

Energy Transformations ?



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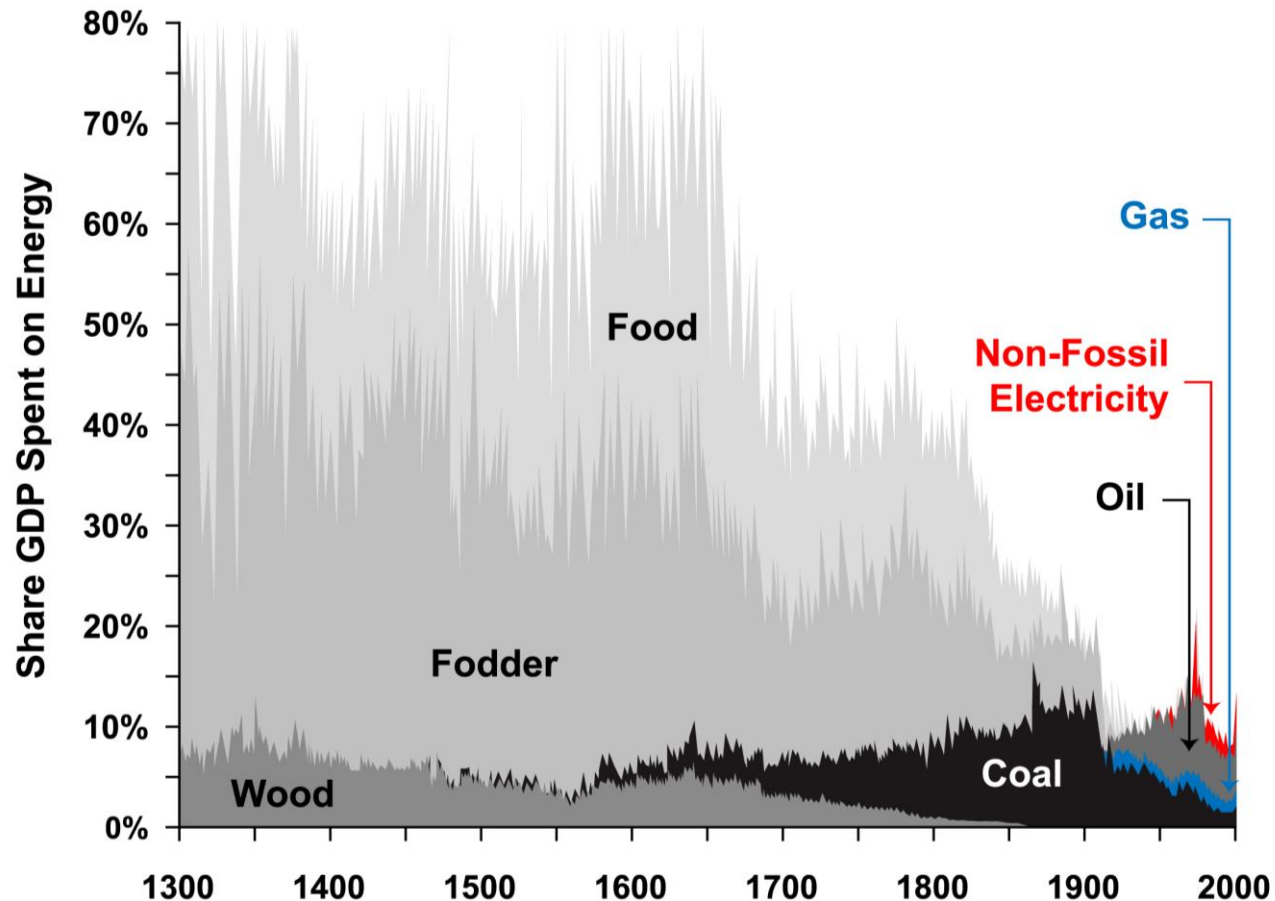
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Fueling Humanity: Share Of GDP

*Earth air, fire, and water in the end are all made of energy but the different forms they take are determined by information. **To do anything requires energy.** To specify what is done requires information."*

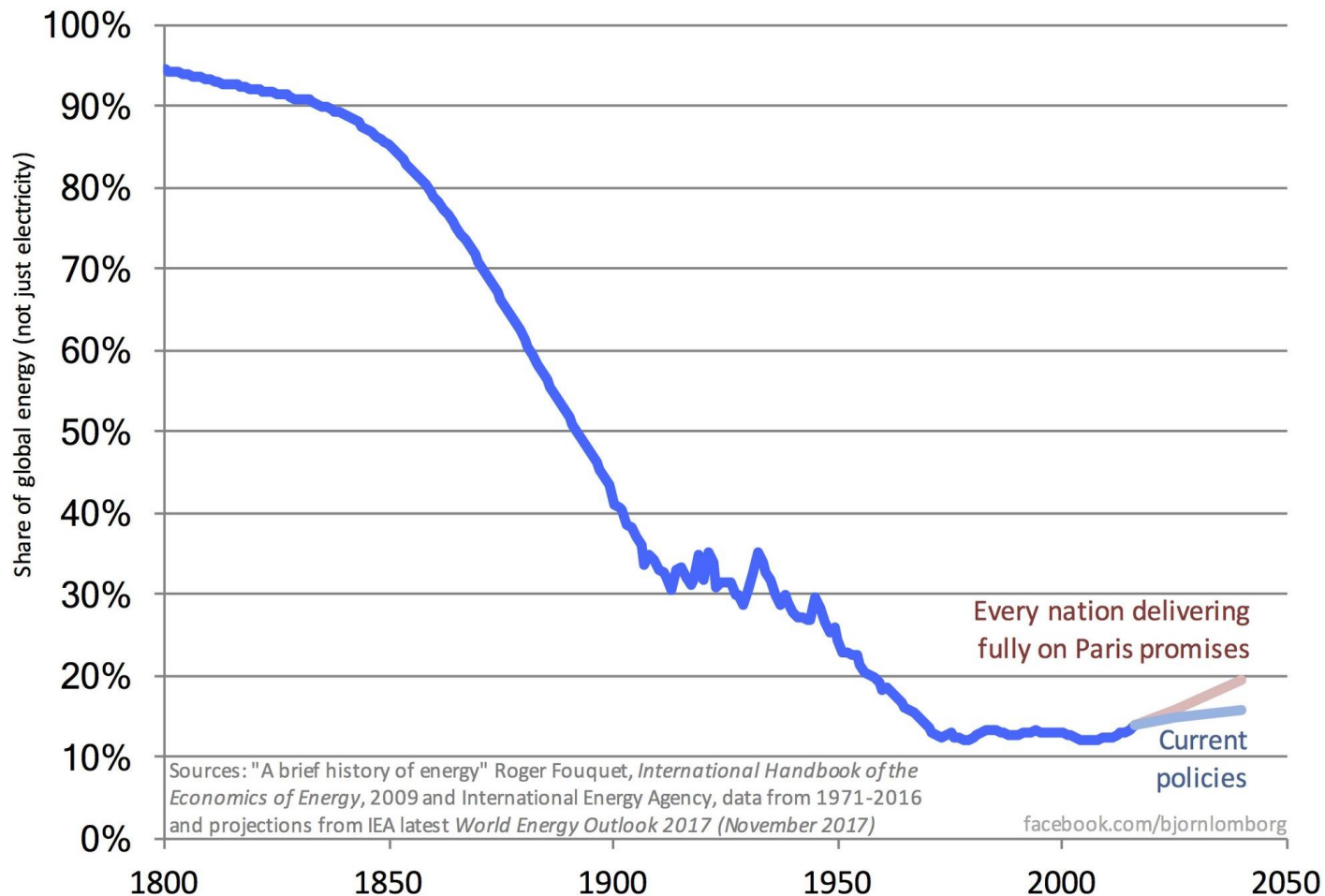
Seth Lloyd, MIT (2006)



