

Grand Nexus: Information, Materials, Energy



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Source of energy *demand*: machine innovation

Model T: 1908

~25 years then +25 mmbd



Ford Trimotor: 1928

~25 years then +8mmbd



Pharma: 1930

25 years then +15mmbd



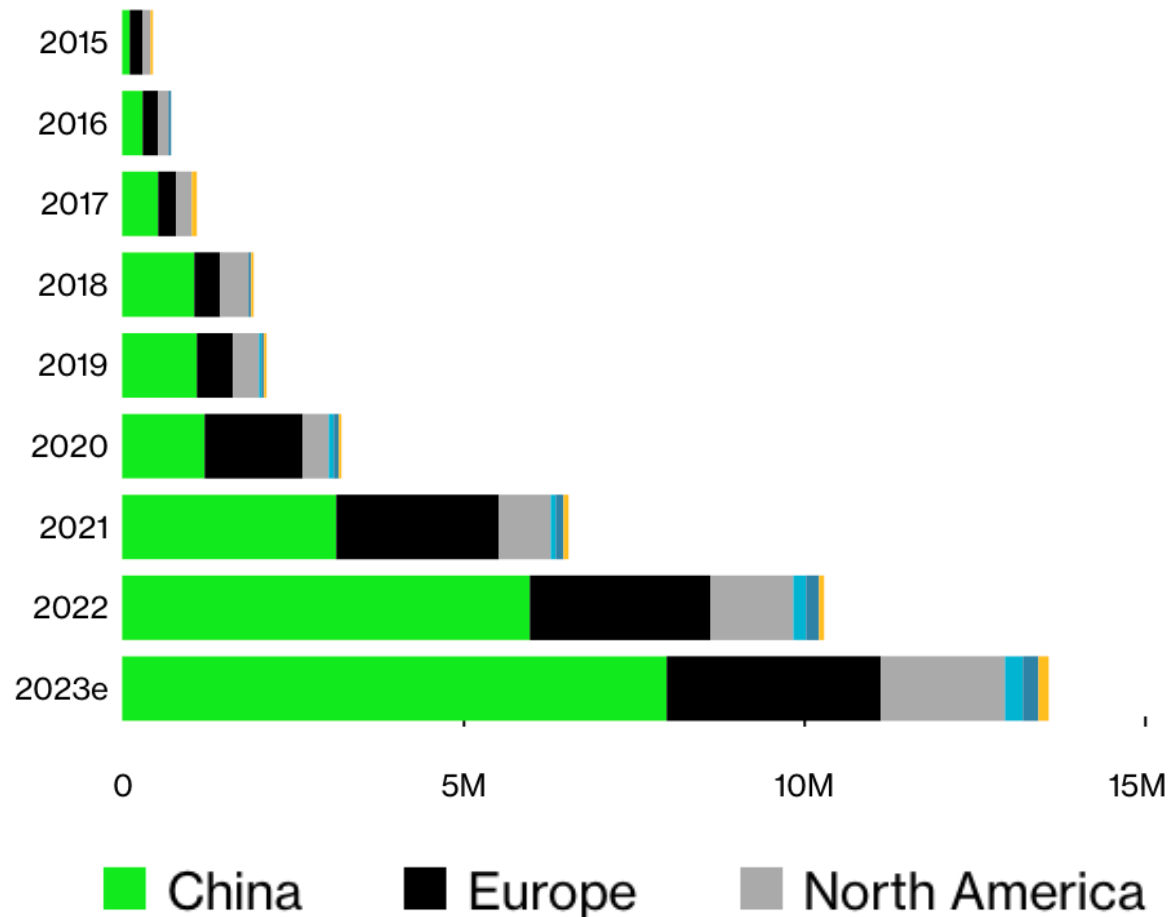
Univac: 1952

25 years then +10 mmbd



The EV revolution is real ... 0 to 12 million EVs in 10 yrs

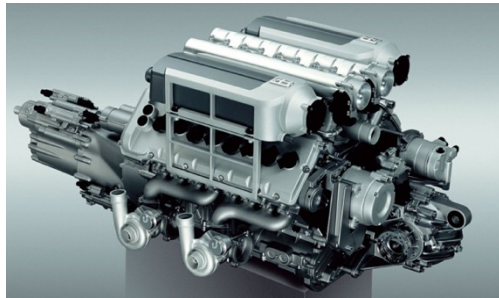
2012 Tesla 0 to 1 million in 92 months
1964 Mustang 0 to 1 million in 18 months



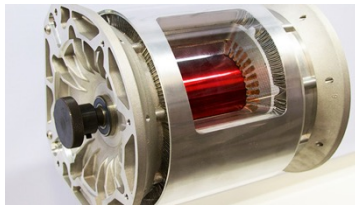
EVs are a complexity swap

PROPULSION

Complex *physical-chemistry*
1000s of parts



Simple



FUEL

Simple

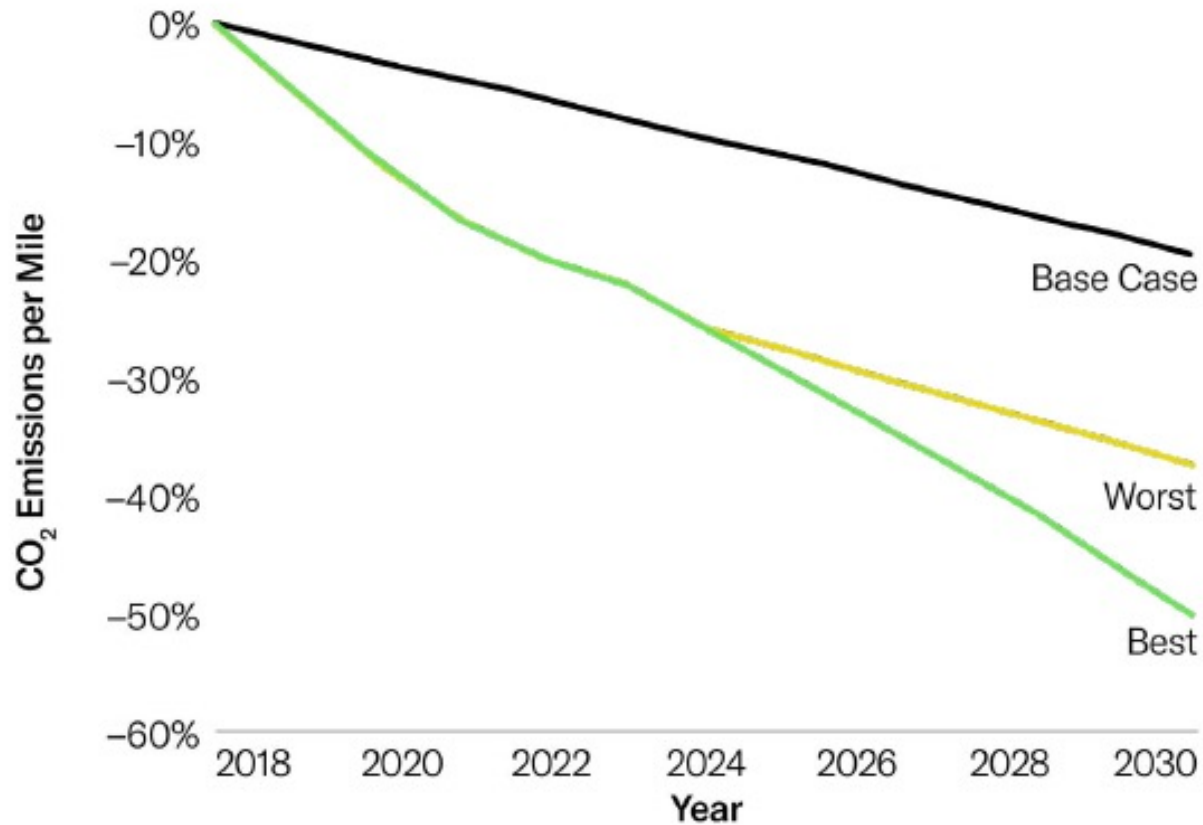


Complex *electro-chemistry*
1000s of parts



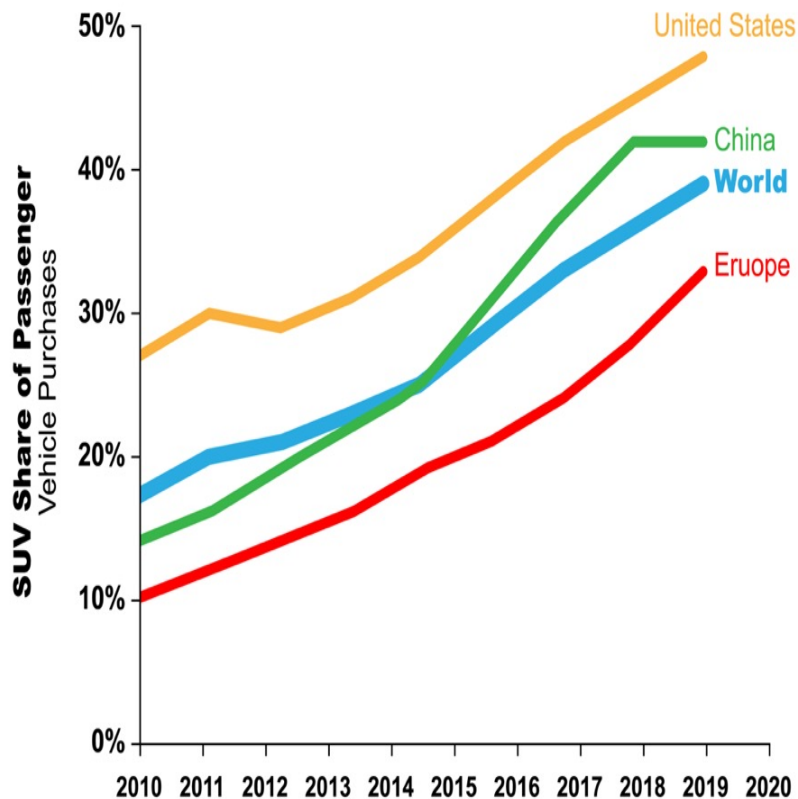
The end of ICE tech innovation?

Known Potential for Internal Combustion Engine CO₂ Emissions per Mile

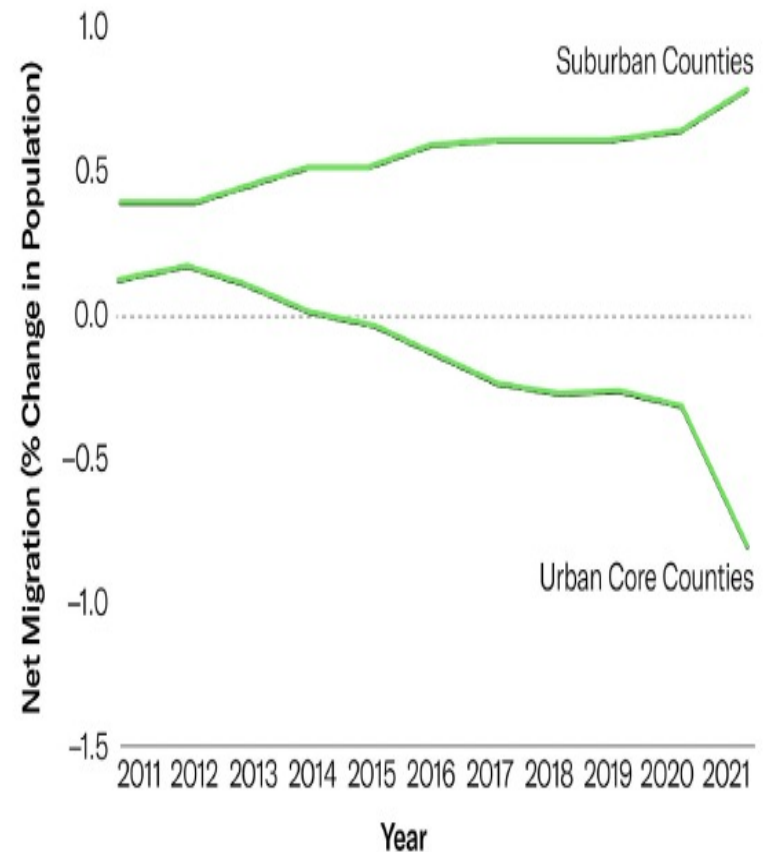


Consumer preferences in the age of climate awareness

Global Car Size Rising SUV Share Up Everywhere



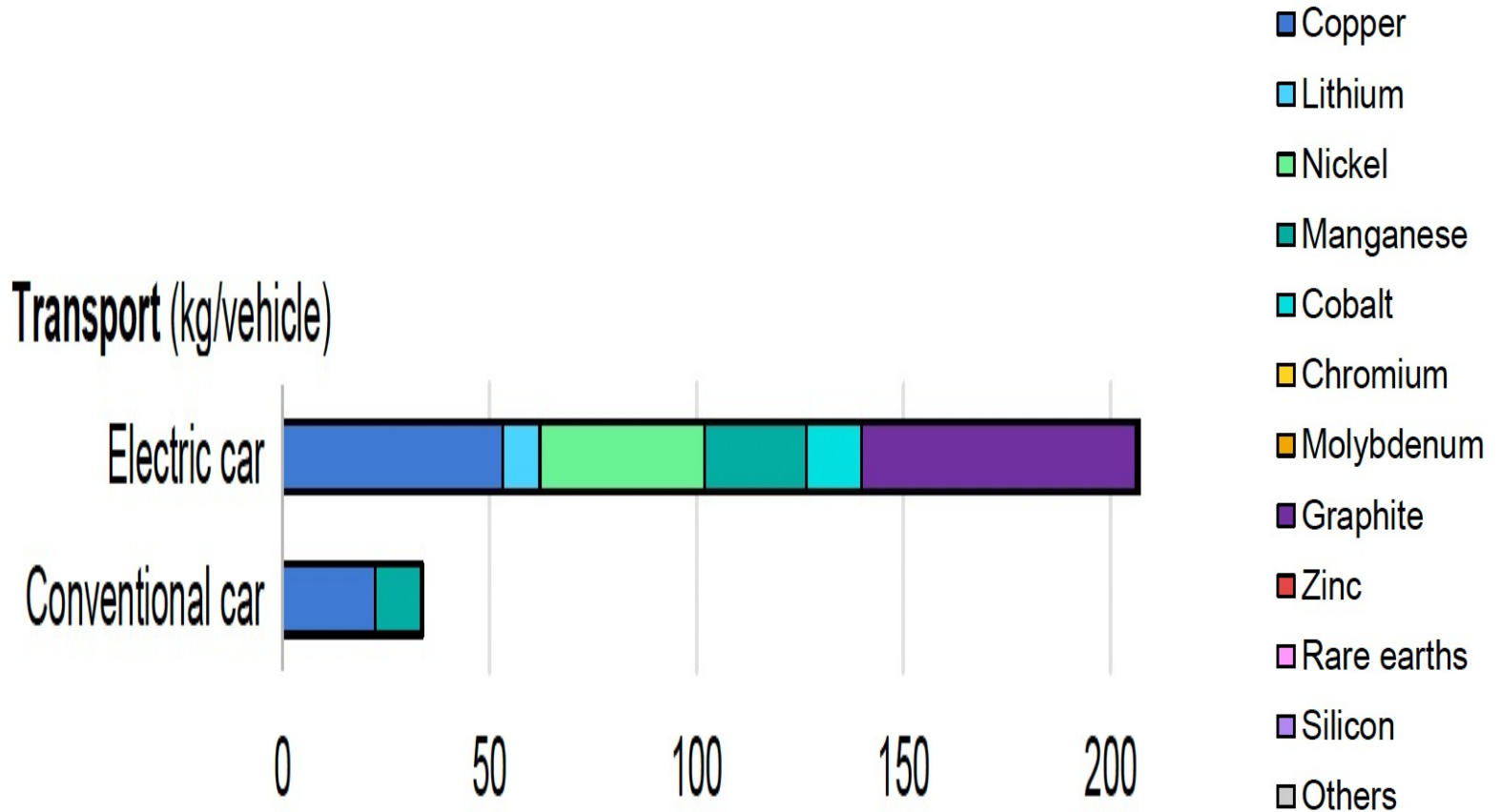
Driving Distances Rising U.S. Nonmetro Population Up



