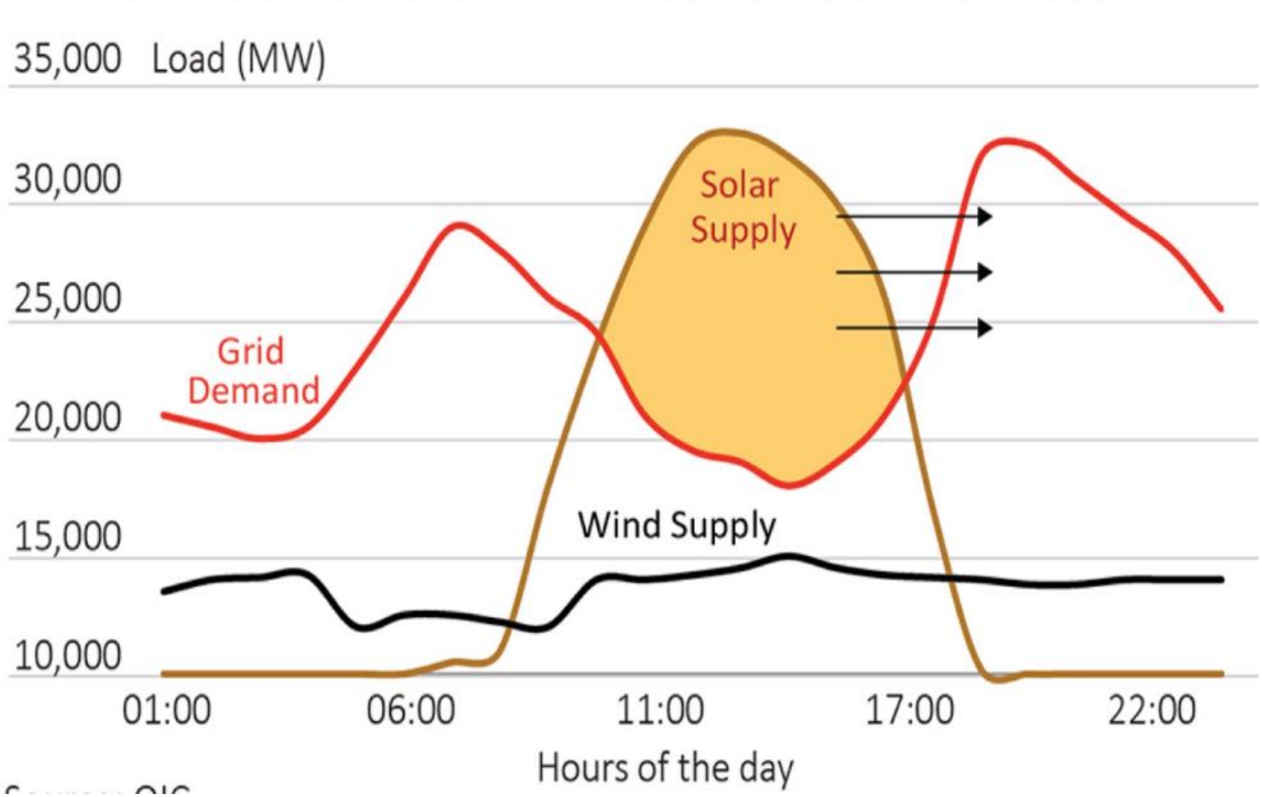
- Clean energy is already cheaper than old-fashioned energy



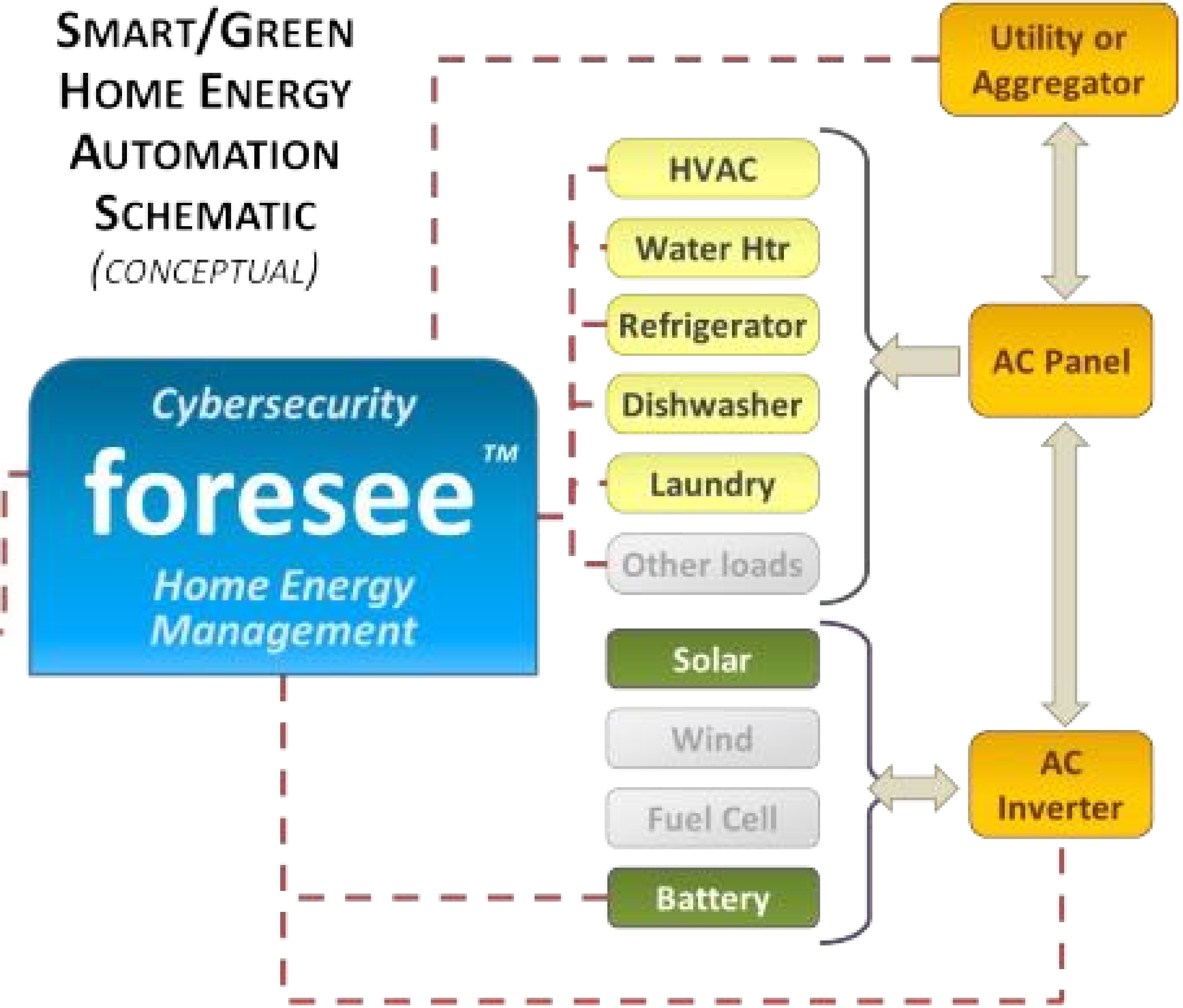
- The real challenge is getting it from where it's made to where and when it's used