Renewable Share Global Energy: 1800-2040

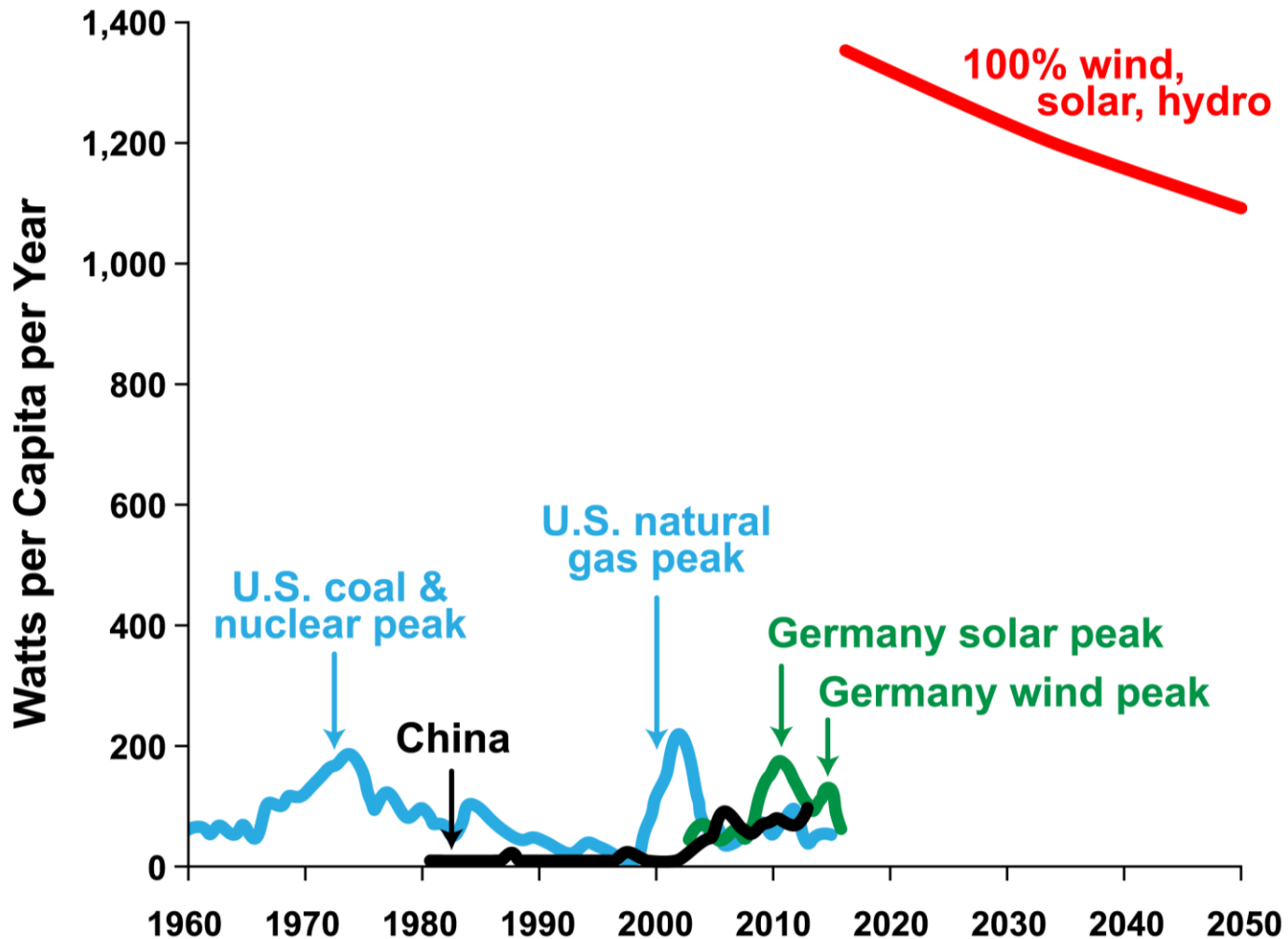
Energy realities:

- Scale & velocity
- Physics & materials
- Desires & demand



The Scale Challenge: U.S. Grid Only

20 yr transition > WWII mobilization

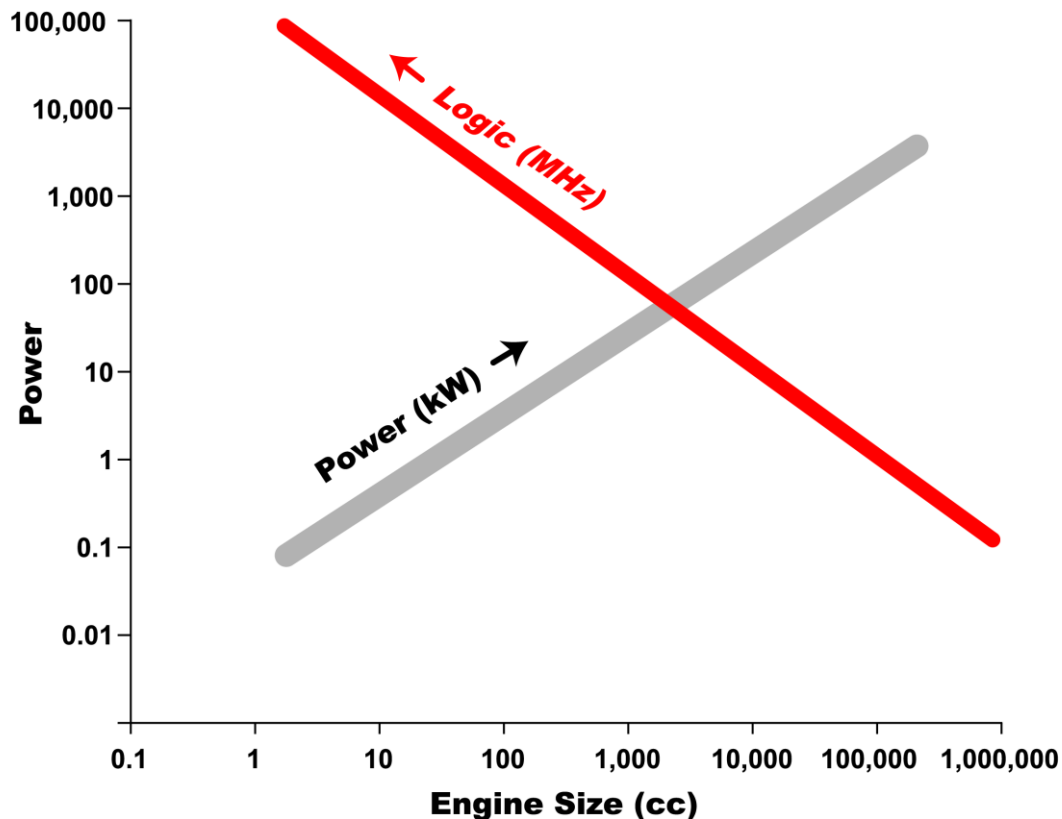


Energy vs. Logic Scaling

“Smartphone substitution seemed no more imminent in the early 2000s than large-scale energy substitution seems today.” *IMF*