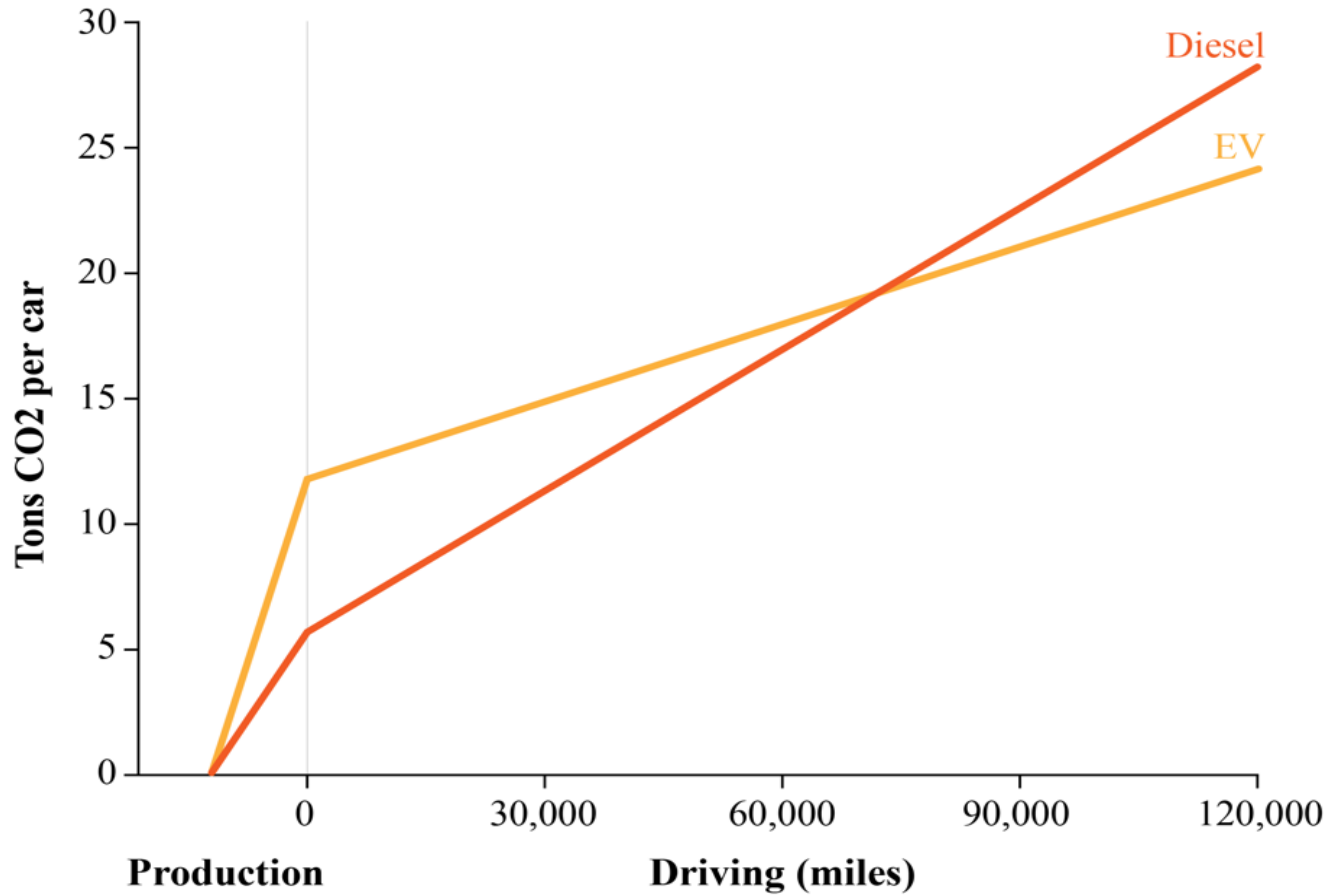
SUV demand by 2040 “offsets 150 million EVs”
Super-commuter grew 3x workforce

The minerals & metals needed to build a car

500,000 pounds mining to build **one EV** battery

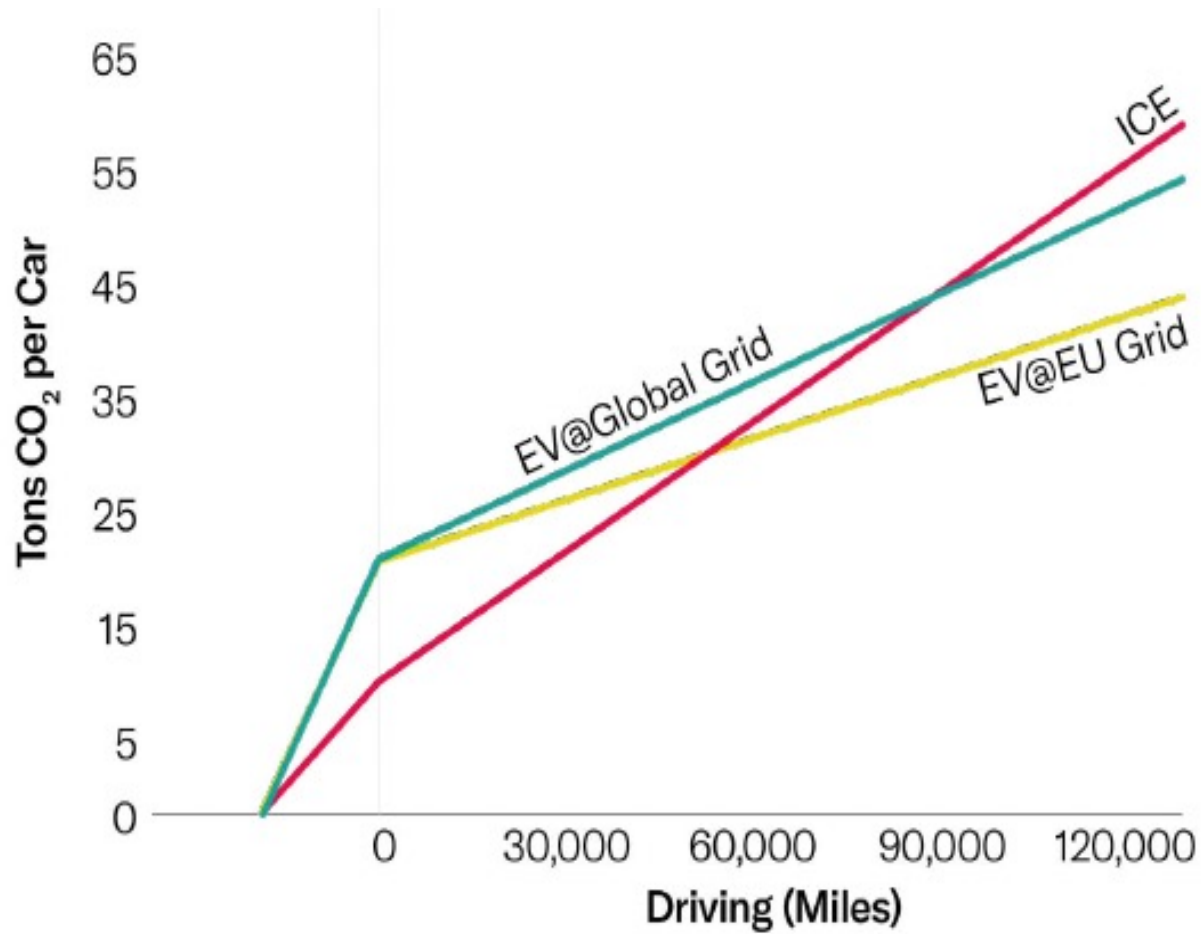


EV elsewhere CO₂ emissions



Battery **1/2** std size

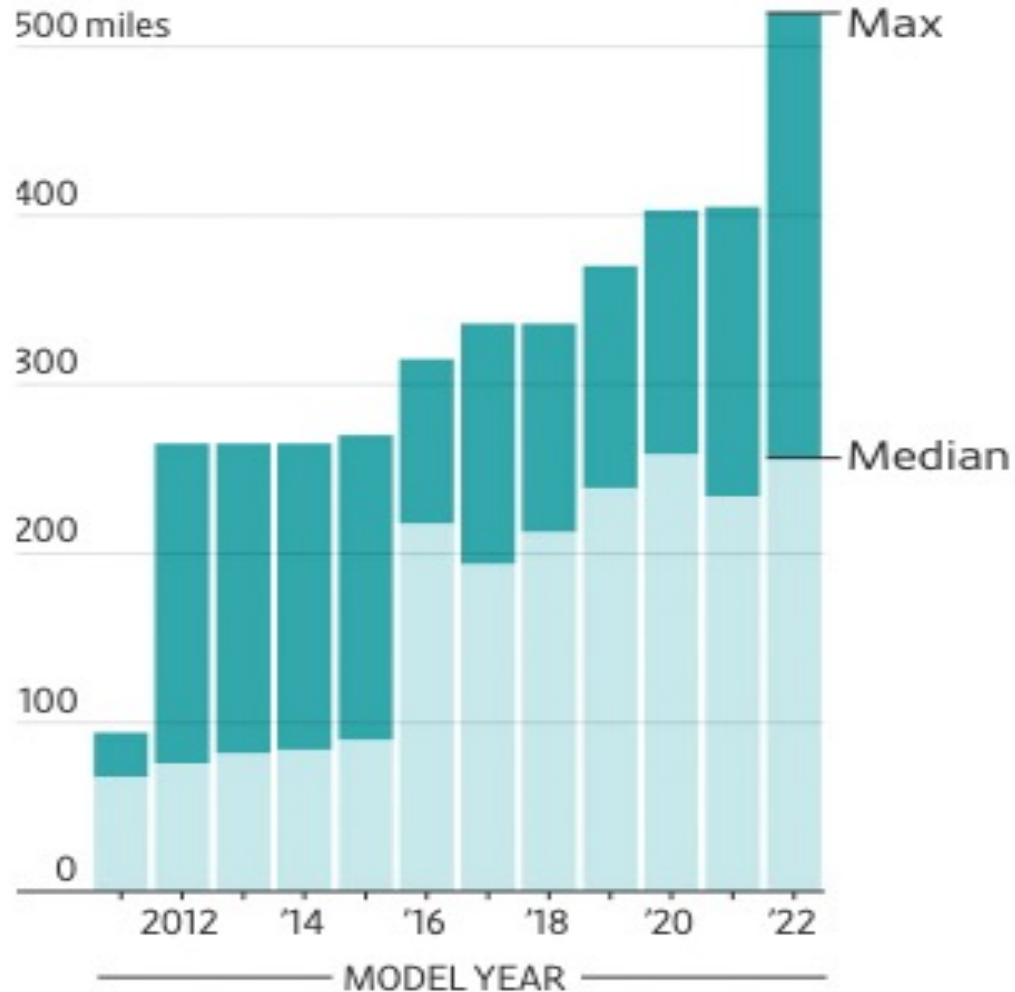
EV elsewhere CO₂ variables



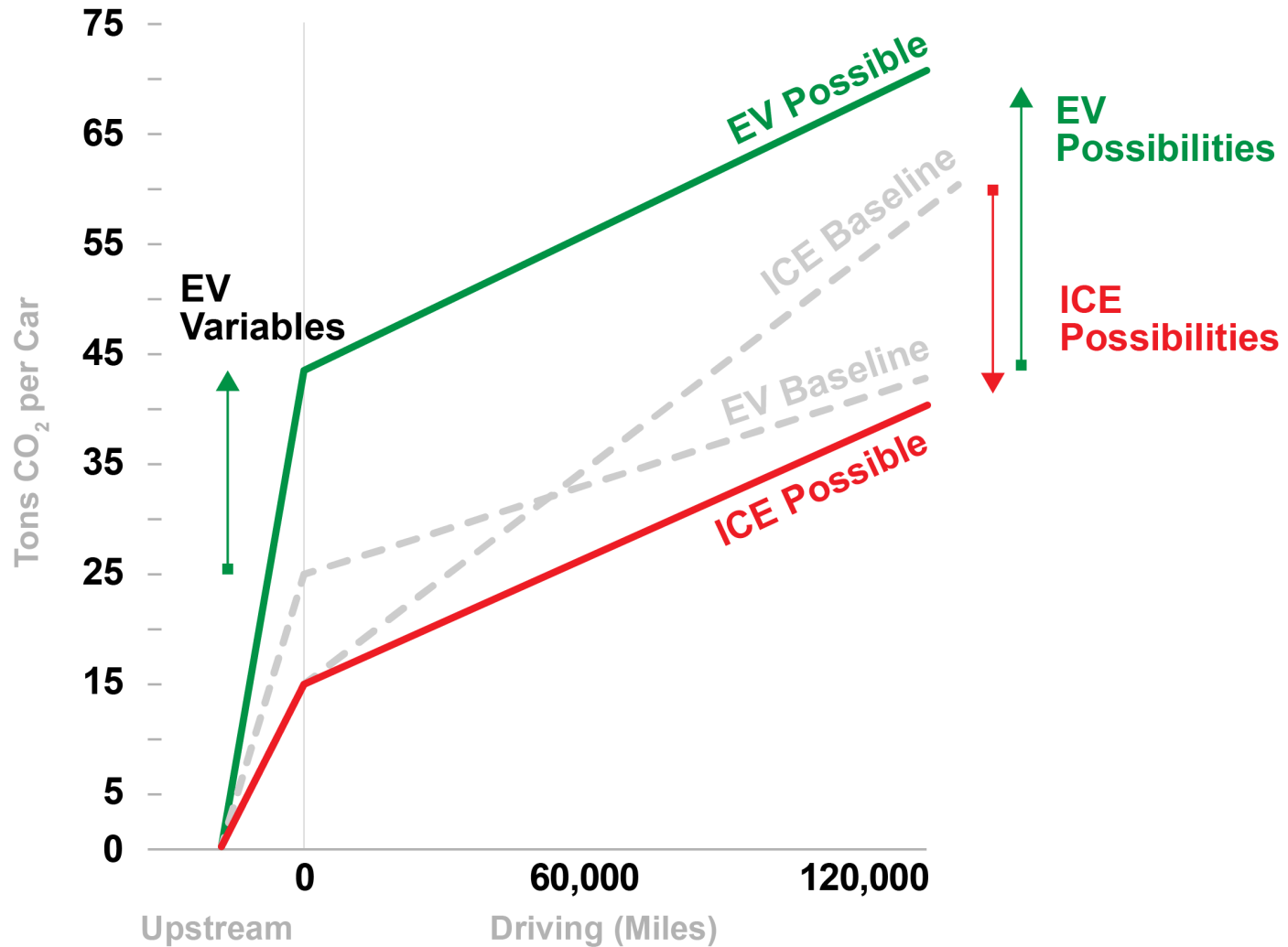
Battery **3/4 std size**

Bigger batteries → more minerals

Median and maximum range of electric vehicles offered for sale in the U.S.