Balancing Supply & Demand

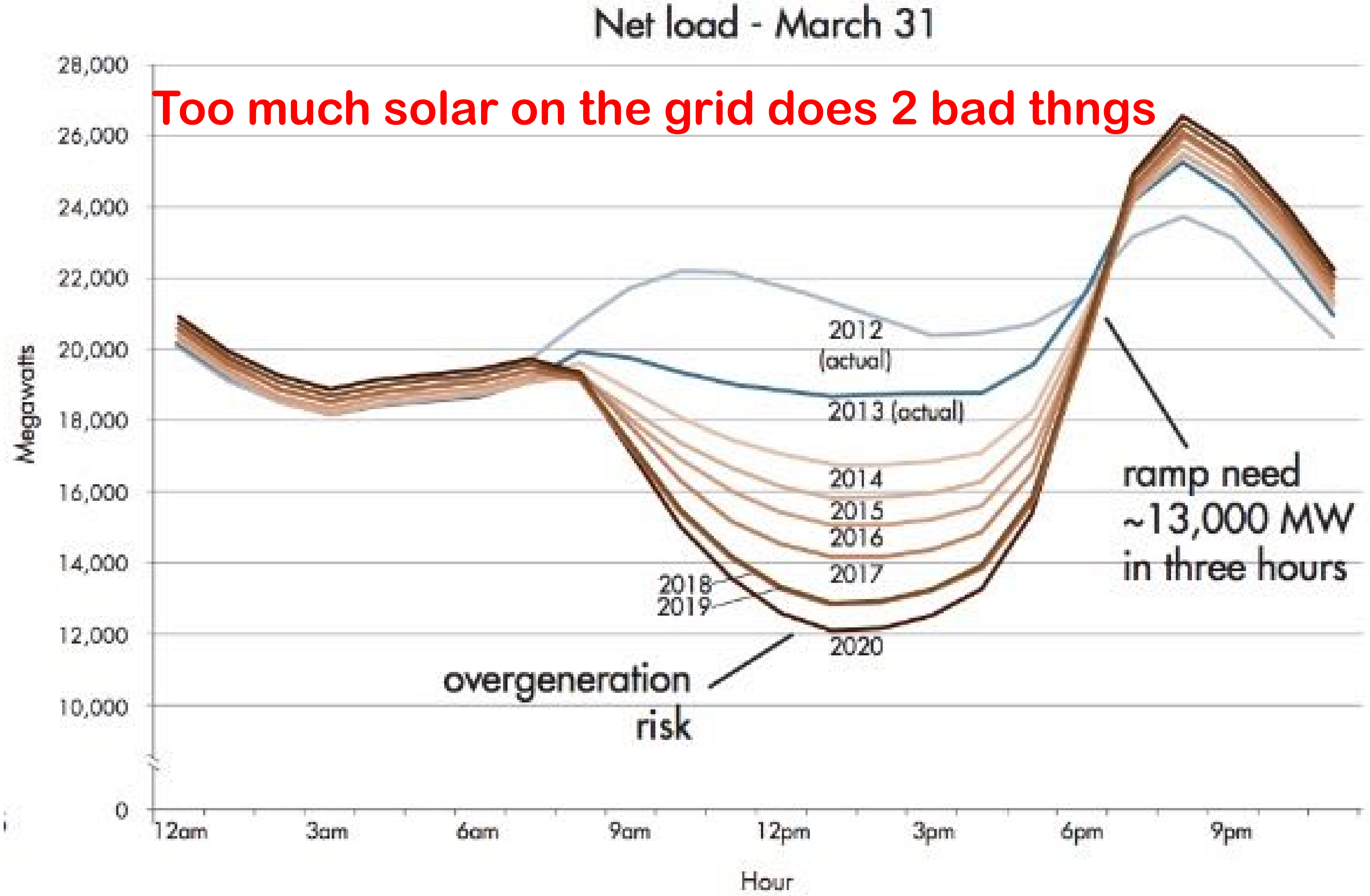
1. Demand Response / "Peak Shaving"
2. Mixing complementary sources
3. Integration Over Time: STORAGE
4. Integration Over Space: TRANSMISSION