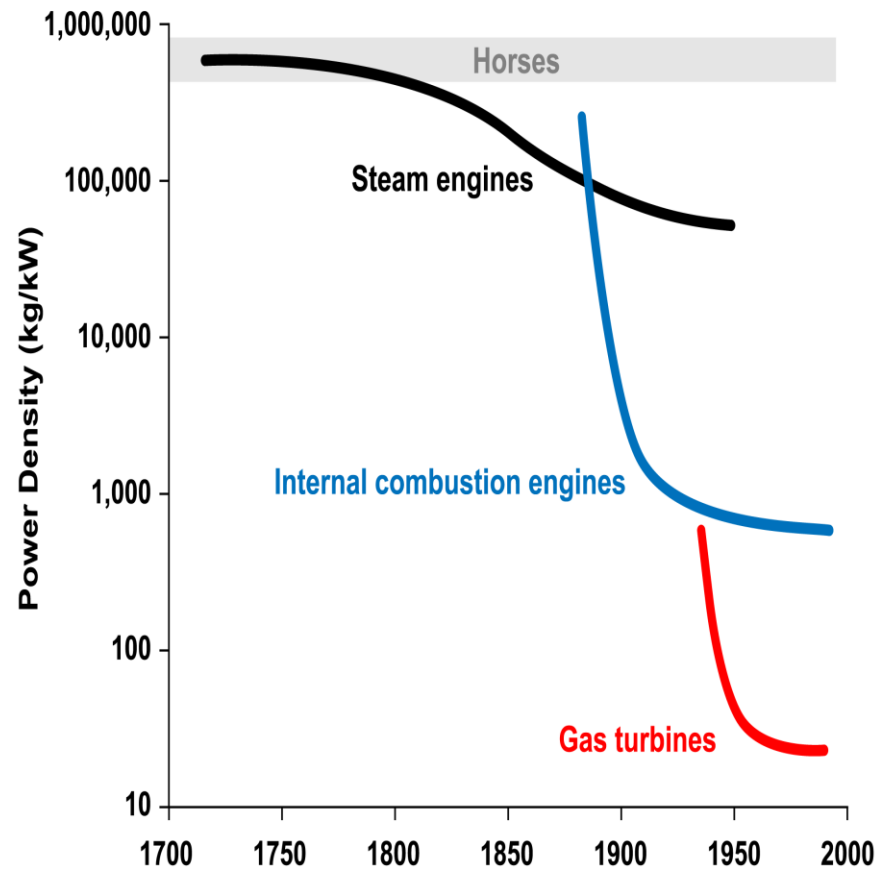
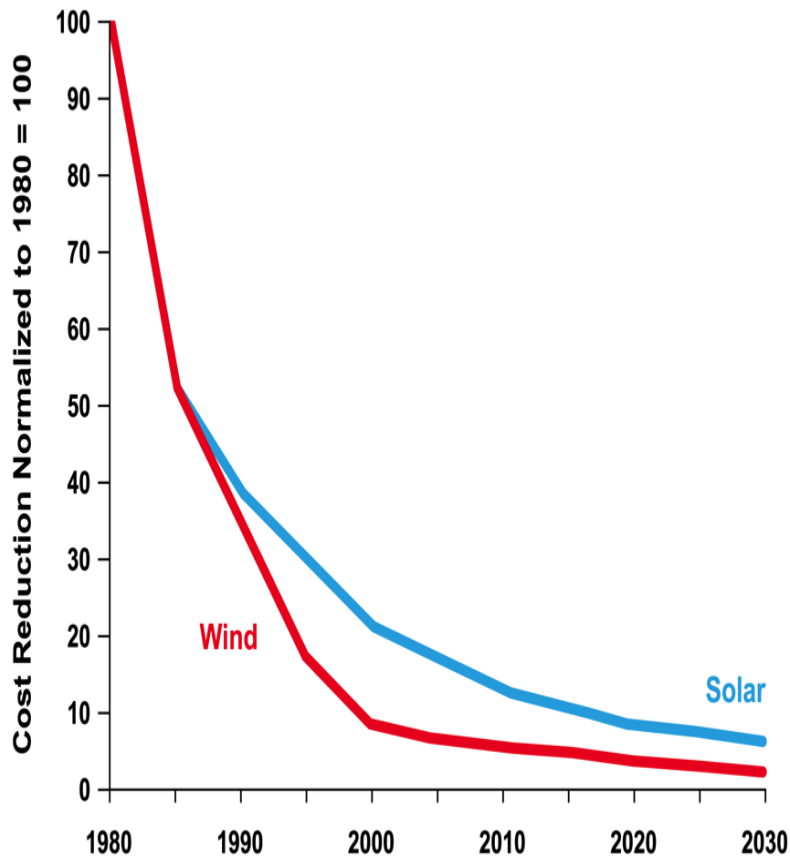
“[Clean-tech] 10x exponential process ...will wipe fossil fuels off the market in about a decade.” *Tony Seba, Stanford economist*