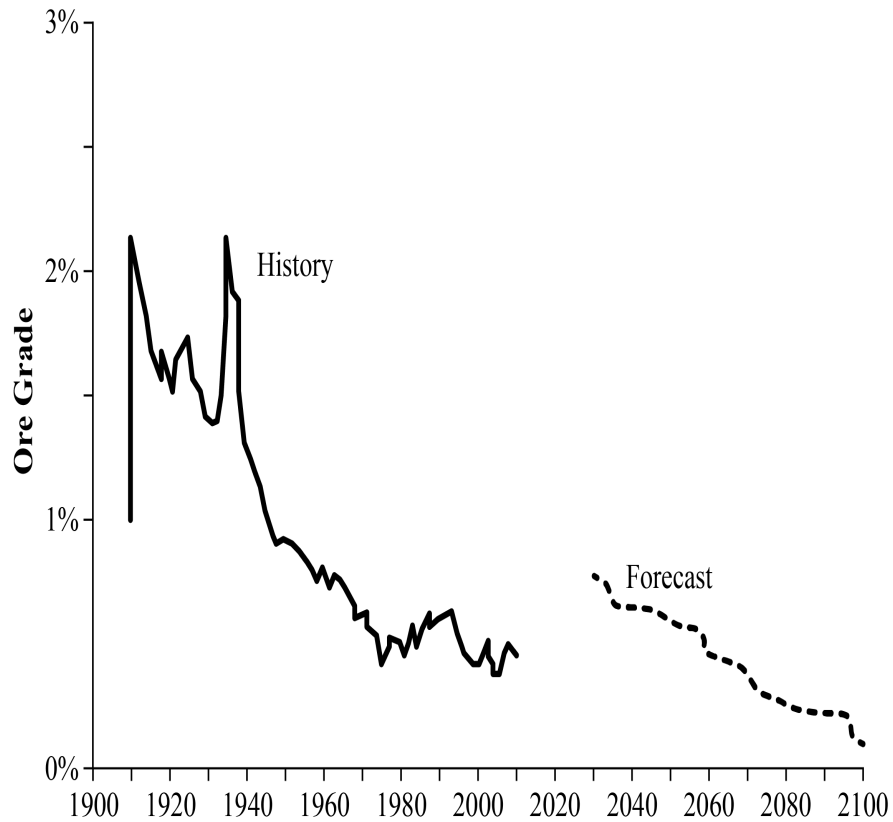


EV CO₂ emissions: Known unknowns

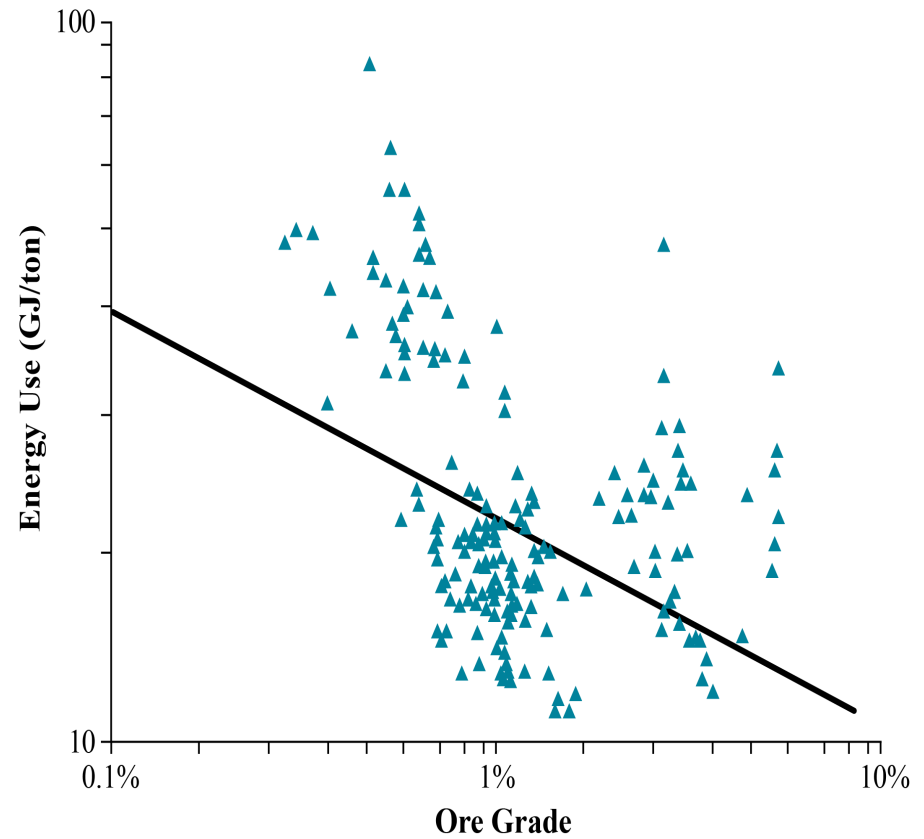


Iron Law of declining metal ore grades

Copper Ore Grades



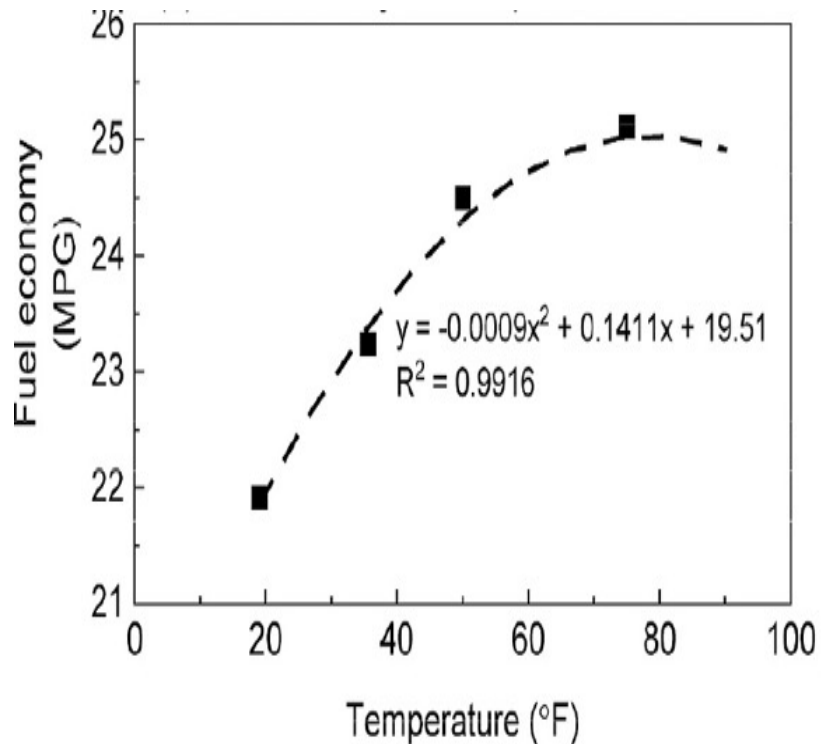
Energy Cost vs Ore Grade



More known unknowns: temperature & fuel efficiency

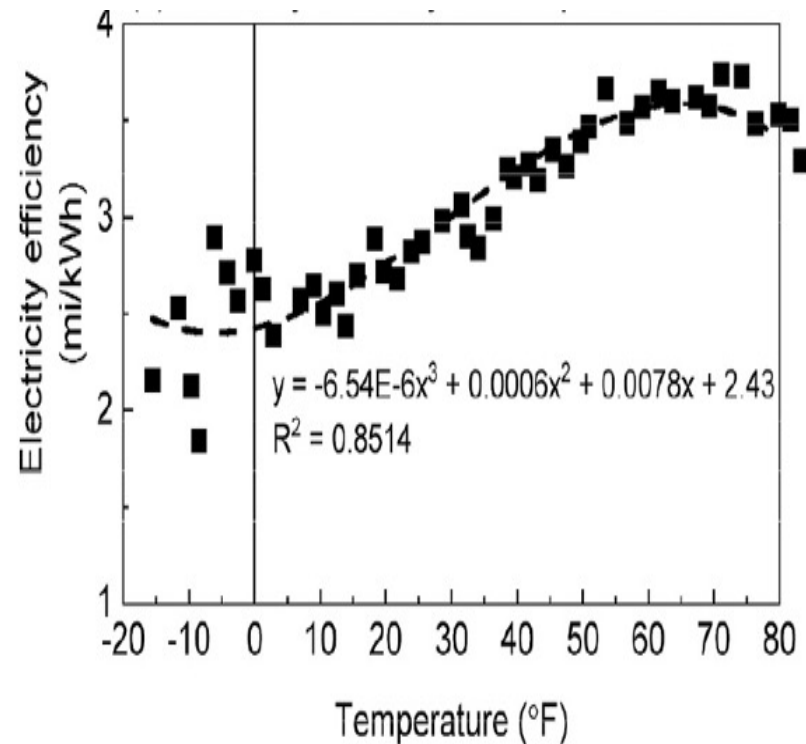
Engine

-6%



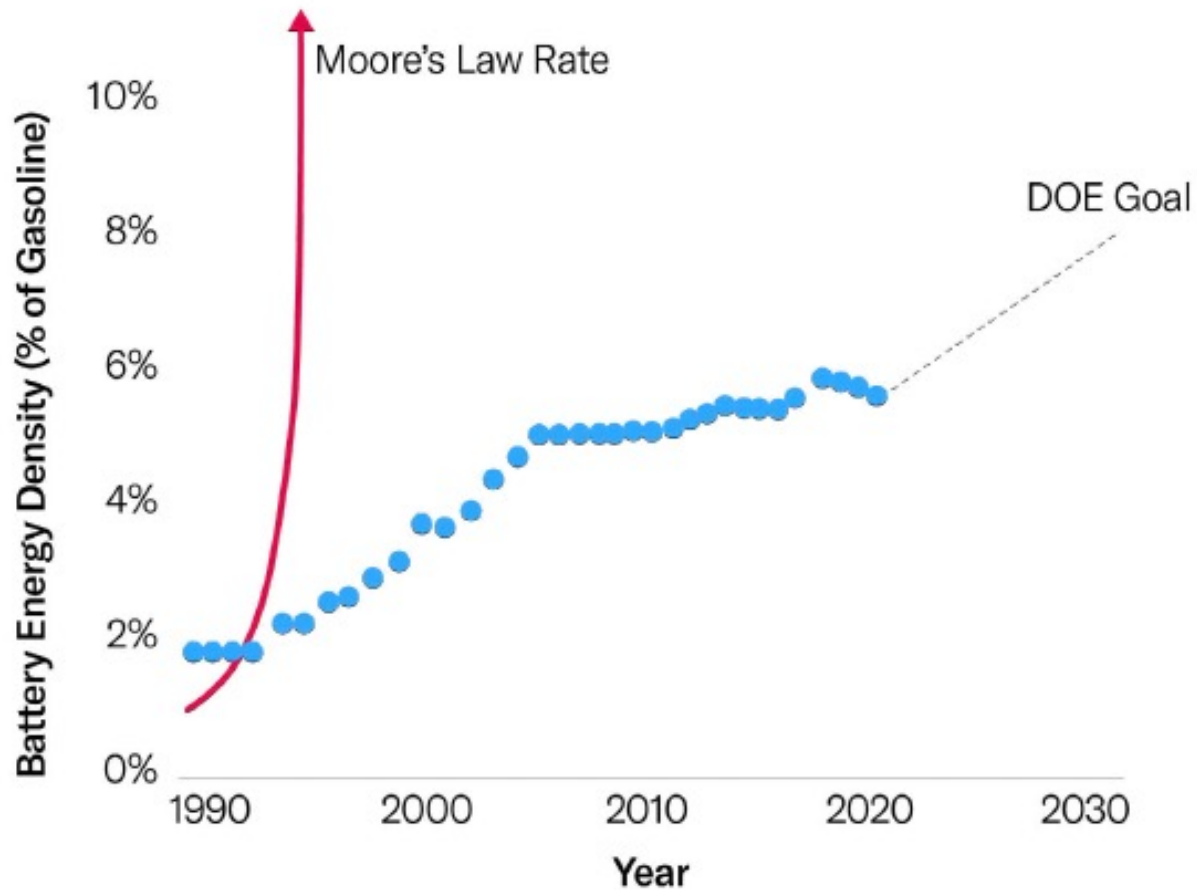
EV

-30%



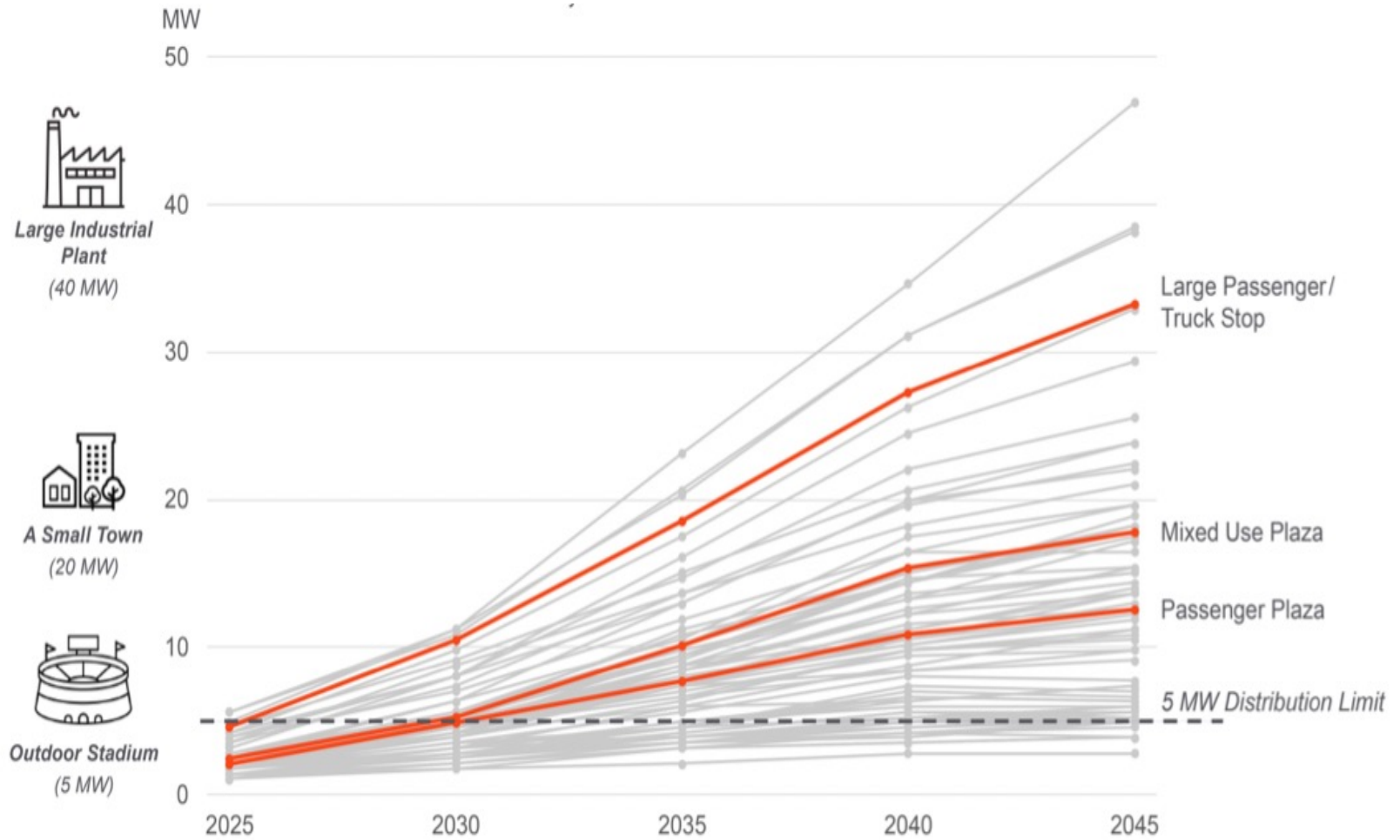
The battery tech trope: Moore's Law

Progress in Lithium Battery Performance*