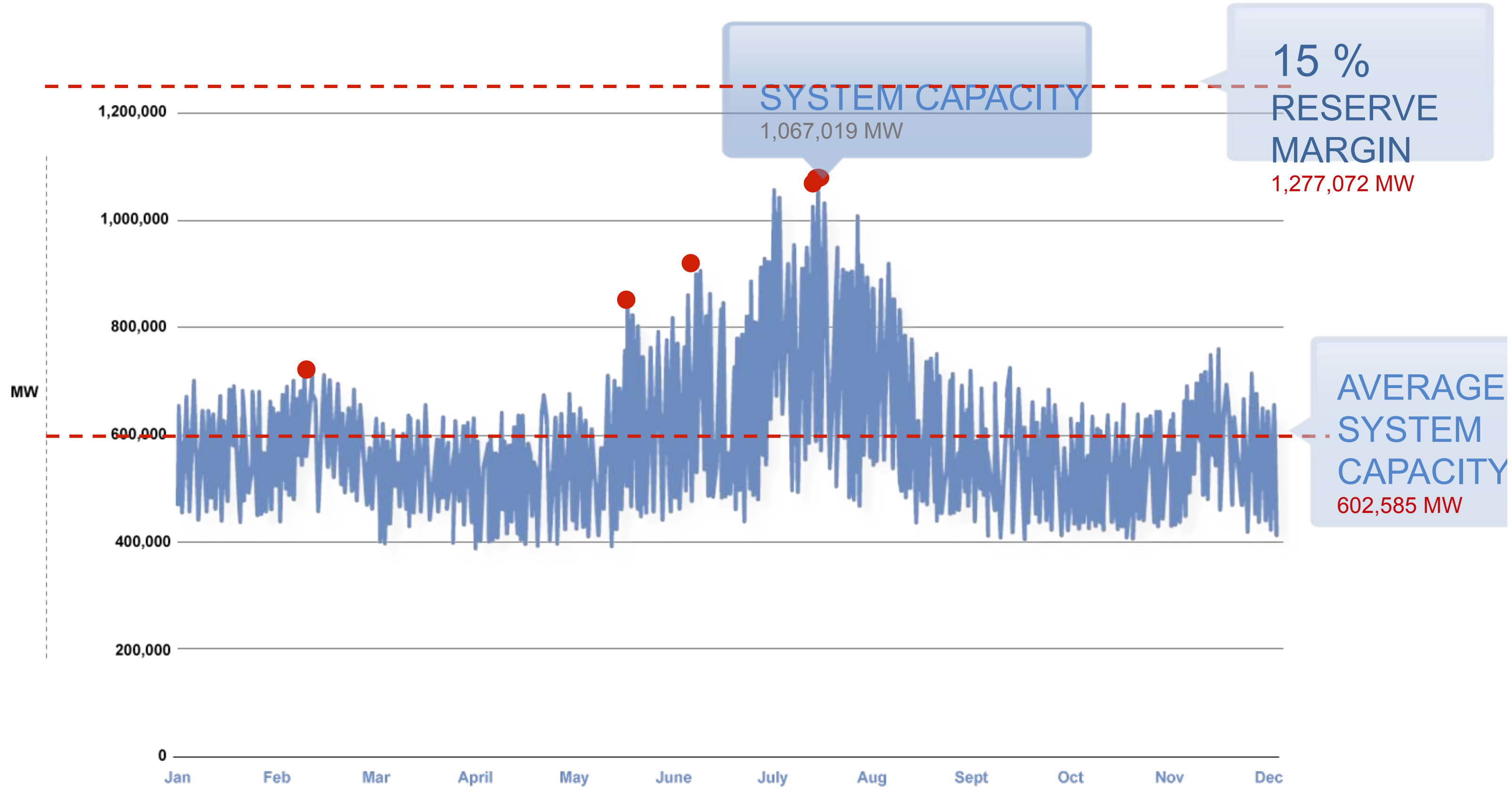
Smart Demand Management



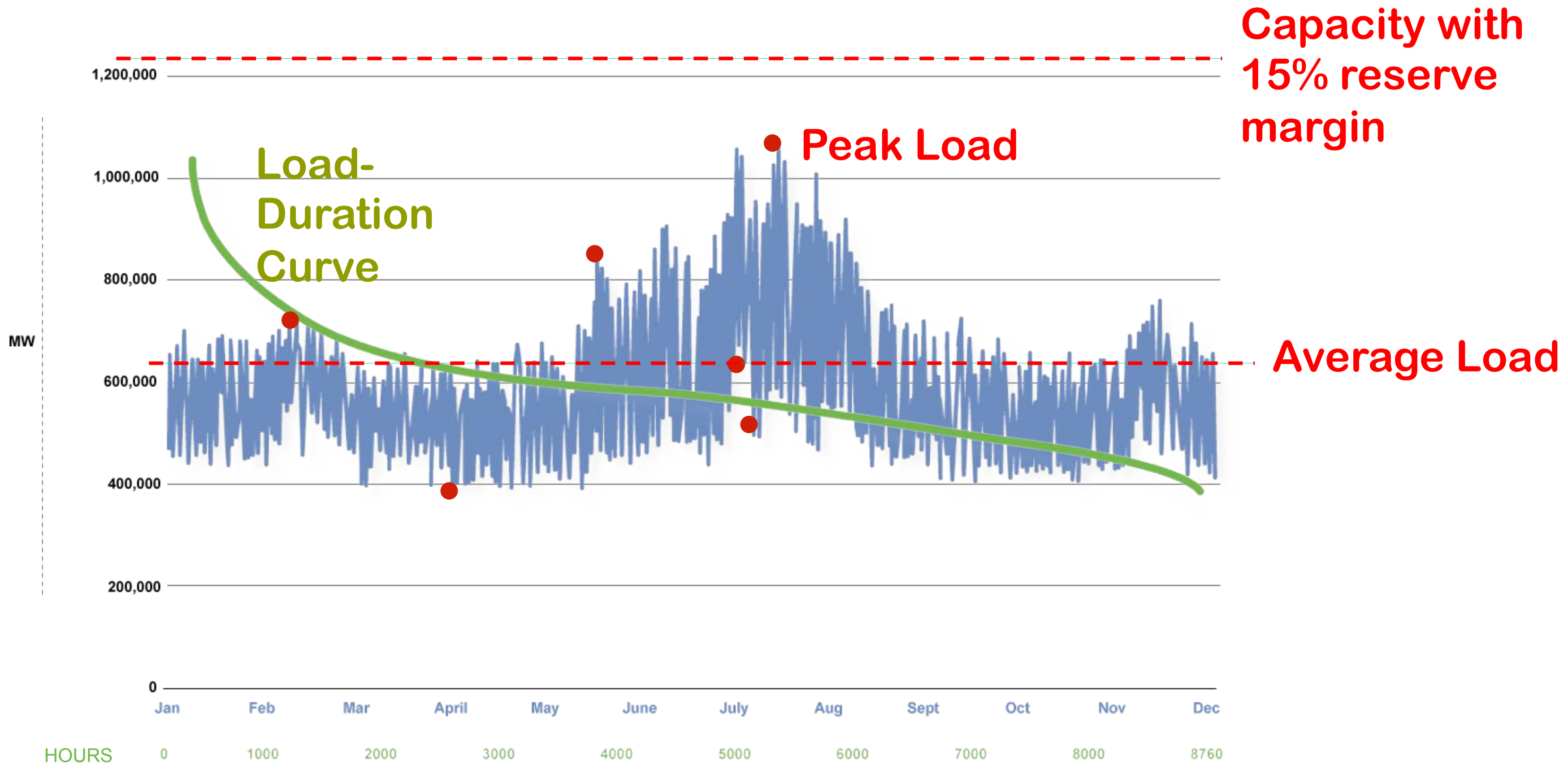
The "Duck Curve"