*Only in comic books does **energy** scale like **logic***



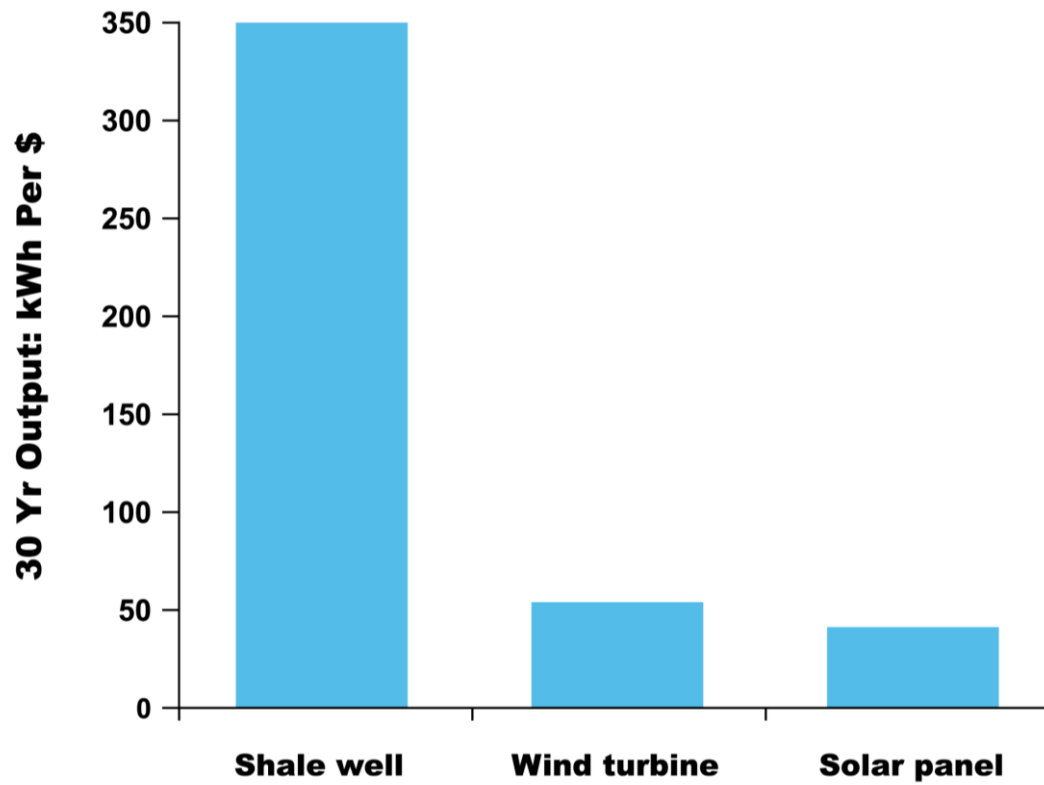
Energy Systems & Limits

Subsidies don't eliminate physics asymptotes



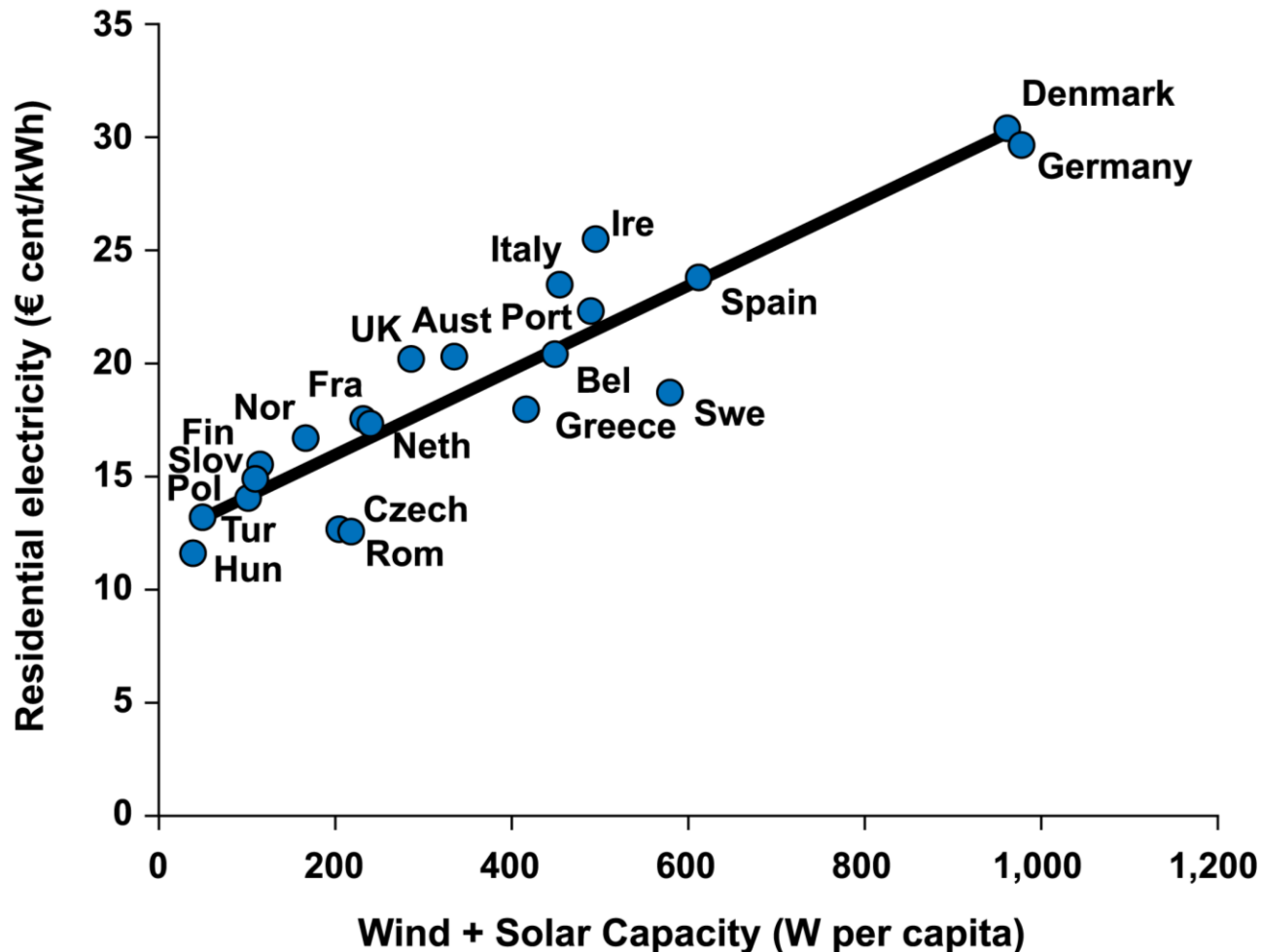
Physics Problem: Densities & Variabilities

- 2 grid-days → 1,000 yrs Gigafactory output



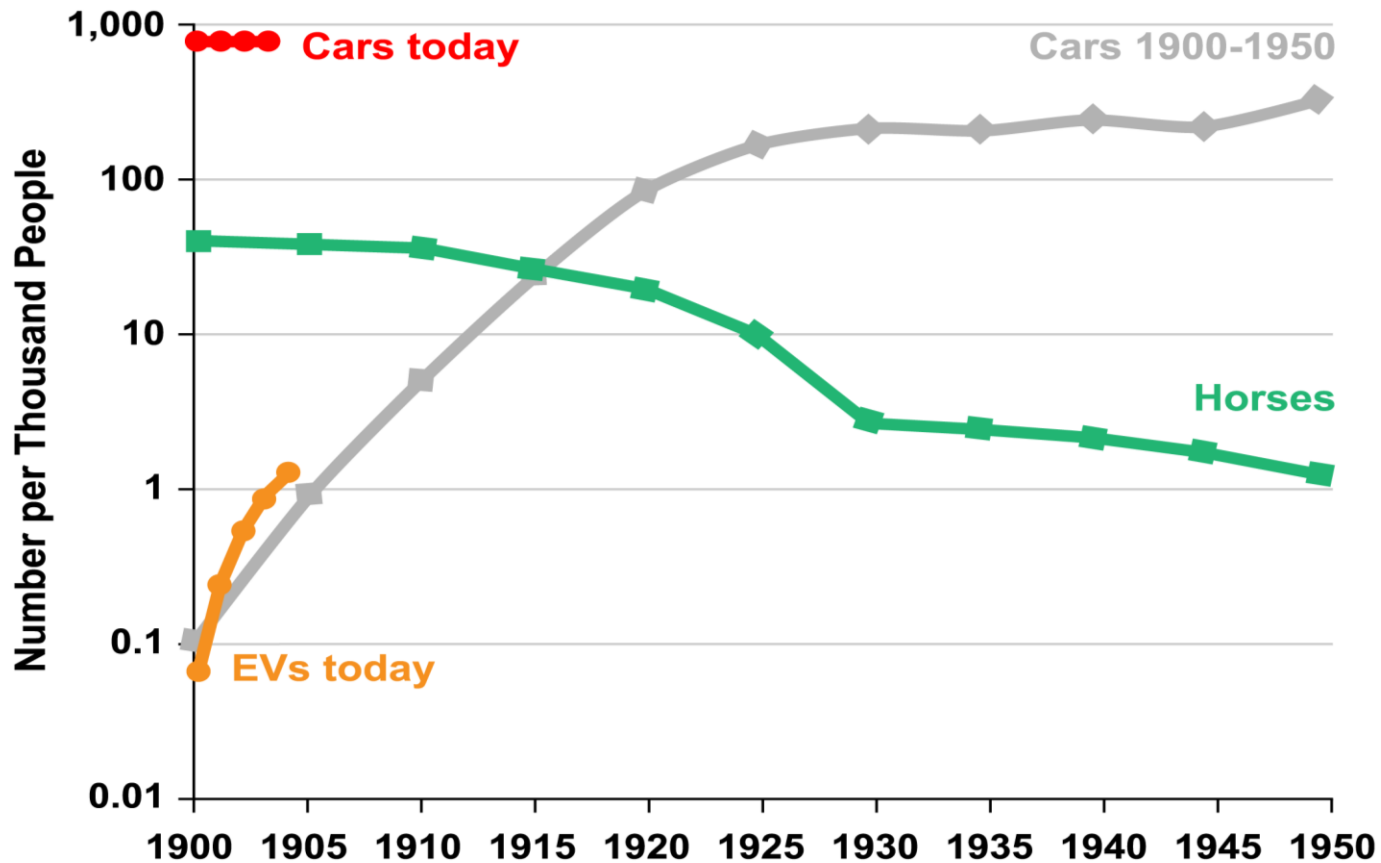
European Experiment: Myth of Grid Parity