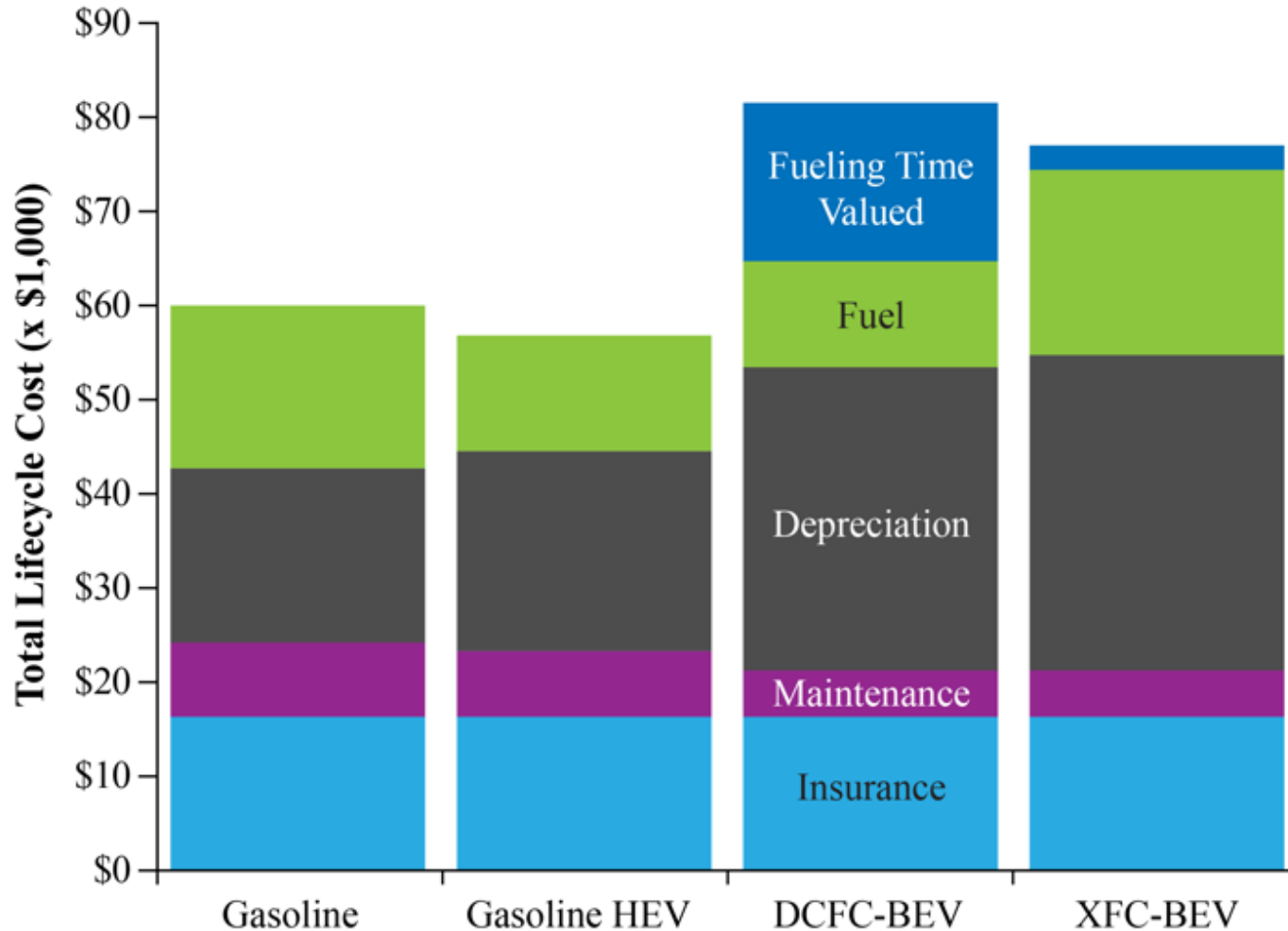


Grid infrastructure costs hidden in plain sight

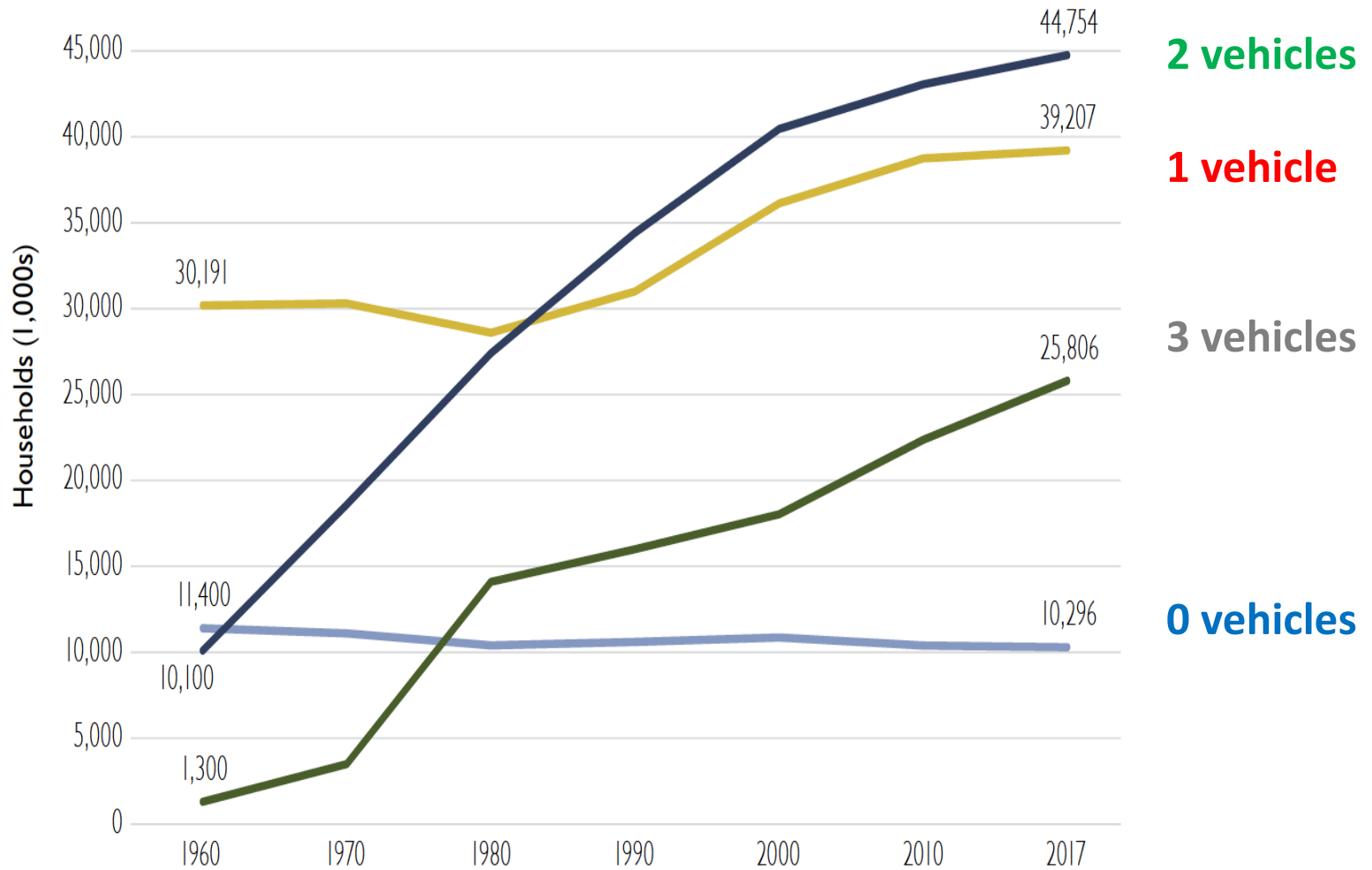
MW grid capacity per single fueling station



The cheaper trope; if people's time is valued . . .

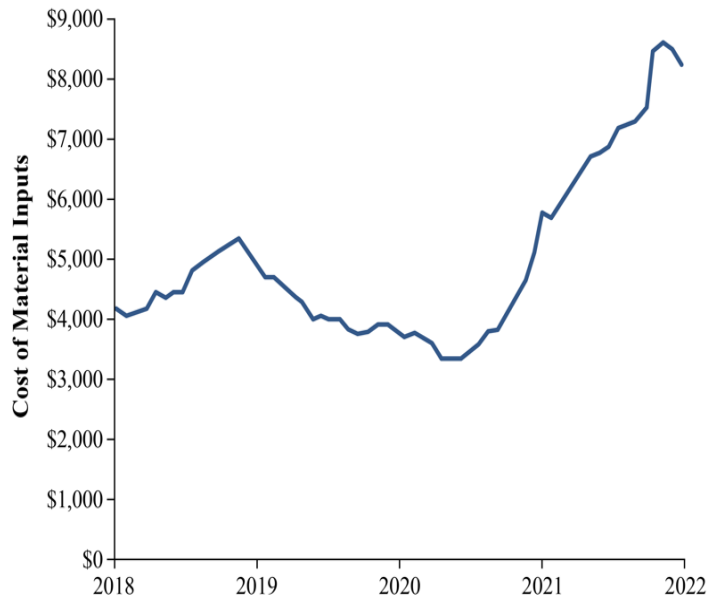


There are lots of multicar households but . . .

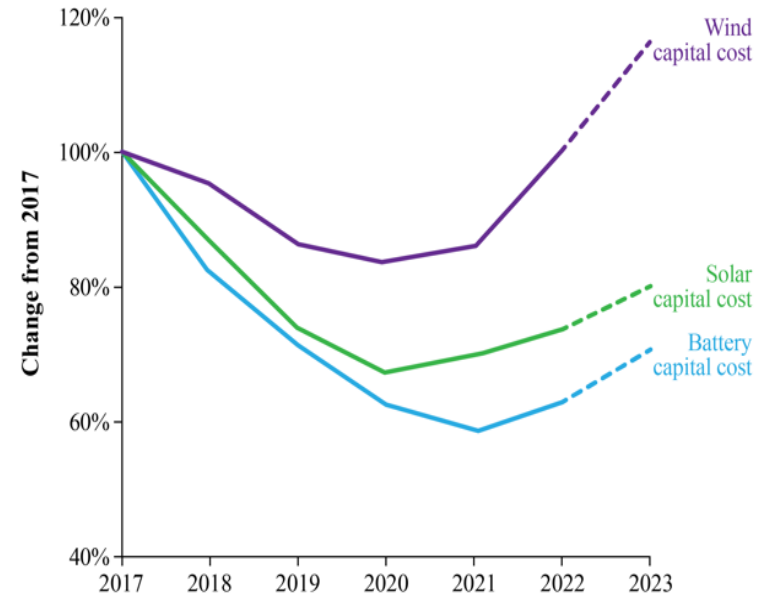


Price impacts from mineral costs

EV: Raw Materials Costs



Green Machine Costs



60% - 70% cost of batteries are in raw materials (solar modules too)

The end of (new) consequential machine innovation?