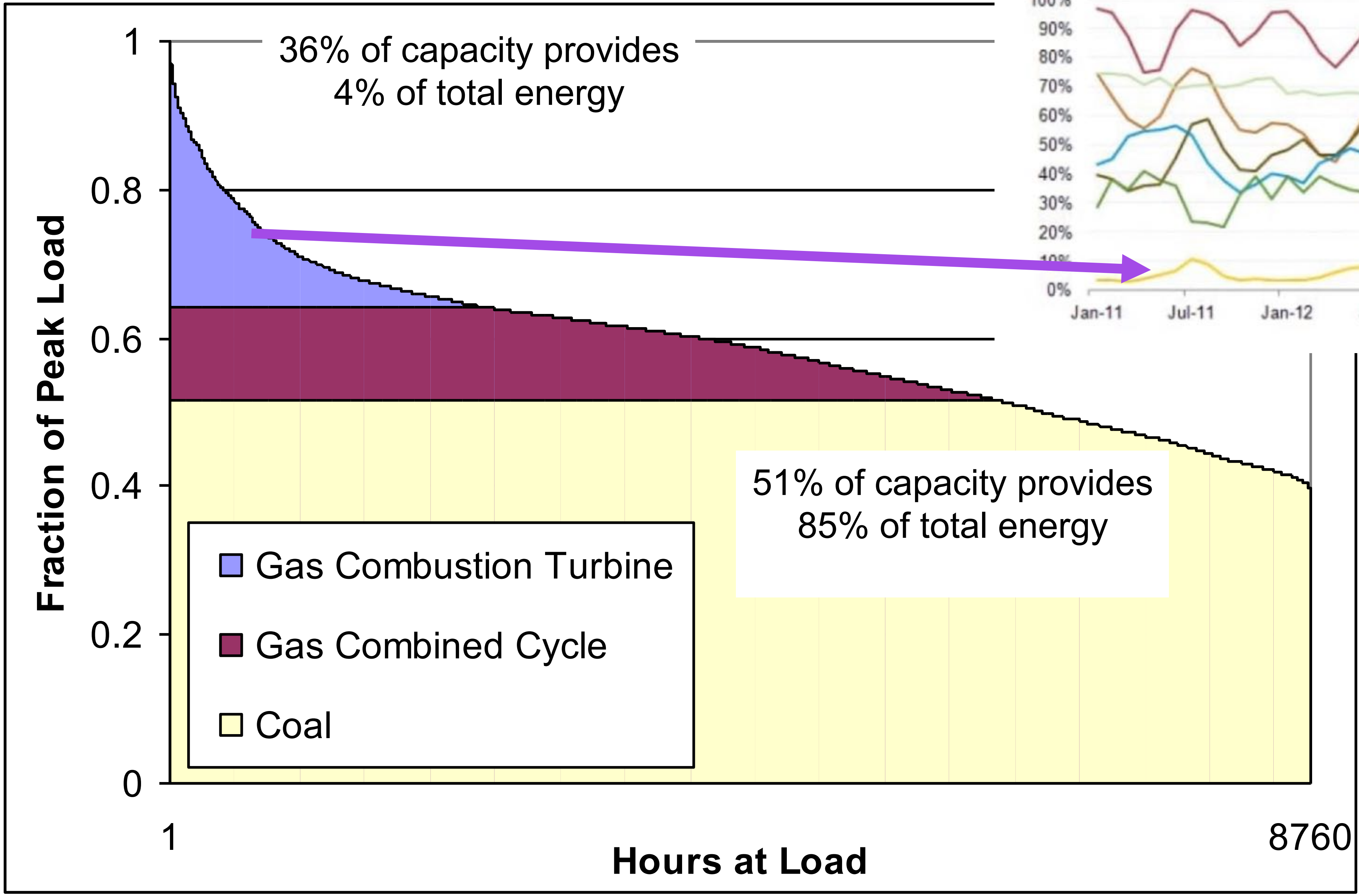
Highly Variable Load

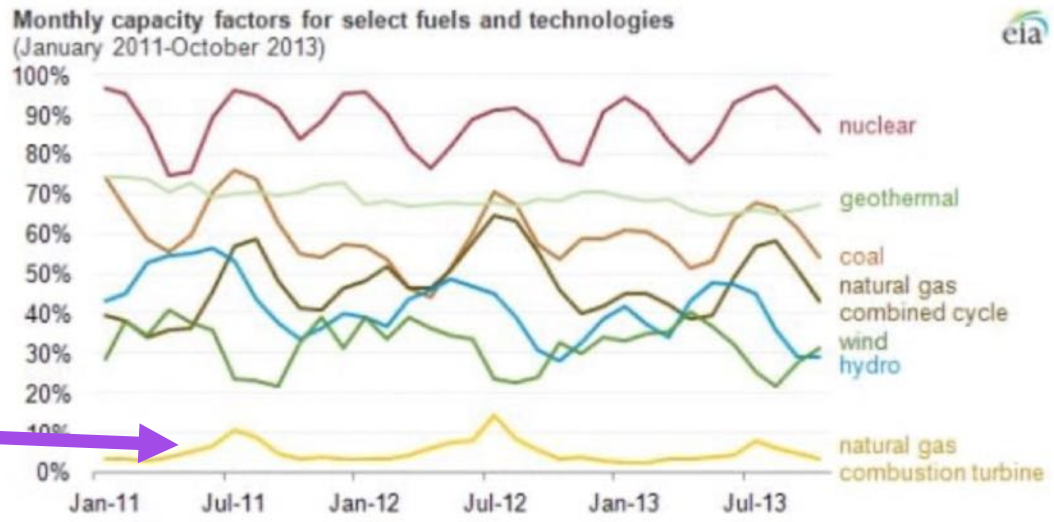


Highly Variable Load



Load Duration Curve





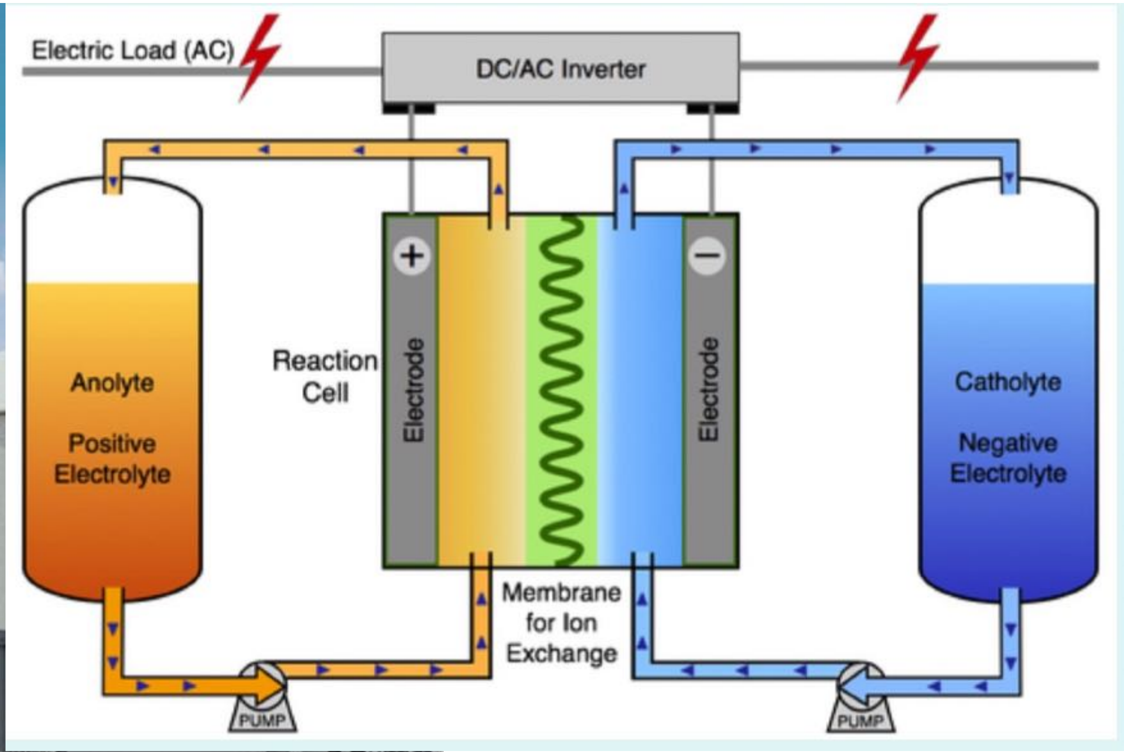
Gas turbine peaker 4x as much $ as PV!