More wind + solar capacity → higher grid costs



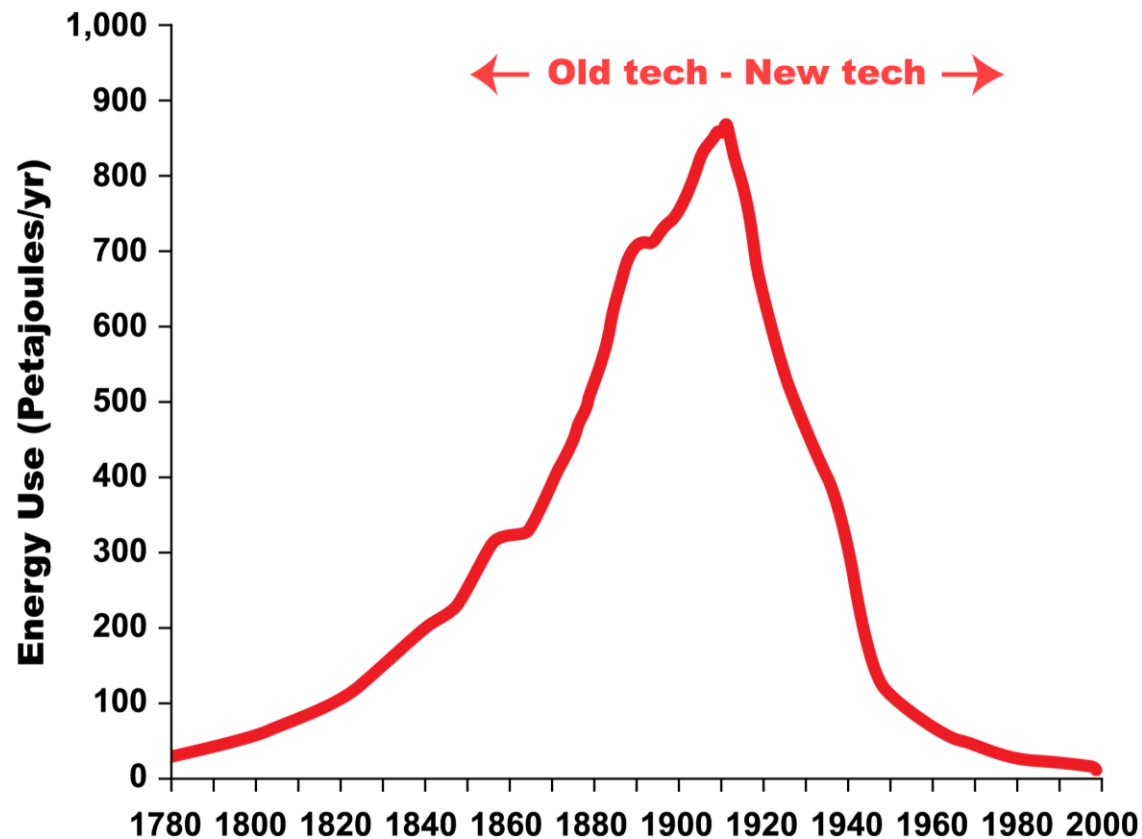
EV vs ICE: Complexity Swap

Horse → car because **10x safer & 100x more useful**



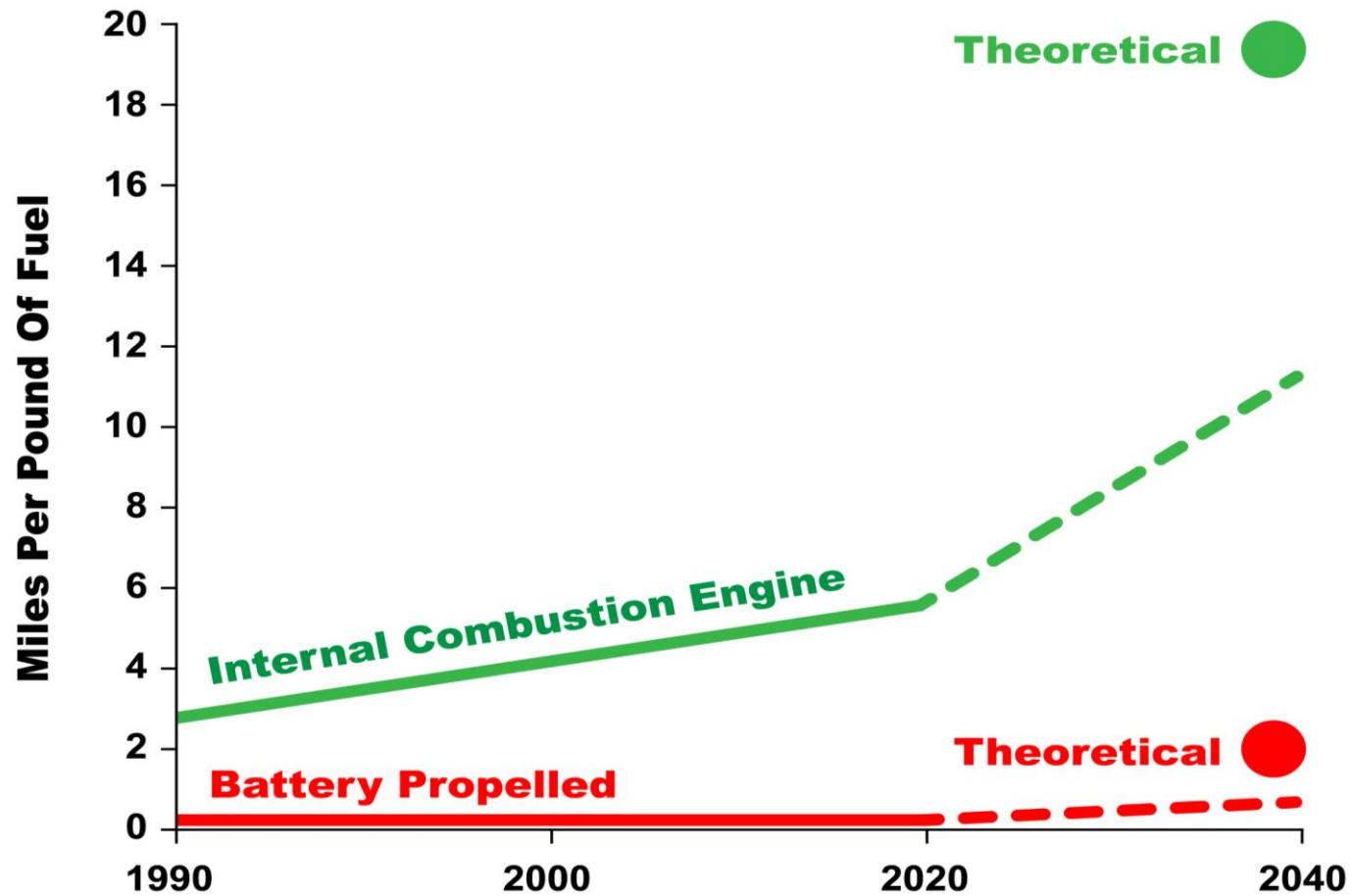
Grand Energy Transition?

100x more EVs → displaces ~ 5% world oil



What If Batteries Get Better?