Drones

\$10B → \$100B 2030



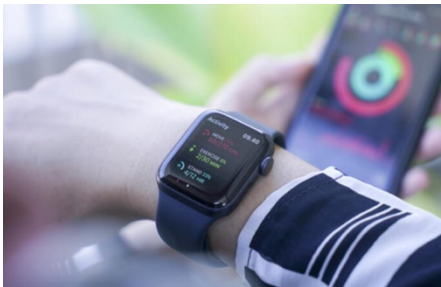
Robots

\$15B → \$150B 2030



Telemedicine & Bioelectronics

\$80B to \$400B by 2030

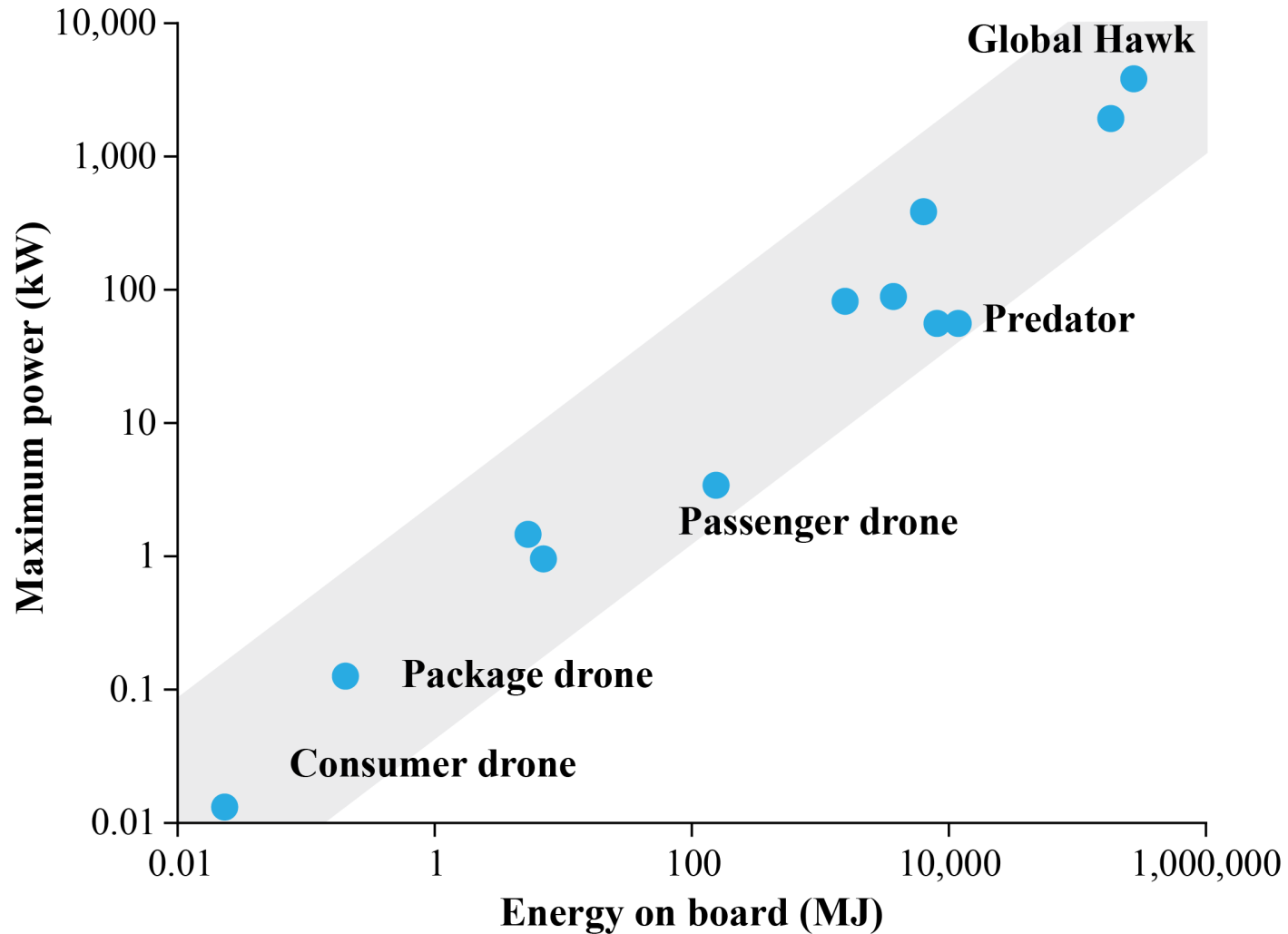


Cloud, AI, VR, AR

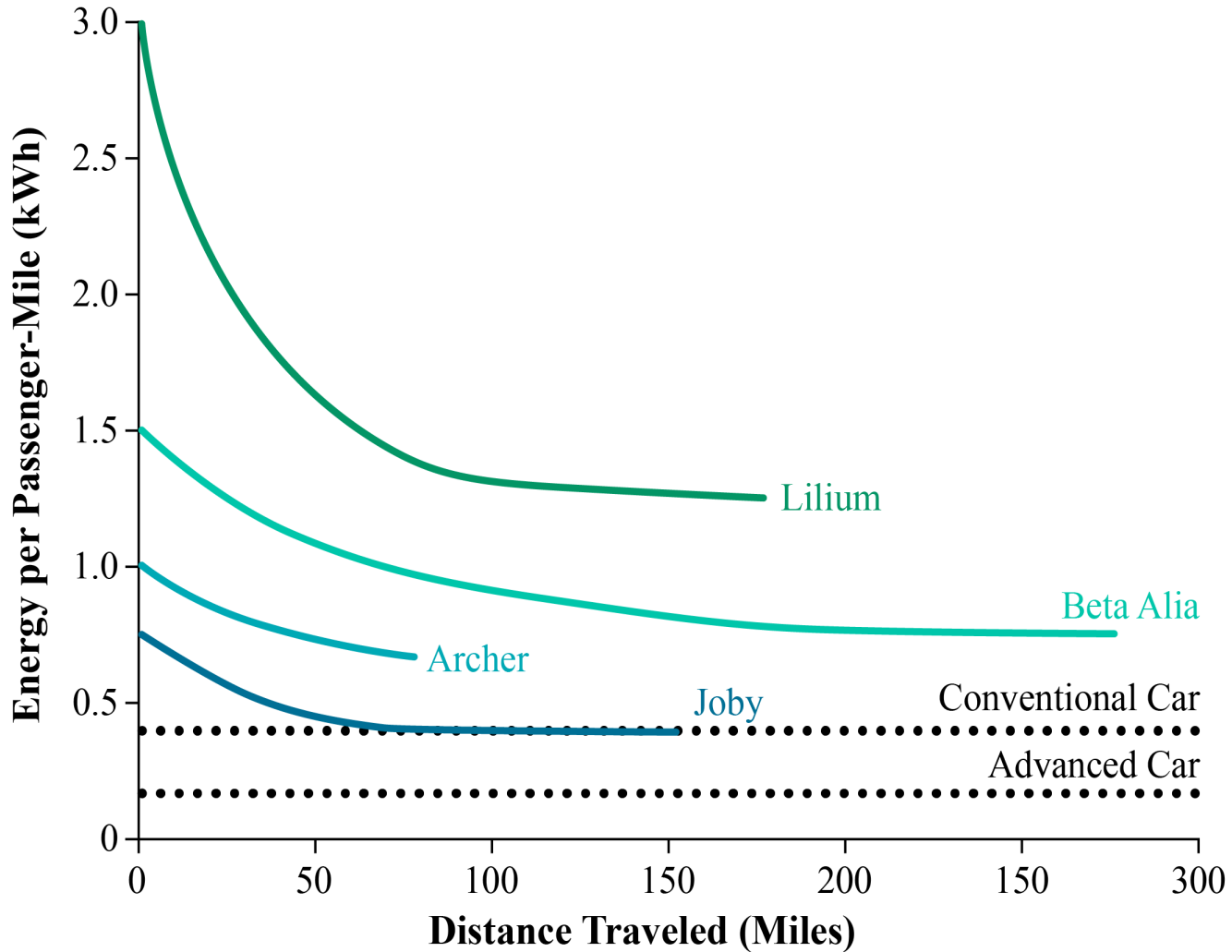
\$20B → \$200B 2030



*Energizing parcel & passenger drones: gravity's a b*tch*

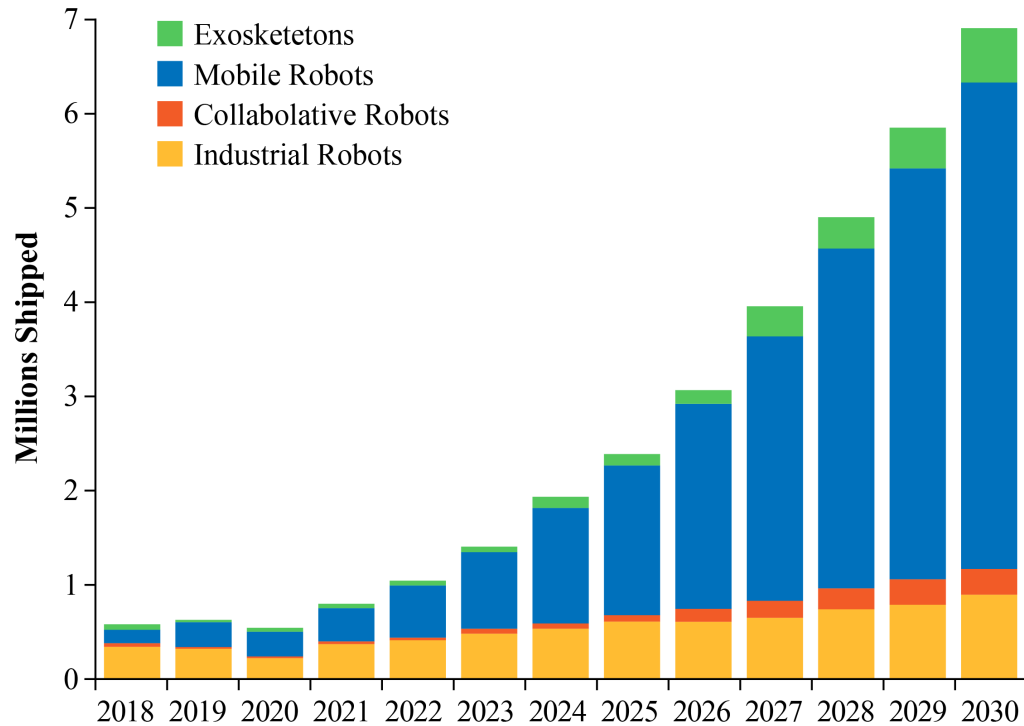


Energy cost of convenience: Air taxis vs automobiles



(At full occupancy)

AI + materials = mobile robots @ \$15B → \$150B by 2030



Unimate

1961 Johnny Carson Show

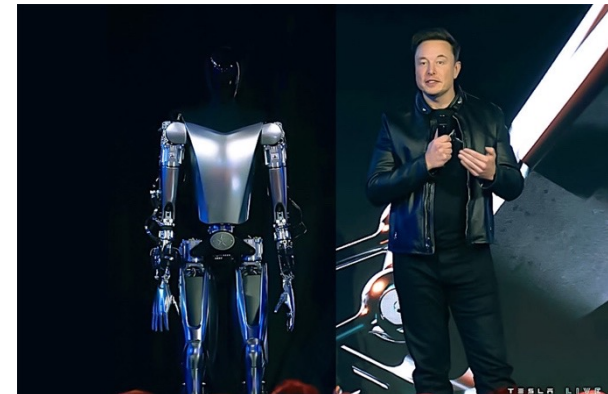
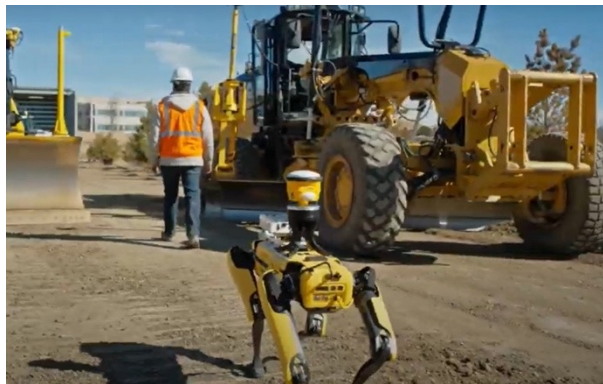
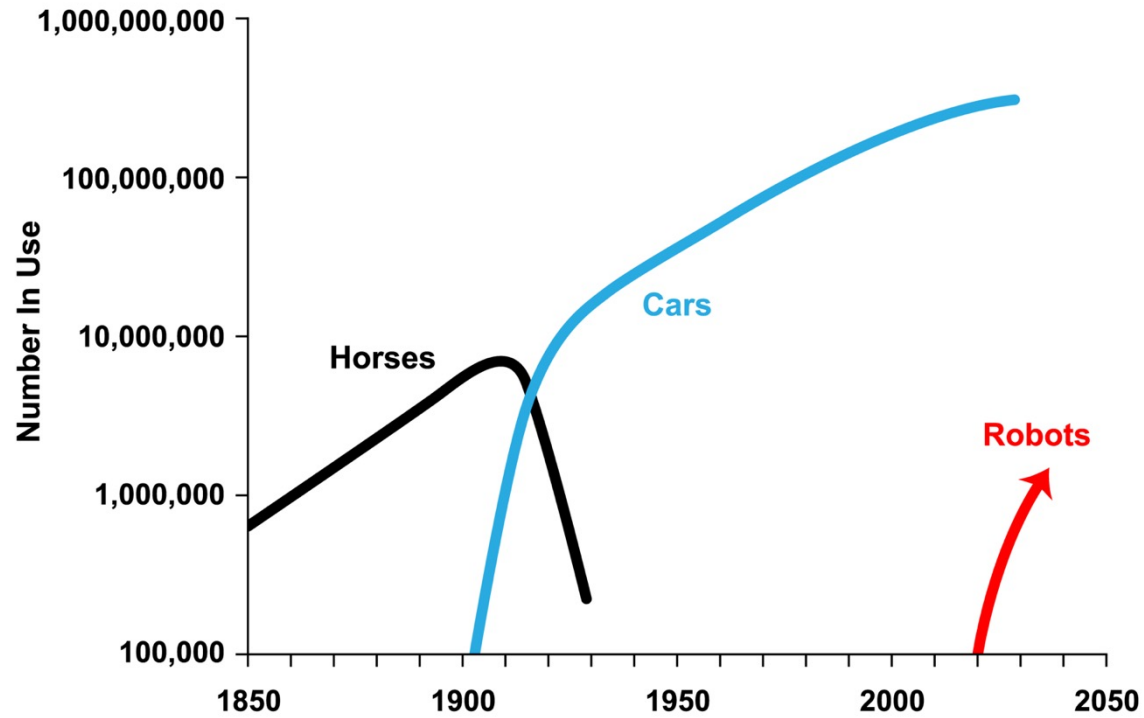