Peaking Power?

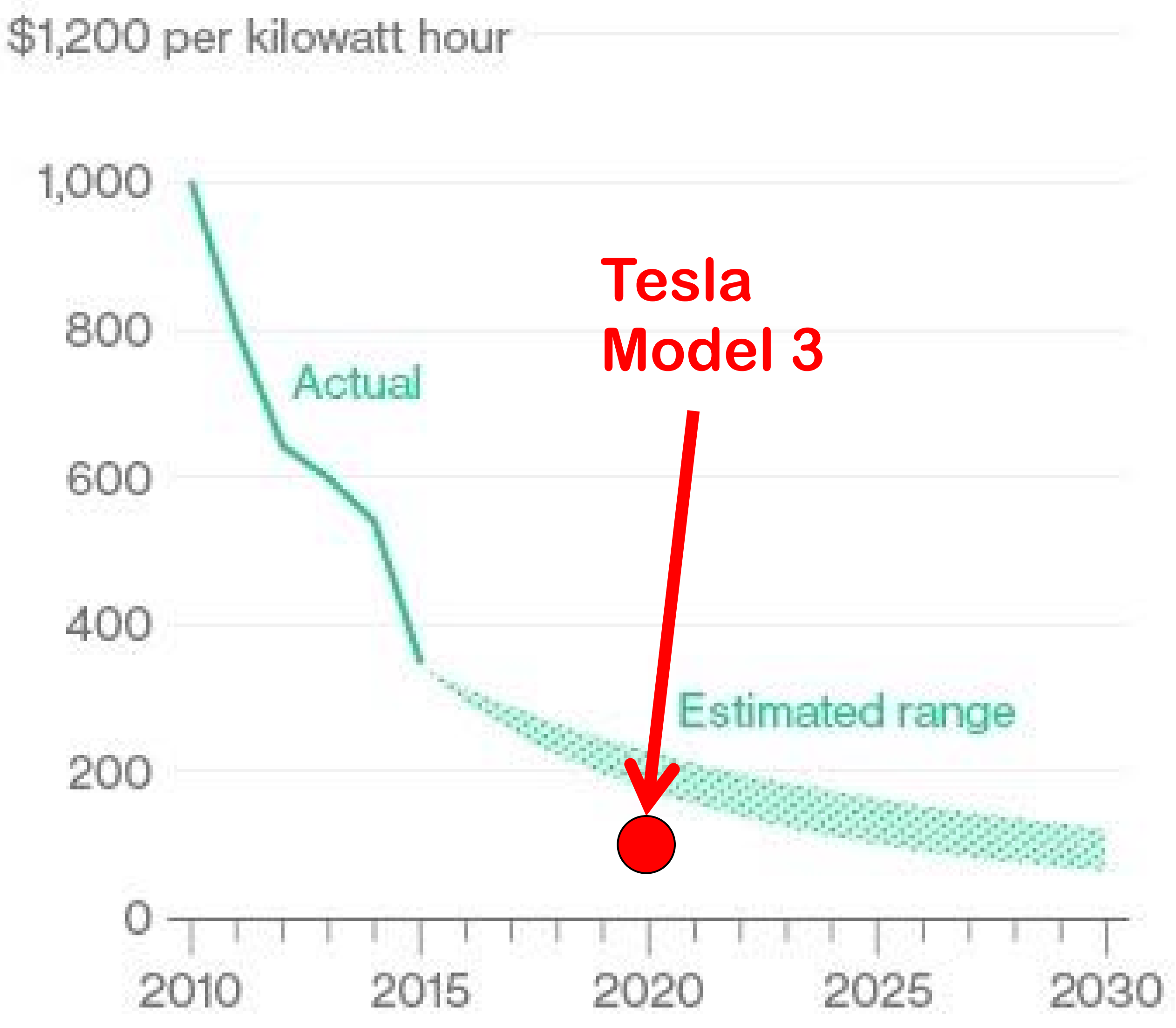
- Not just for intermittency: very valuable for voltage & frequency matching at grid scale!
- Storage doesn't compete against baseload; it competes against the MOST expensive gas peakers!