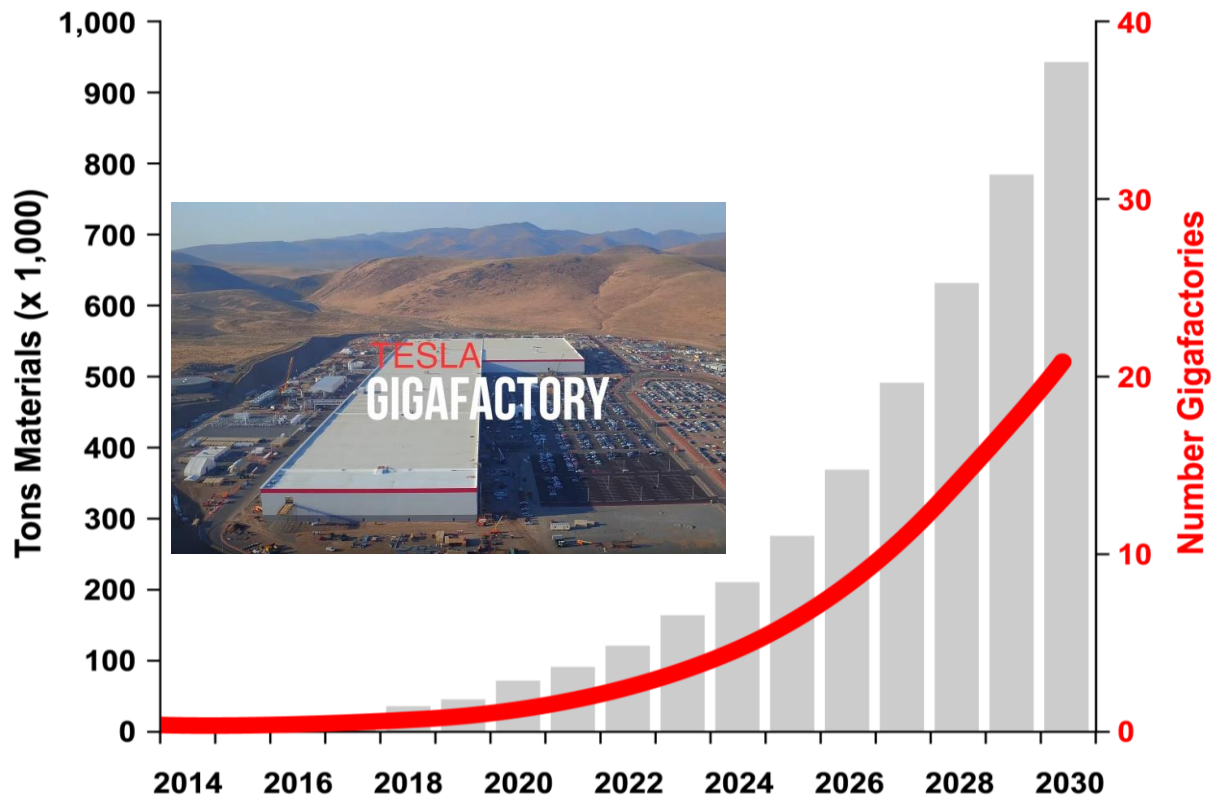
- \$1 vs \$100 per BOE



More Batteries → Mining Bonanza

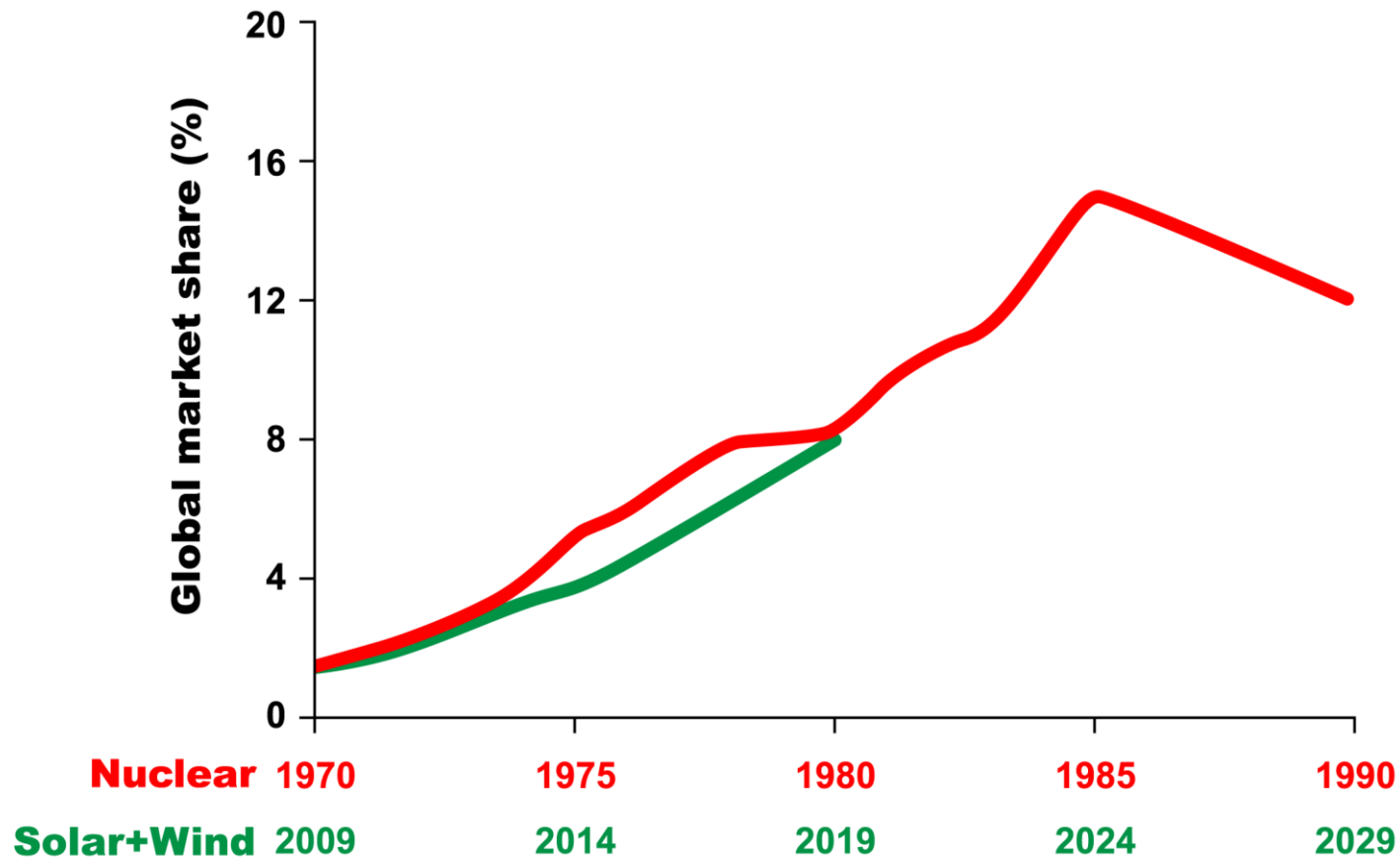
“Exponential growth in [global] renewable energy production capacity is not possible...” *Leiden University*