Spot

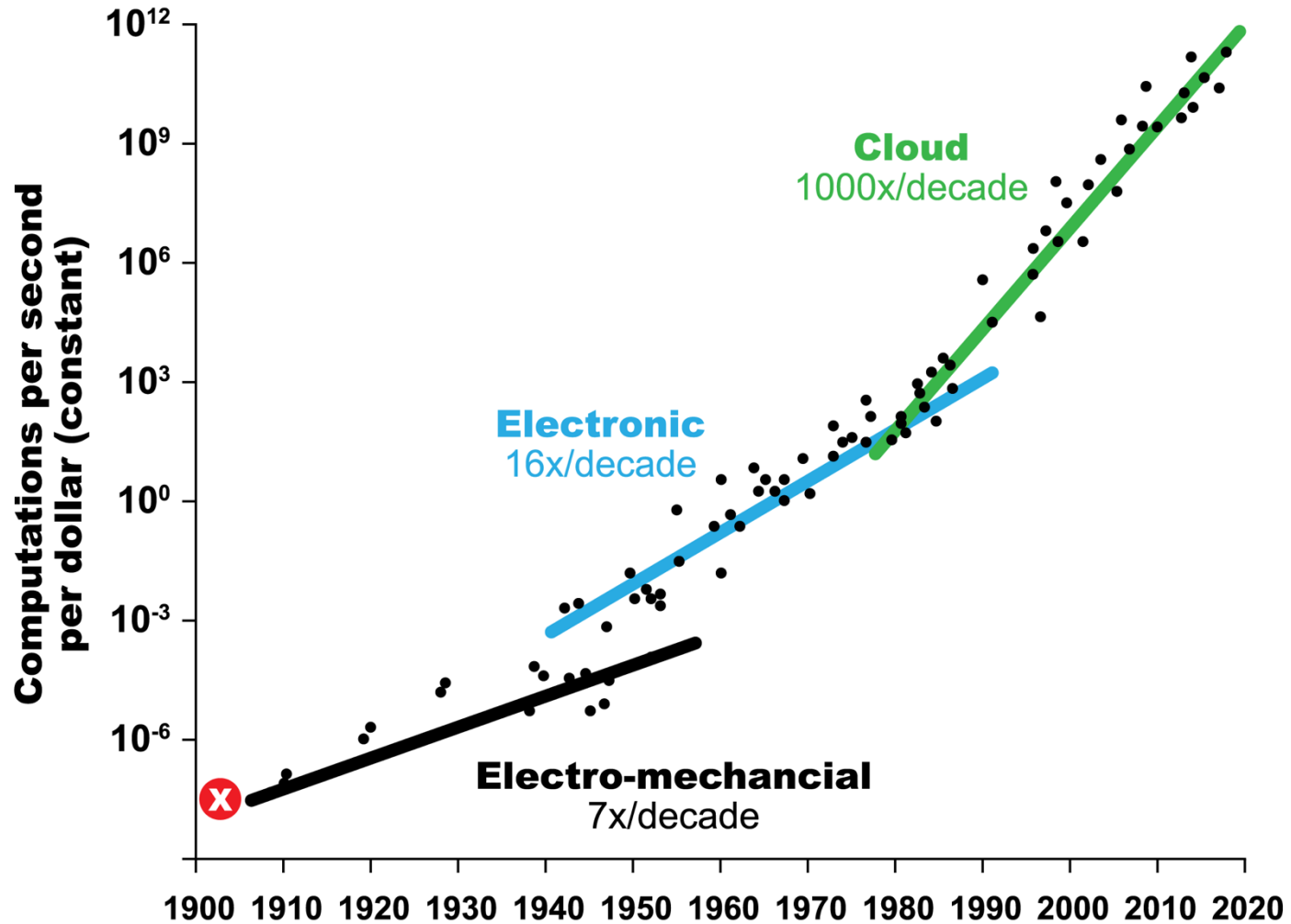
2022 Jimmy Fallon Show



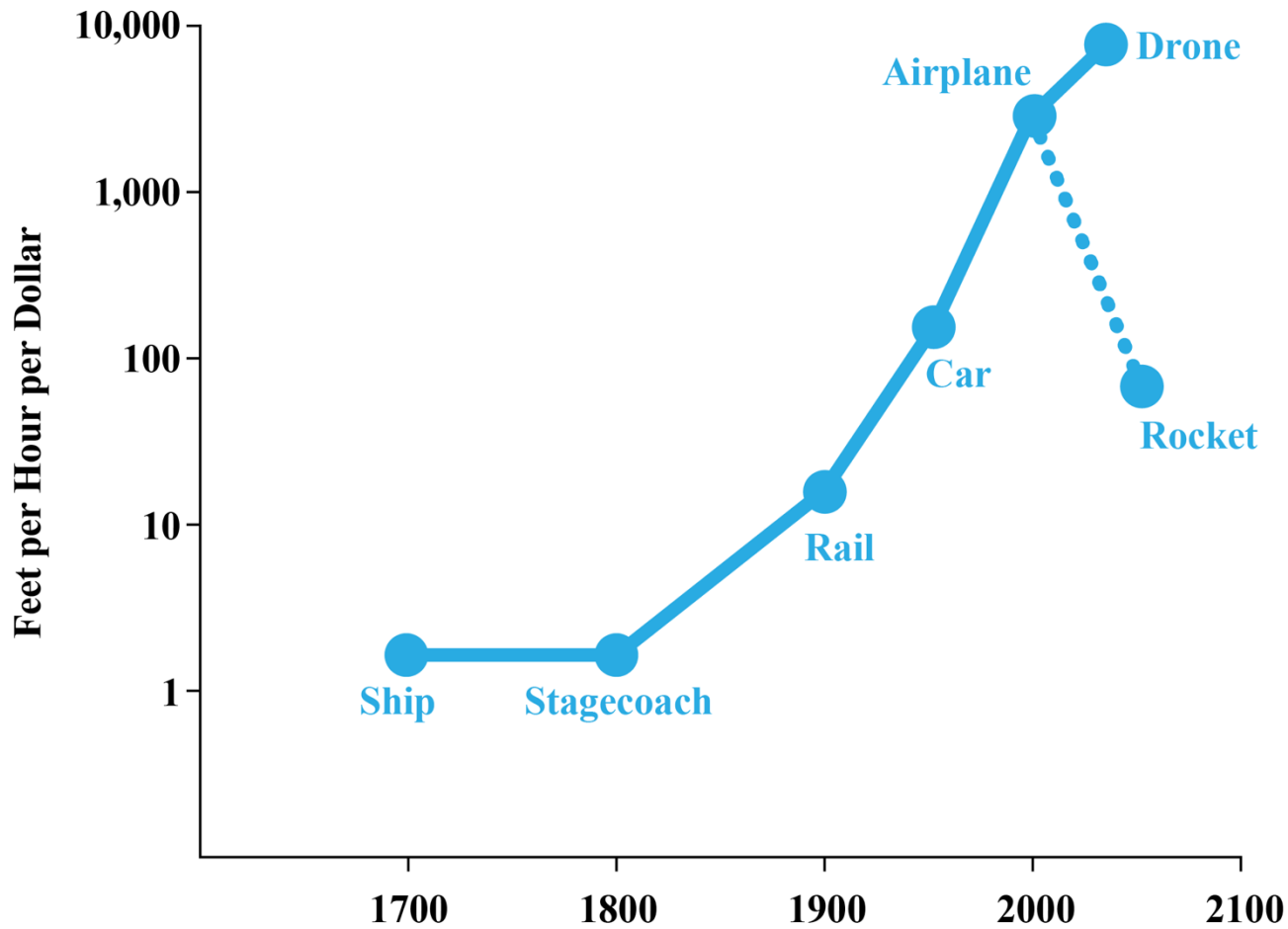
Artificial intelligence: The great accelerator



Economics of information services



Economics of transportation services

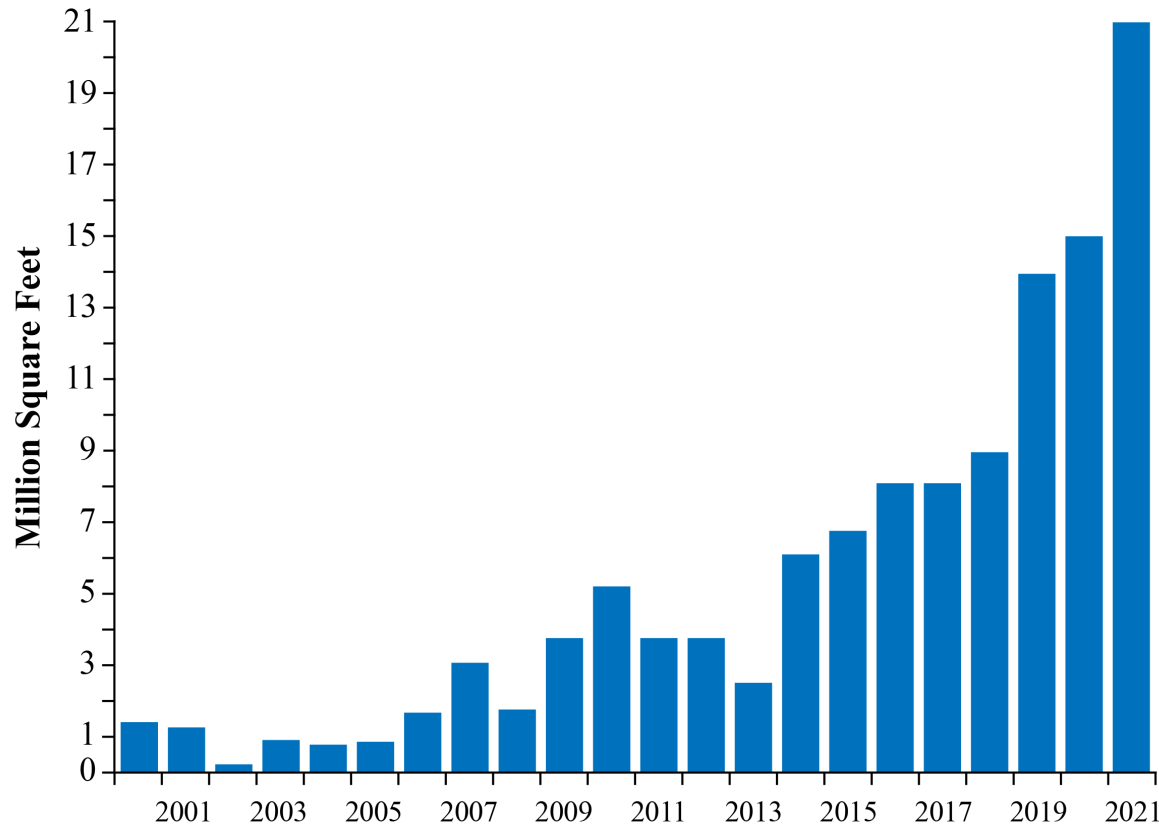


Information infrastructure: Datacenters vs skyscrapers

5,000 enterprise-class datacenters vs **1,500** Empire-class skyscrapers

Each square foot of datacenter vs skyscraper:

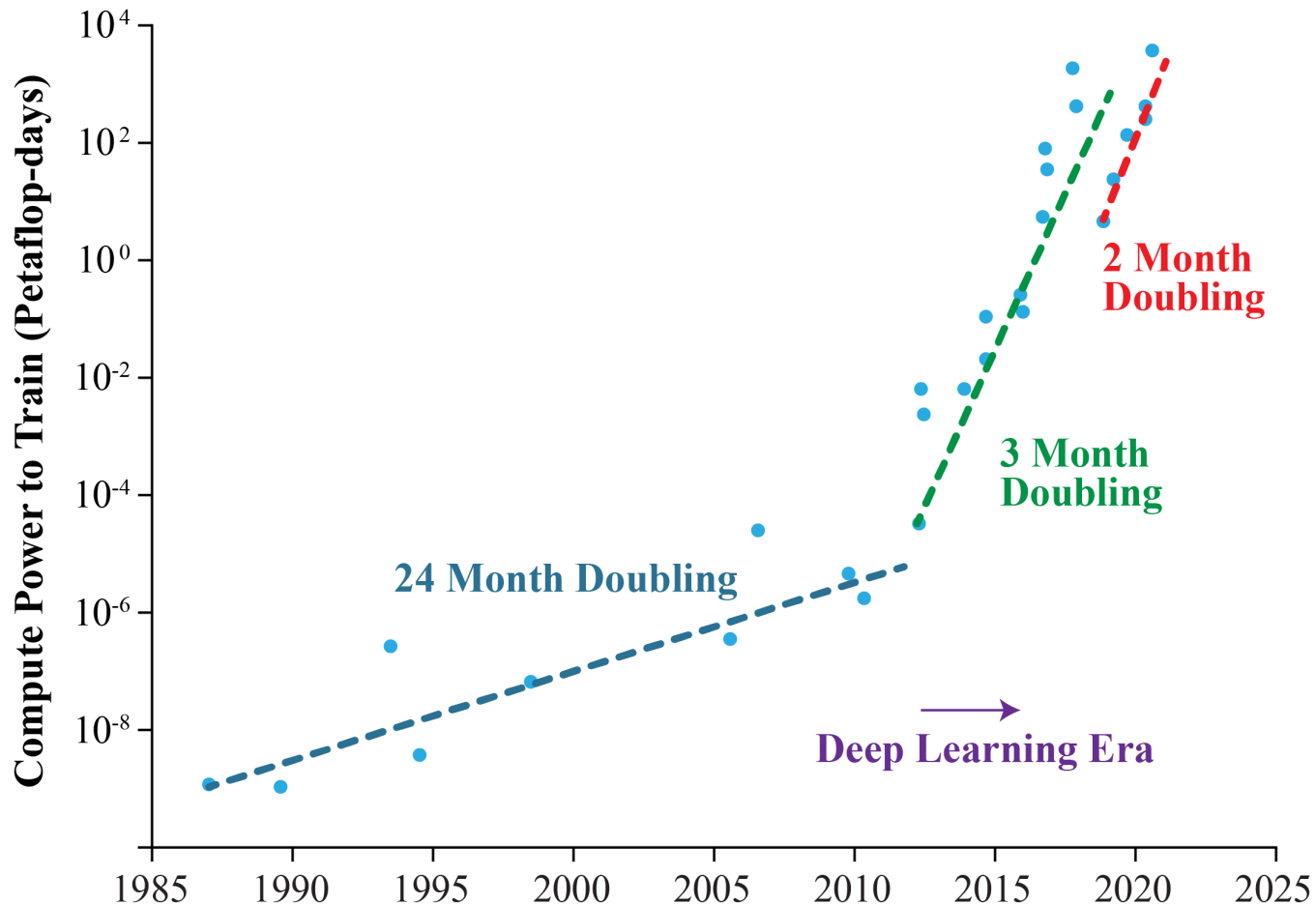
- Same capex to build
- 5x rent
- 100x power demand



Artificial intelligence: The great accelerator

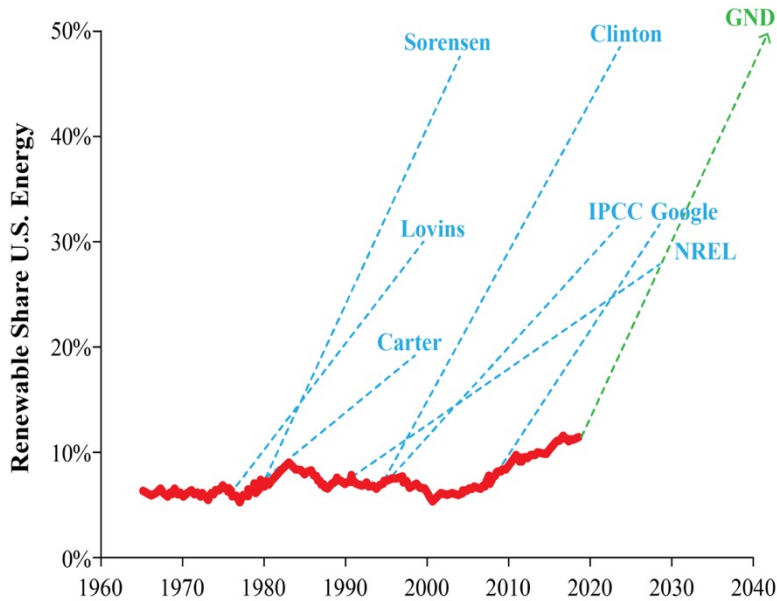
“It’s really a **phase change** in terms of how we look at infrastructure.”