A typical lithium-ion battery system can store and regulate wind energy for the electric grid.

Utility-Scale Battery Storage



Li-Ion Batteries



Bloomberg New Energy Finance Data

- **In 2015, BNEF predicted $150/kWh by 2030**
- **Tesla and GM have beaten this target a decade early**

Distributed Batteries

ELECTRONICS

Wireless Electric Vehicle Charging System (WEVCS)

By **Kiranmai Momidi** Jul 12, 2019

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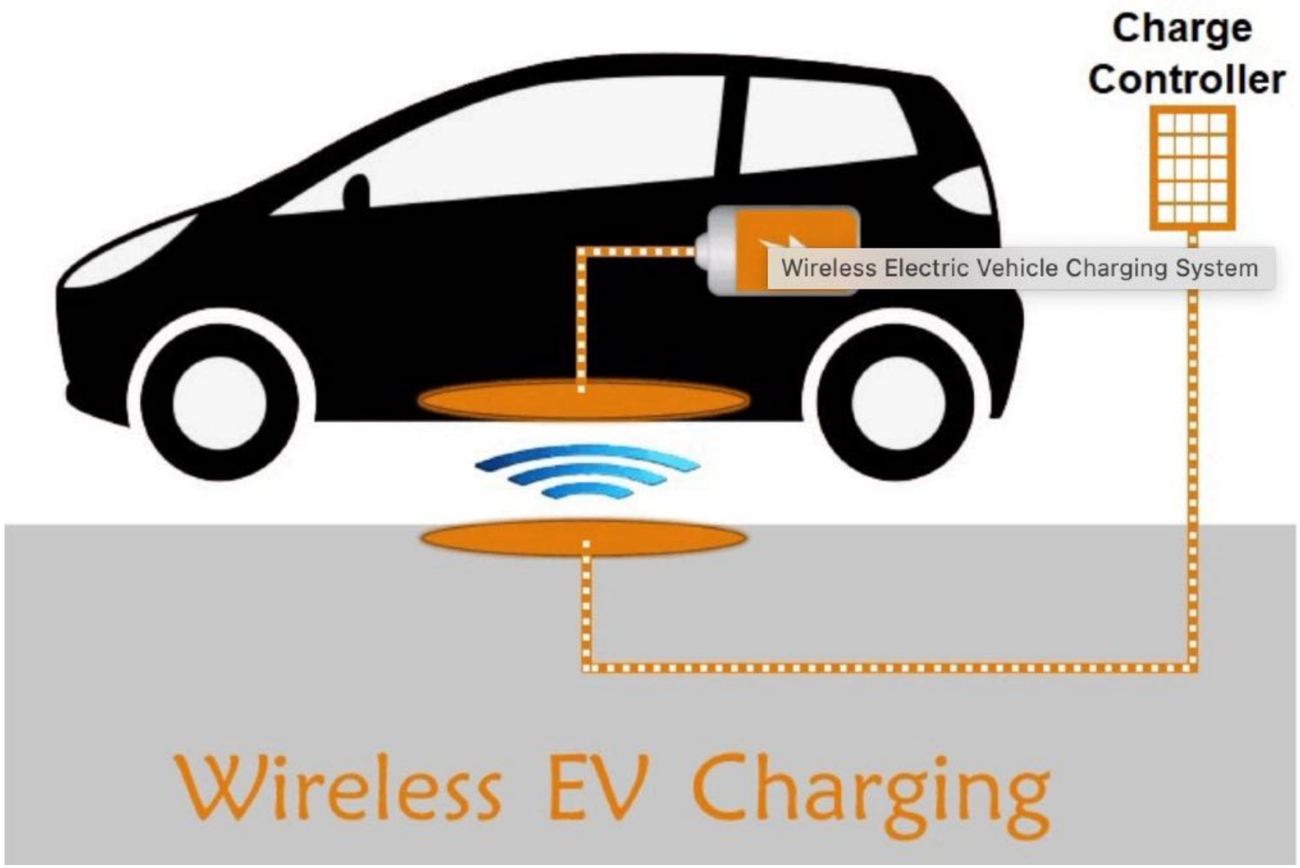
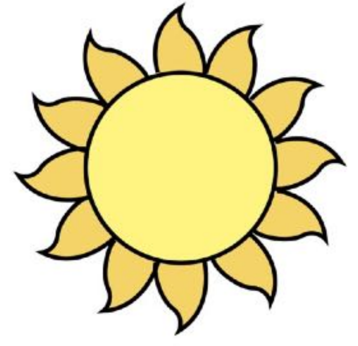
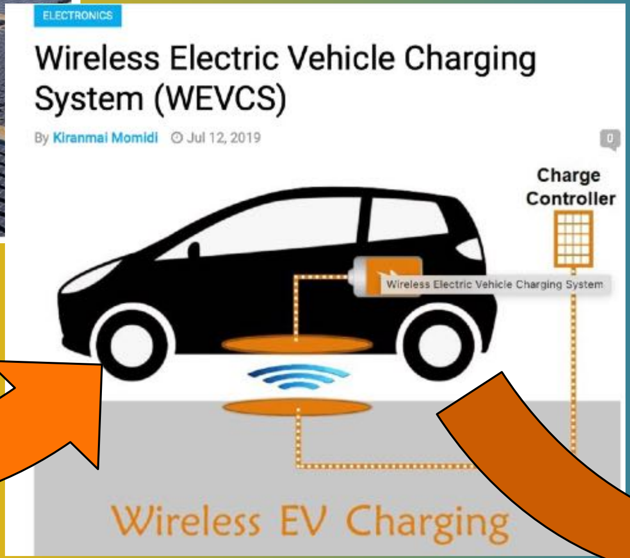




Science Fiction?