- **1 car battery @ 1000 lbs → 500,000 lb materials**



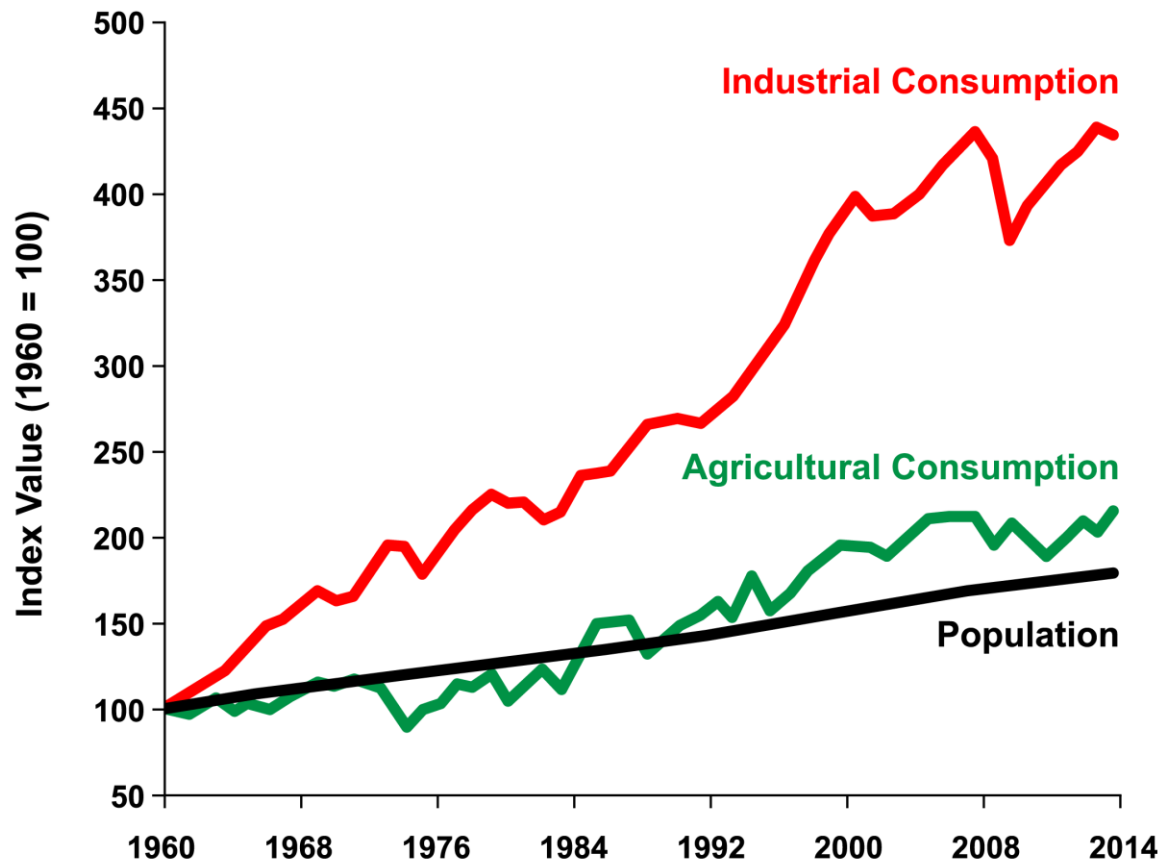
More Solar & Wind: The Scale Challenge

- **Nukes at peak ~ 16% world electricity, < 4% all energy**
- **Ended because? Expensive + subsidy exhaustion**



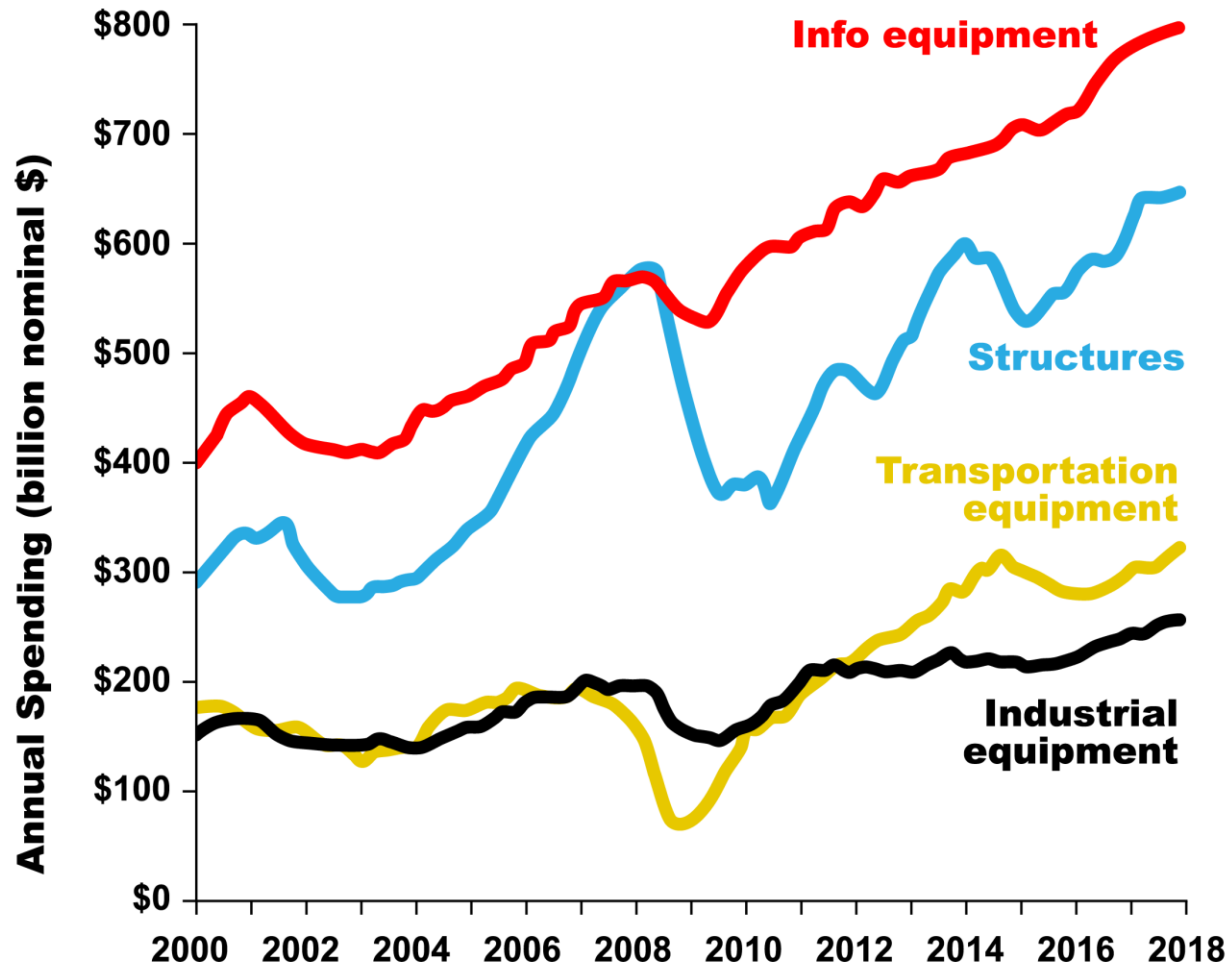
The Future: Food vs Stuff

It's a manufactured world → unlimited demand



Digital Future: “Software is eating everything”