Amin Vahdat, VP machine learning and Cloud AI Google Cloud

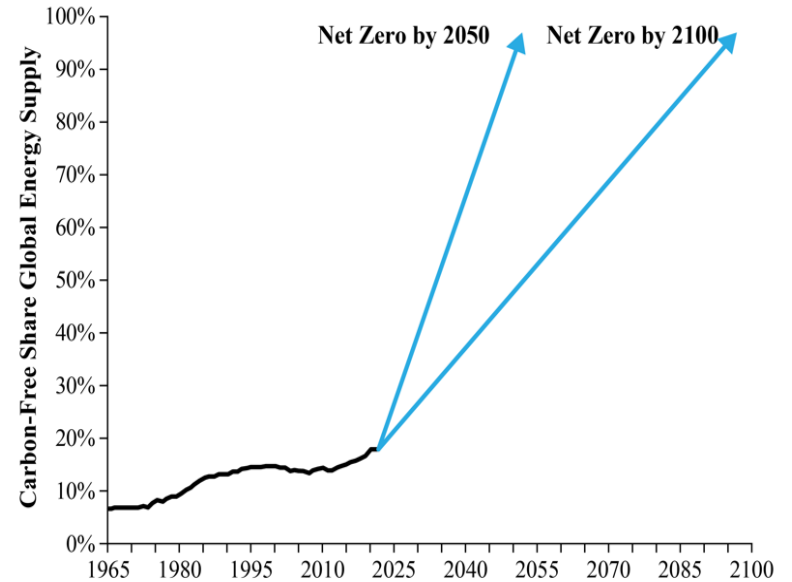


Wildly unrealistic forecasts and policy aspirations

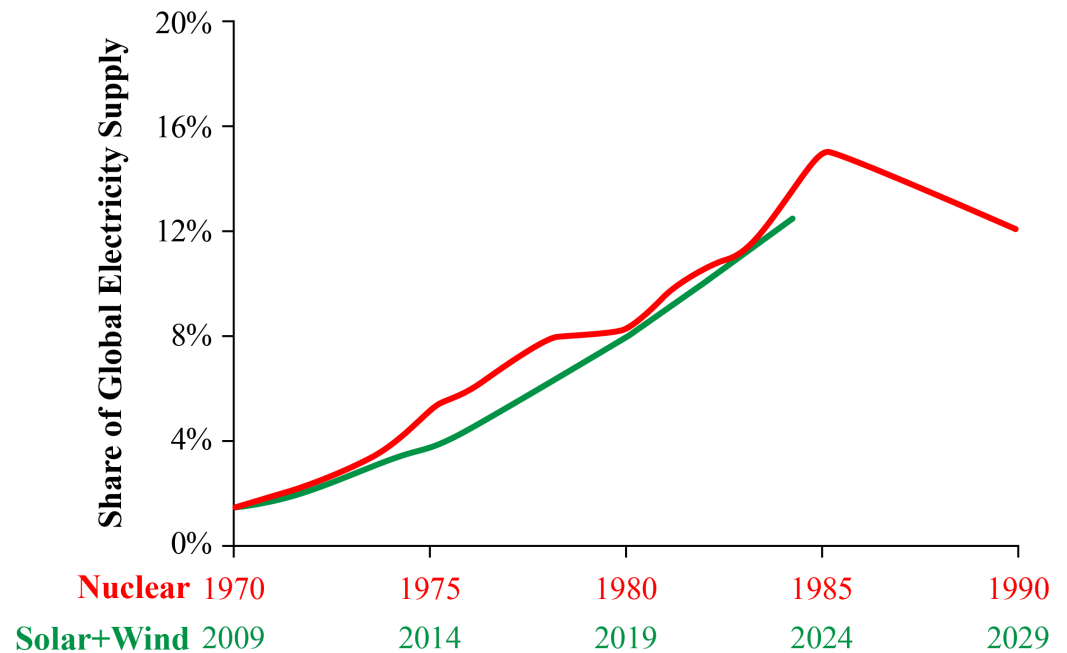
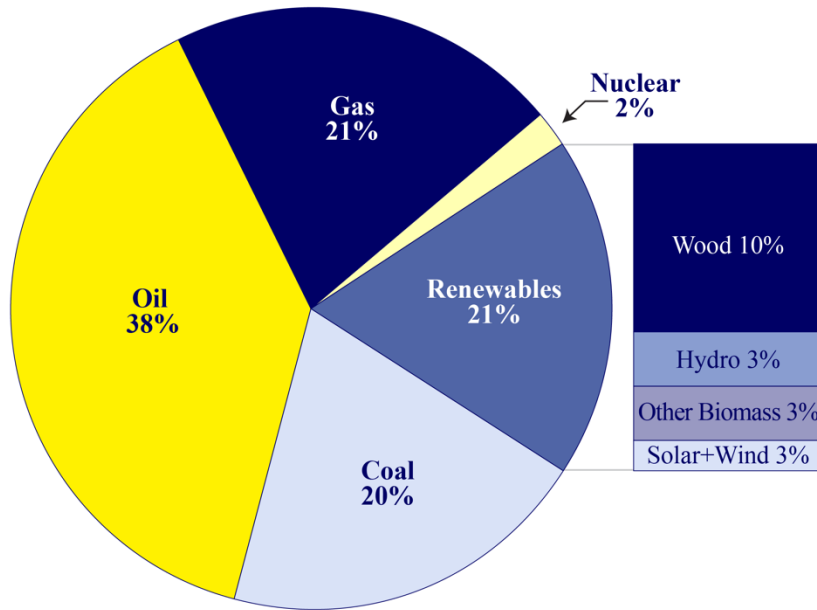
U.S. Renewable Energy Share & Forecasts



Global Carbon-Free Energy Share & Aspiration

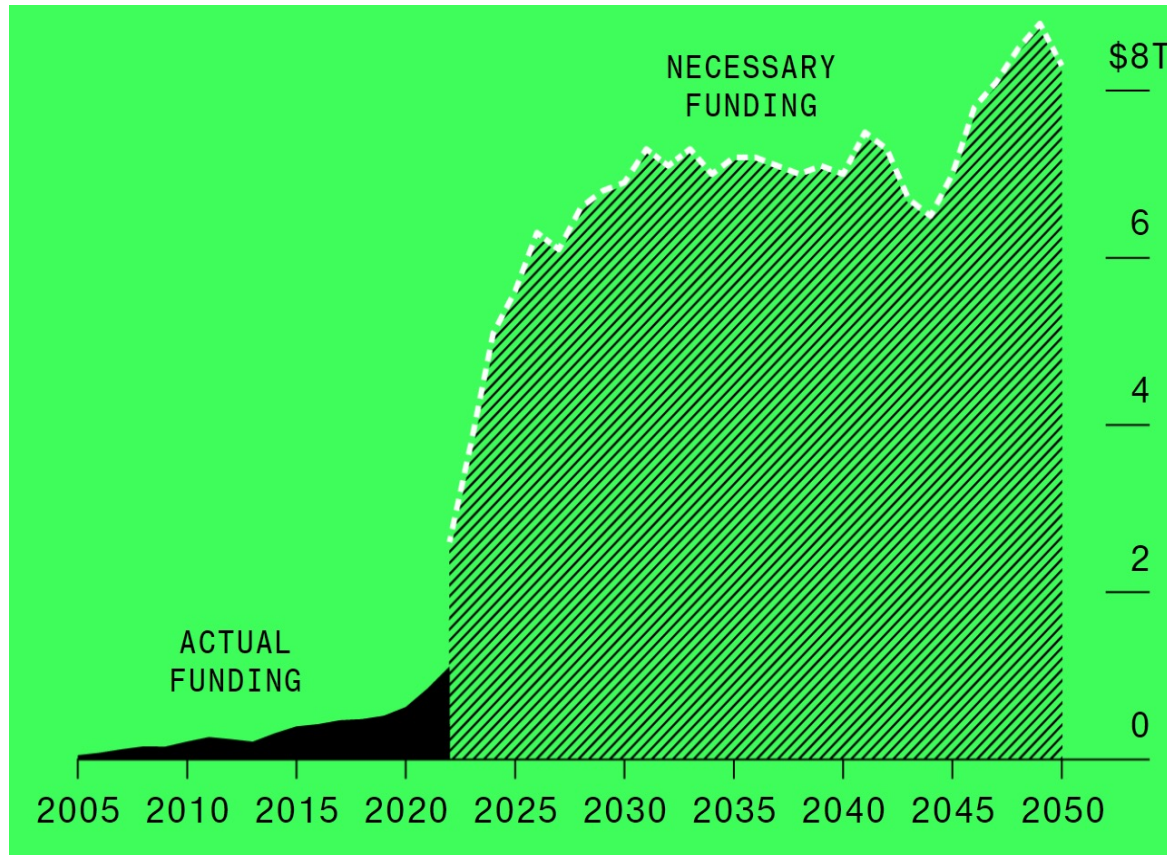


The transition so far: **Wood** still dominates



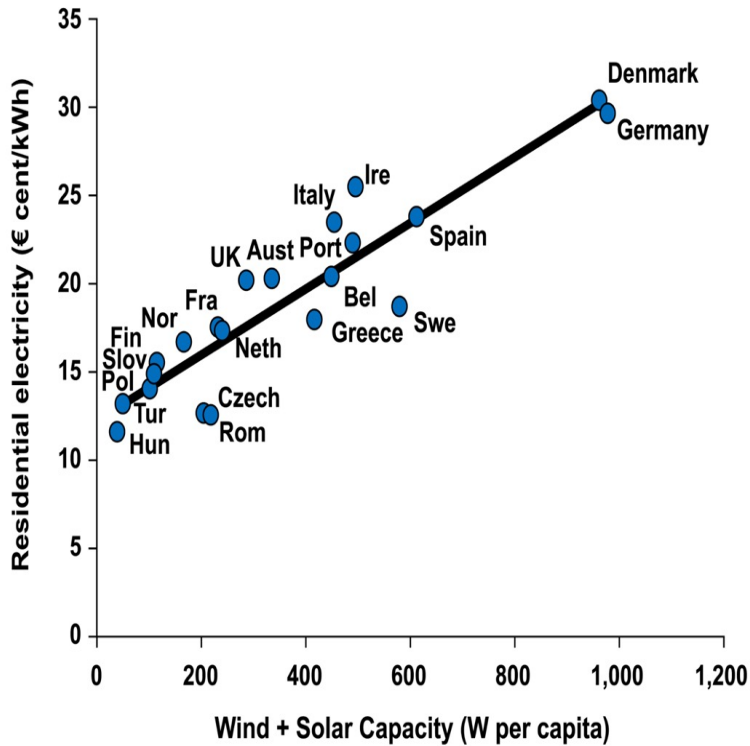
Global renewables & IRA's "Christmas for climate tech"

Global "Transition" Spending Gap

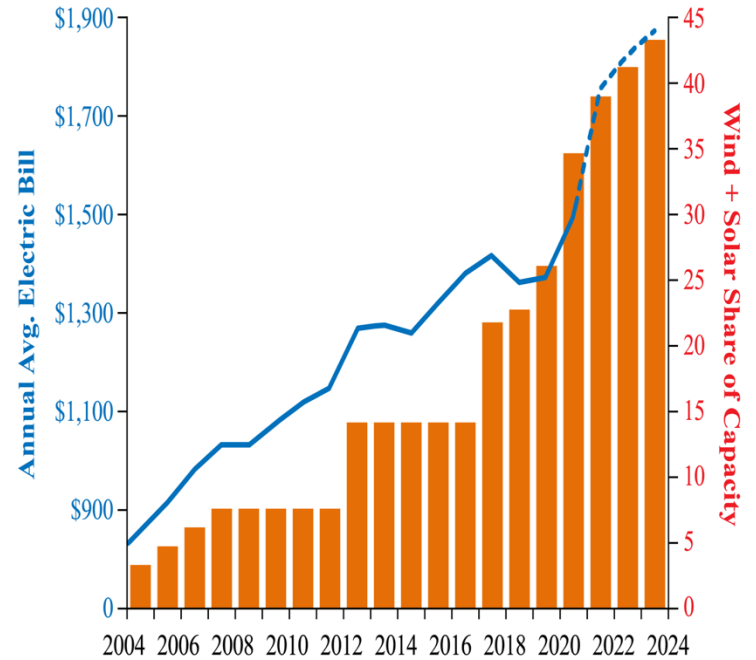


Higher grid costs come with more solar & wind

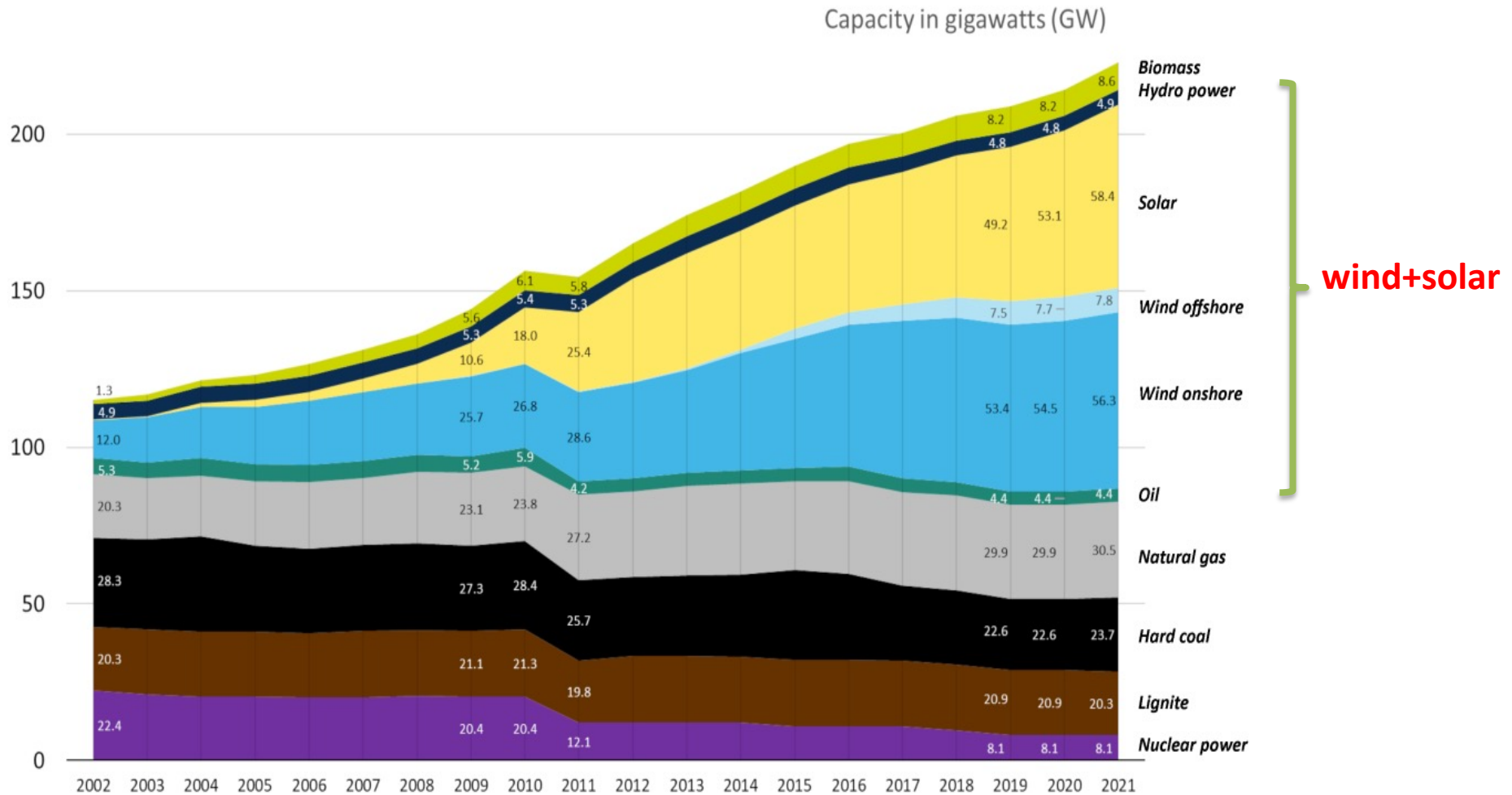
Europe



Xcel (4 million customers)