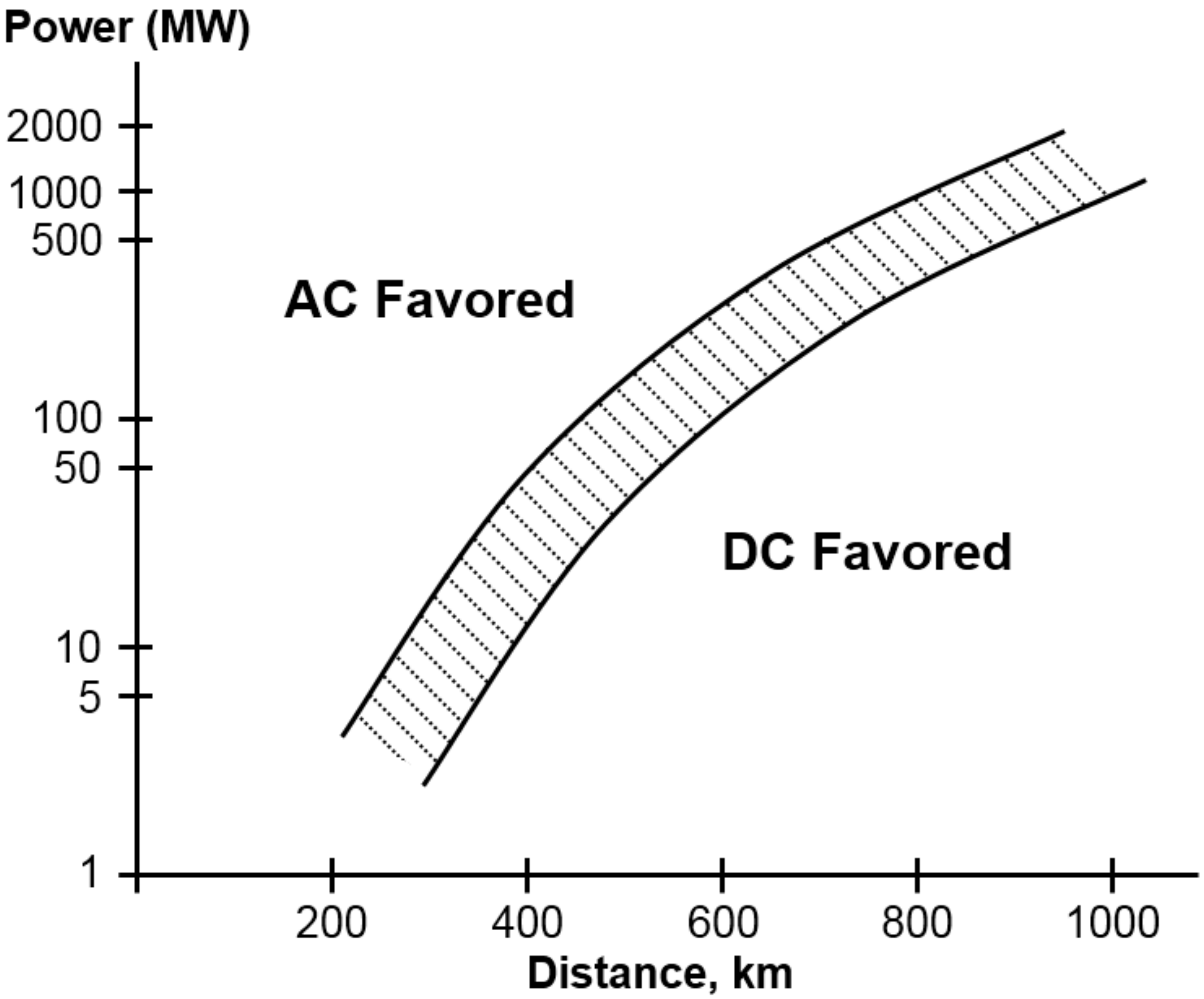
During the day, billions of EVs are charged using excess PV capacity

In the evening, the stored energy in EV batteries powers the grid to heat homes, cook meals, & entertain us



Transmission

Transmission Costs



- HVDC is cheapest over long distances
- The bigger the area, the less variable are solar & wind!

nature climate change

ARTICLES

PUBLISHED ONLINE: 25 JANUARY 2016 | DOI: 10.1038/NCLIMATE2921

Future cost-competitive electricity systems and their impact on US CO_2 emissions

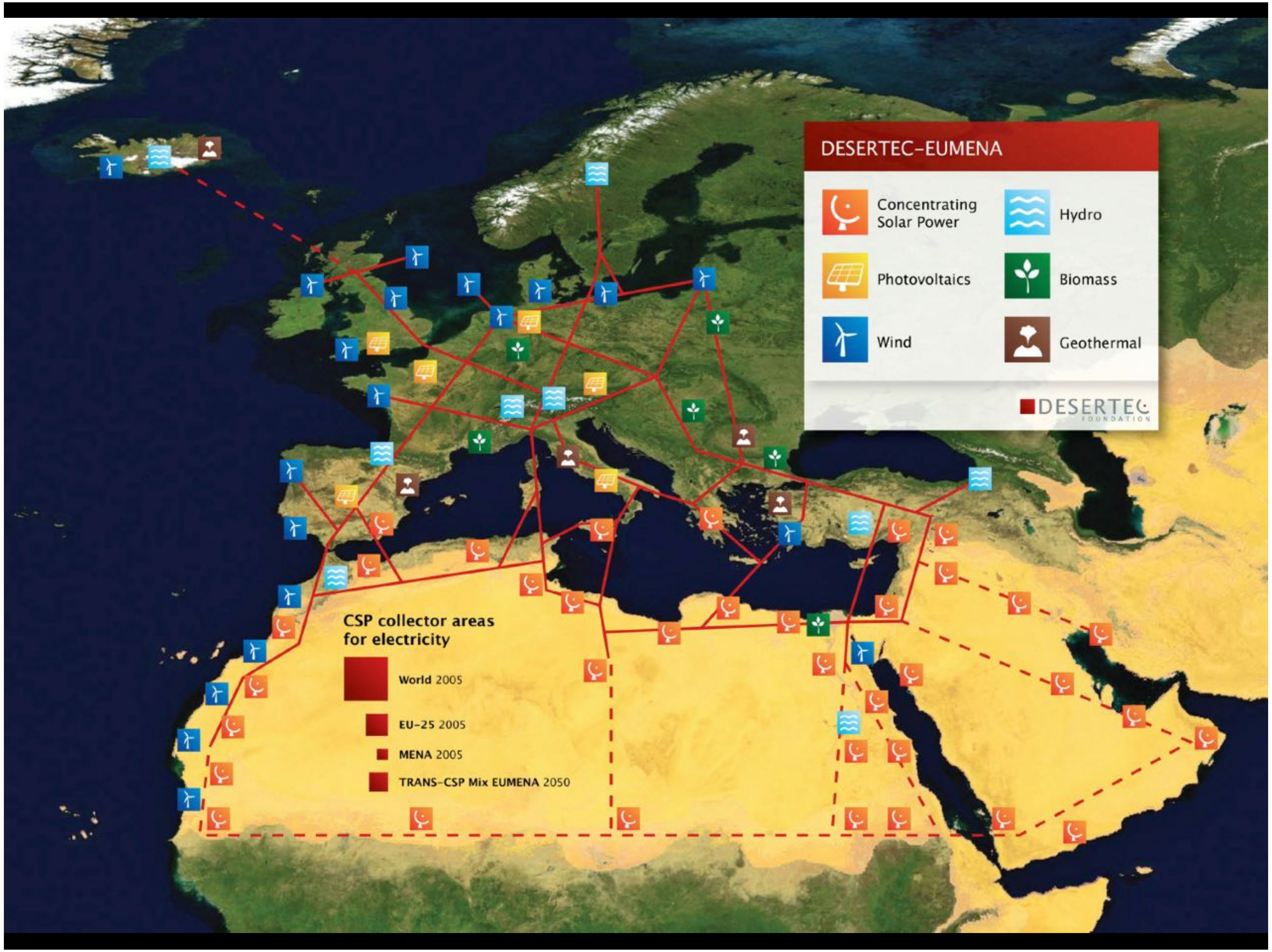
Alexander E. MacDonald[1*†], Christopher T. M. Clack[1,2*†], Anneliese Alexander[1,2], Adam Dunbar[1], James Wilczak[1] and Yuanfu Xie[1]