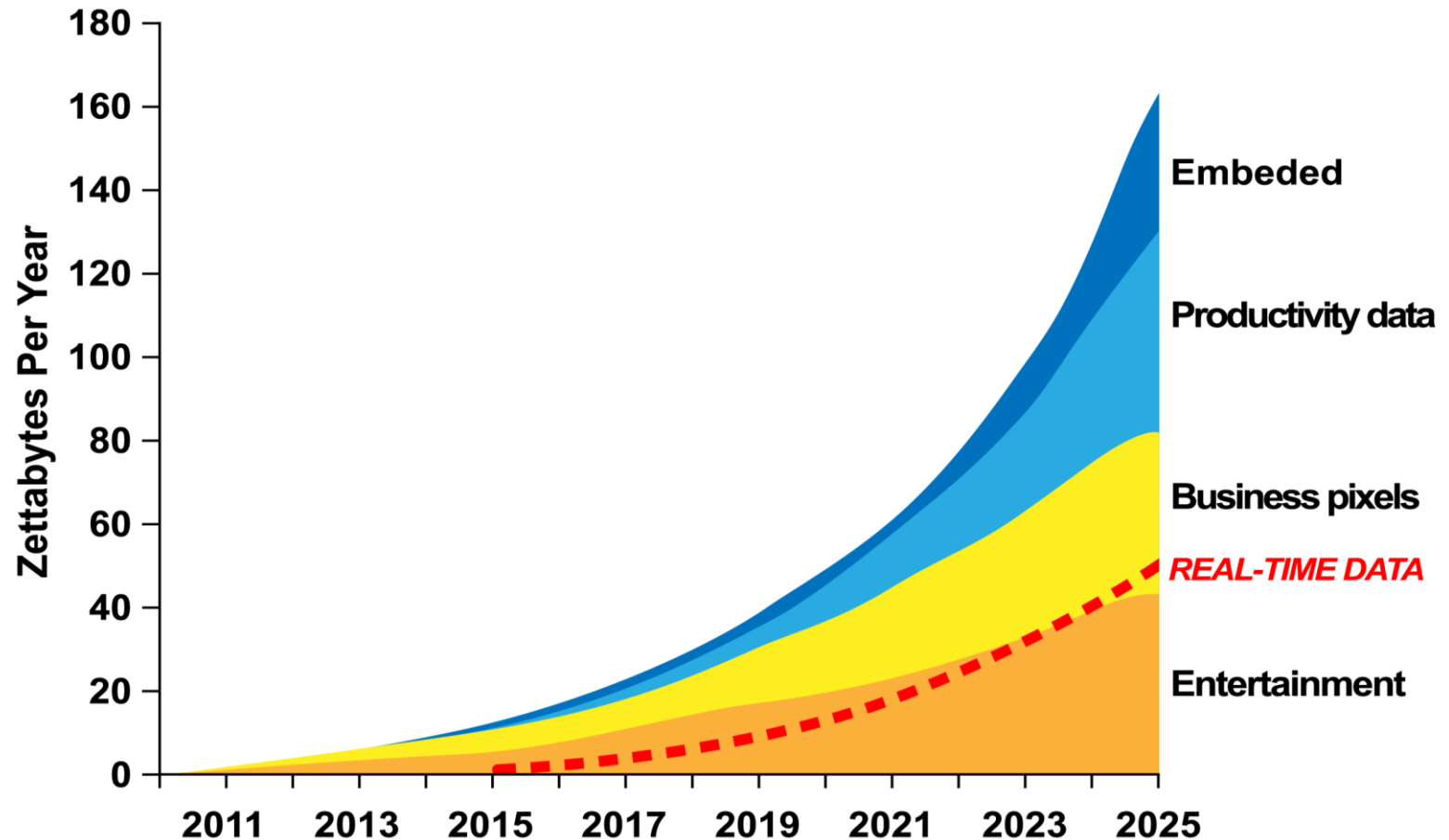
\$1 billion in datacenters → \$2 billion kWh/decade
• **\$400 billion/yr**



Data Tsunami: Bits Are Electrons

In 1960, **\$1** bought **1** calculation per second ...

- In 2000 → **10,000**
- Today → **1 billion**



How Much Does A Zettabyte Weigh?

1/10th zettabyte sent to the Cloud on...

- High-speed fiber takes **20 years**
- Snowmobile takes **2 weeks**

Annual internet traffic →

- 2,700 **mile** row of Snowmobiles weighing...
- 10 **million** tons

Amazon's "Snowmobile"



Datacenters: A New Class Of “Real Estate”

1,500 skyscrapers

5,000 enterprise-class datacenters

Square foot of datacenter vs. skyscraper

- Same construction
- 5x rent
- 100x power demand

Gazprom, St. Petersburg

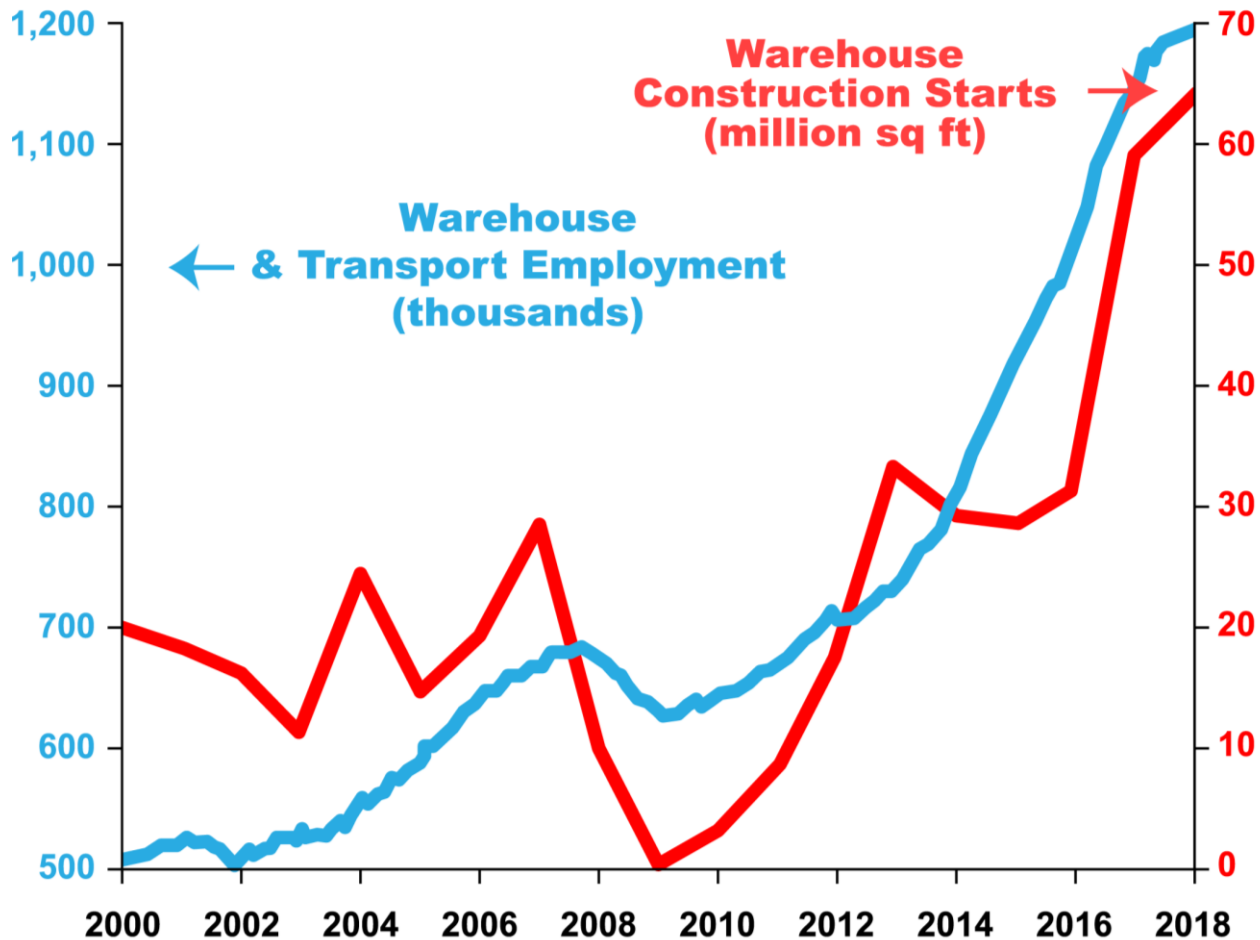


Datacenter, Nevada



Digital Future: From Bits To Atoms

"One click" → Trucks & warehouses



The Future: More Efficient & More Demand

When **2 billion poor @ 15%** what we have → **2x global** energy demand