- For the US, build out new generation sources that are cheaper than just OPERATING existing sources
- Connect them across regions w/a new HVDC grid
- Meet 100% of demand 100% of the time
- 80% CO2 emissions reduction in 10 years
- Nobody's electric bills go up

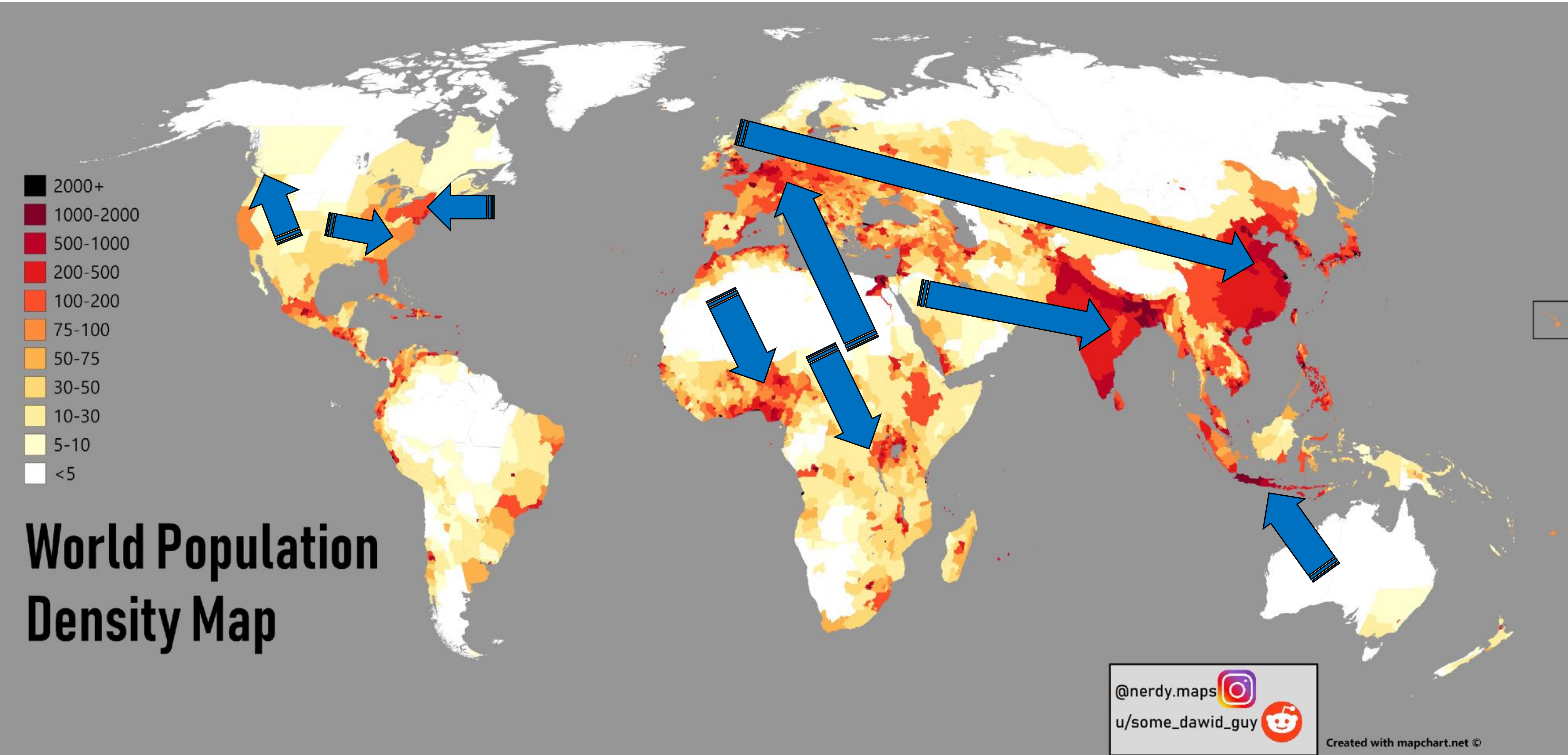
Sun Cable, Northern Territory Australia

- 30 GW! Equivalent to ~ 25 to 50 big coal-fired generators
- 30 GW-hr battery storage
- 4200 km HVDC transmission to Singapore
- Adds A$30 billion of Australian economy

DesertTec


DESERTEC-EUMENA
Concentrating Solar Power
Hydro
Photovoltaics
Biomass
Wind
Geothermal
DESERTEC
FOUNDATION
CSP collector areas for electricity
World 2005
EU-25 2005
MENA 2005
TRANS-CSP Mix EUMENA 2050

HVDC Transmission!



Summary

- It is CERTAINLY possible to provide abundant energy to everybody al the time without burning carbon!
- It can ALSO quite feasible in terms of costs and benefits