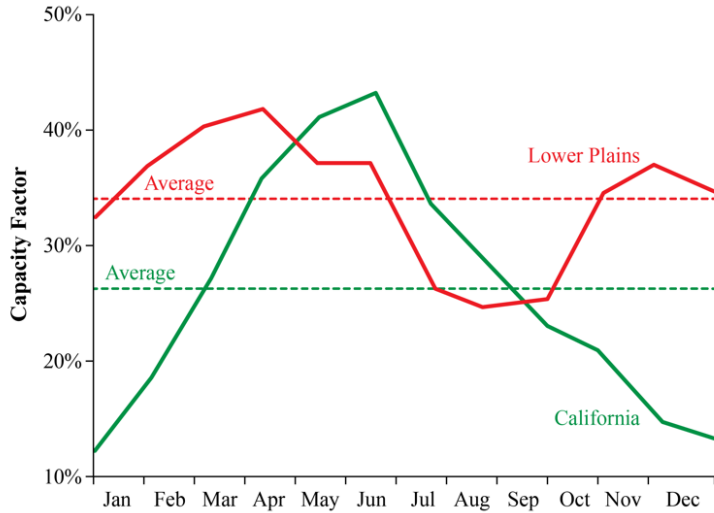


Germany's wind+solar → 6% primary energy

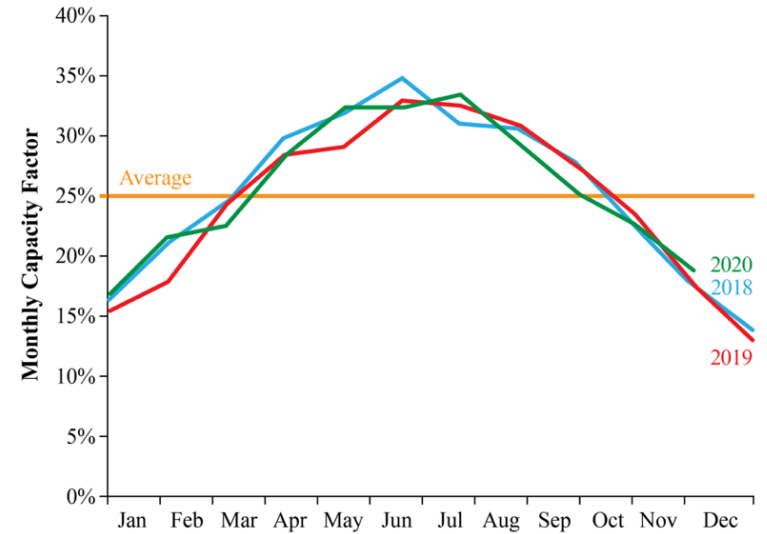


5-day wind/solar “drought” = \$20 trillion batteries

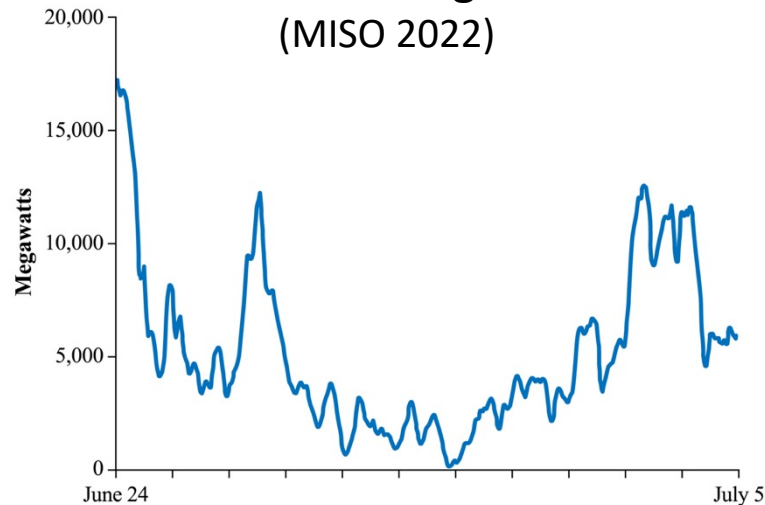
Seasonal Wind Capacity Factor



Seasonal Solar Capacity Factor

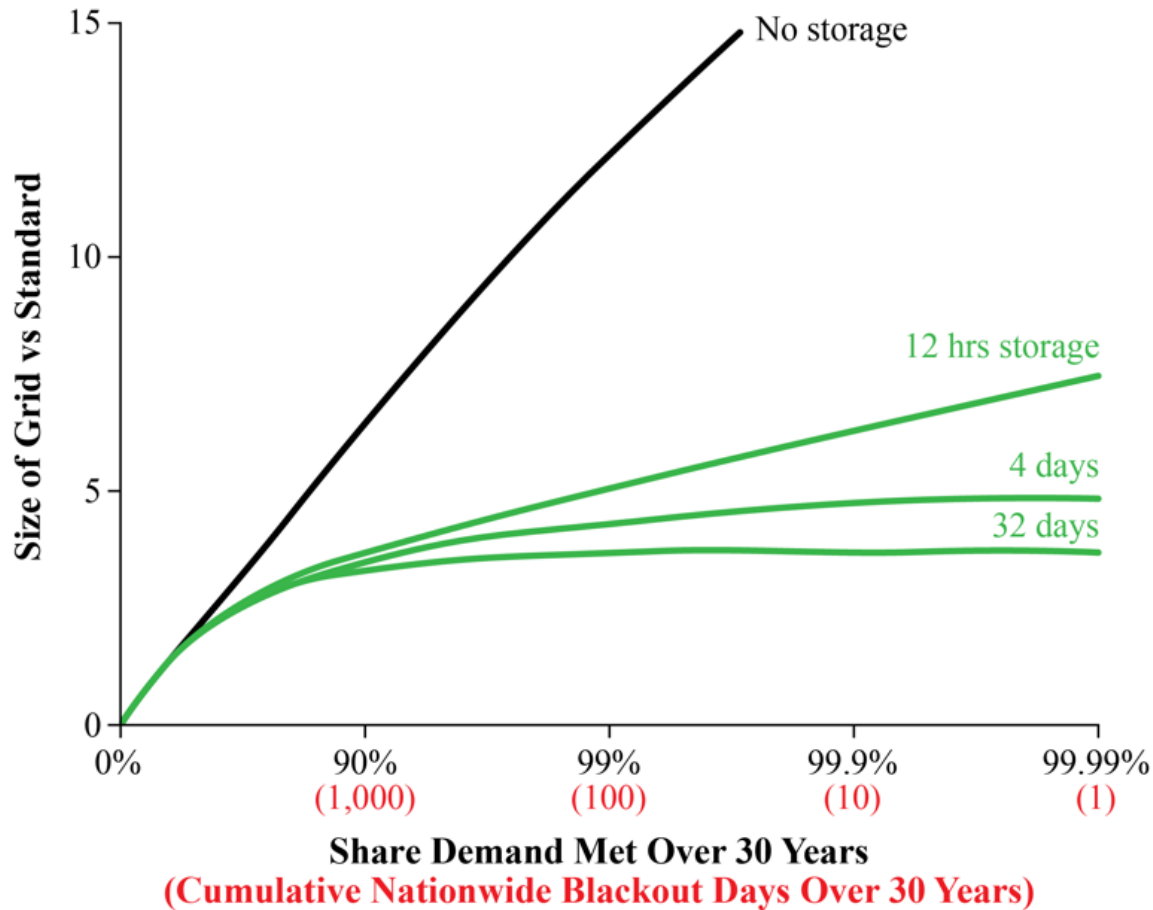


Wind Droughts (MISO 2022)

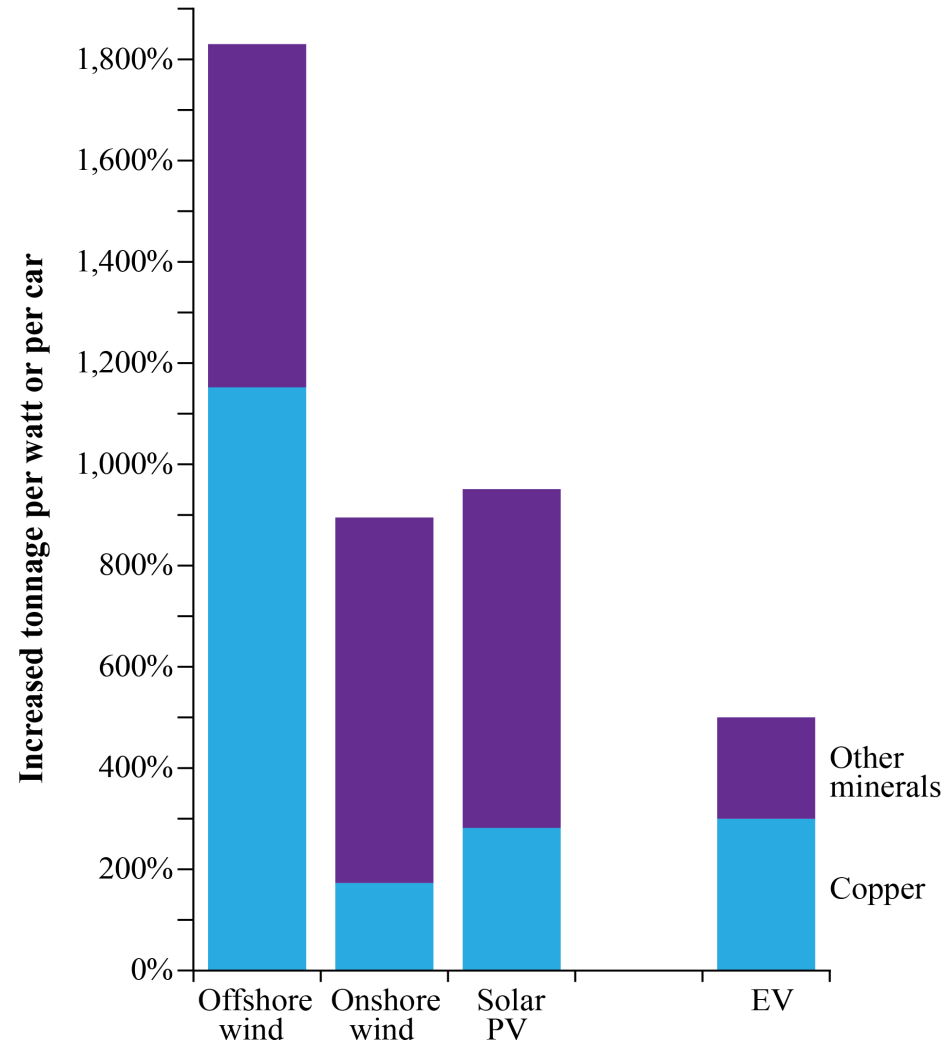


Grid's multi-decade challenge w. variable resources

U.S. Grid Size & Storage Needed All Solar + Wind Grid

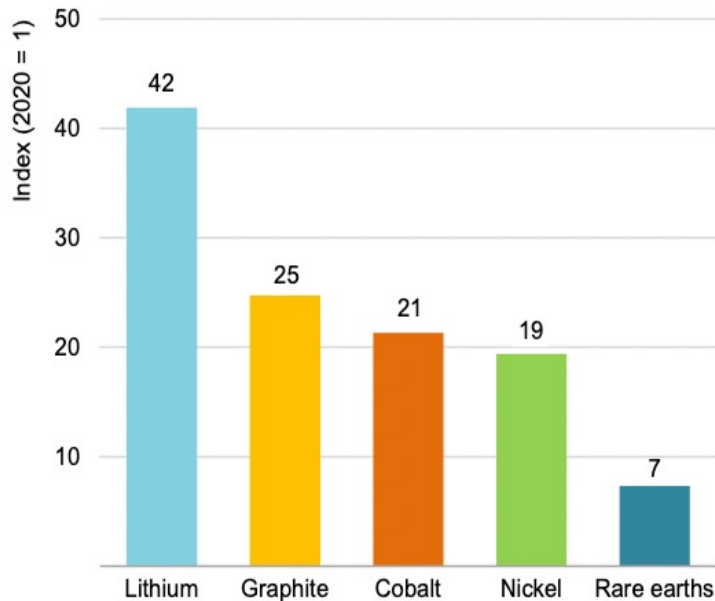


'Green' is an unprecedented shift to mining

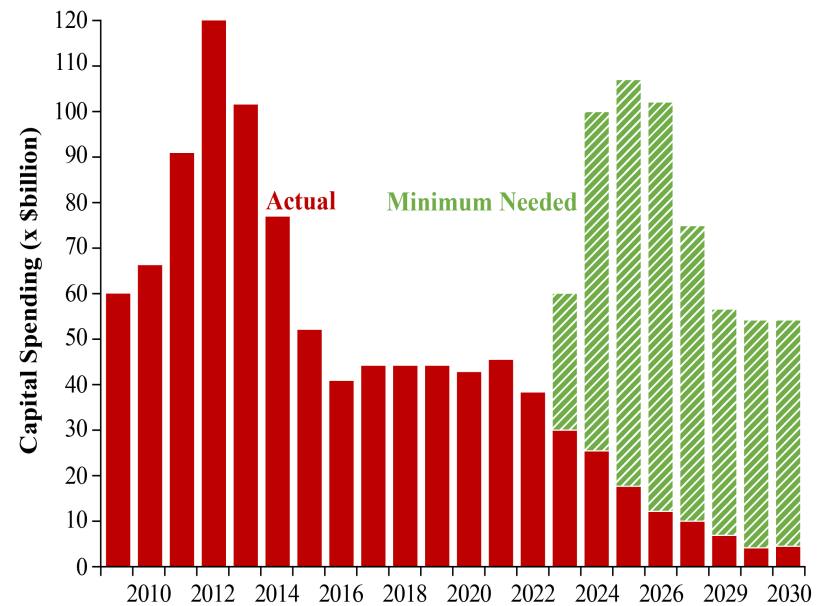


100s new mines needed & 16 yr avg to open new mine

Global Increase in Supply Needed



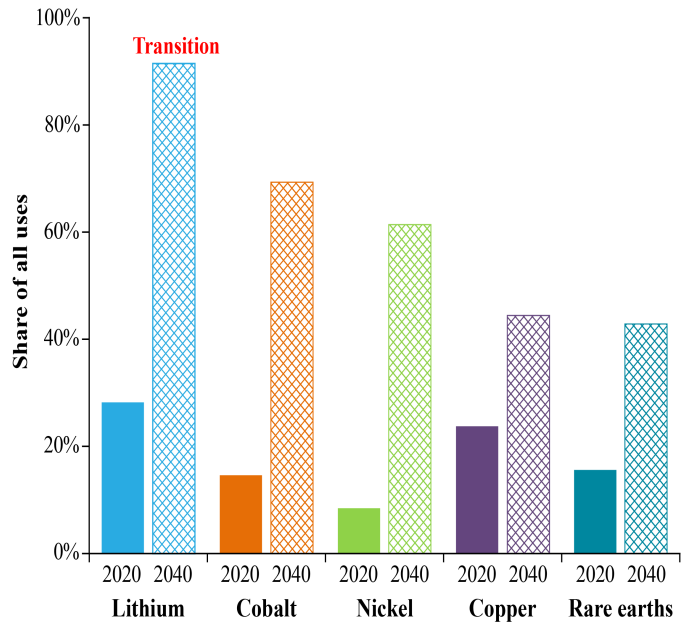
Global Mining Capital Spending



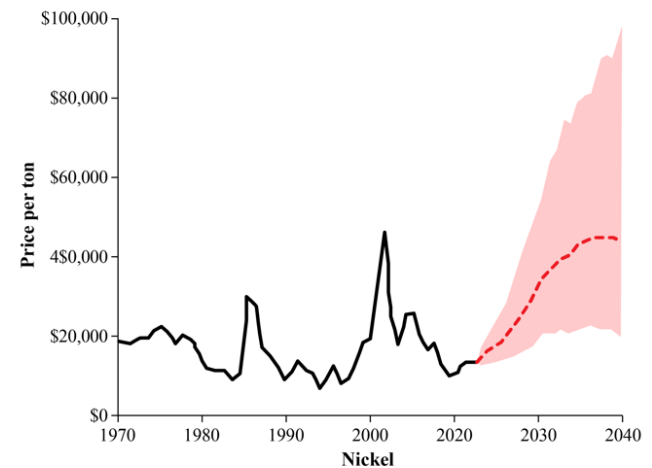
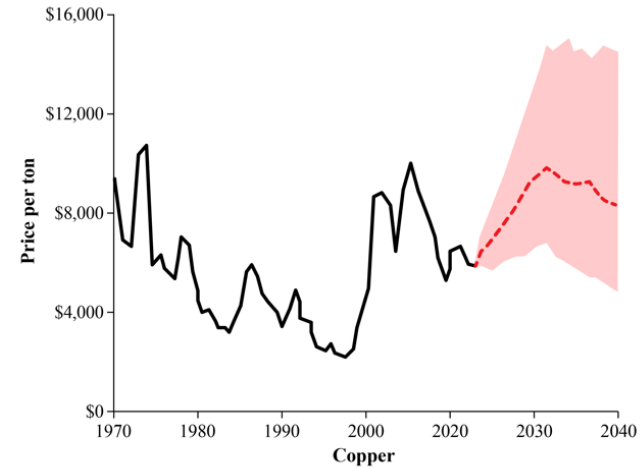
Coal mining capex >> all minerals combined

Price impacts from mineral demands

Energy Minerals Dominate All Uses

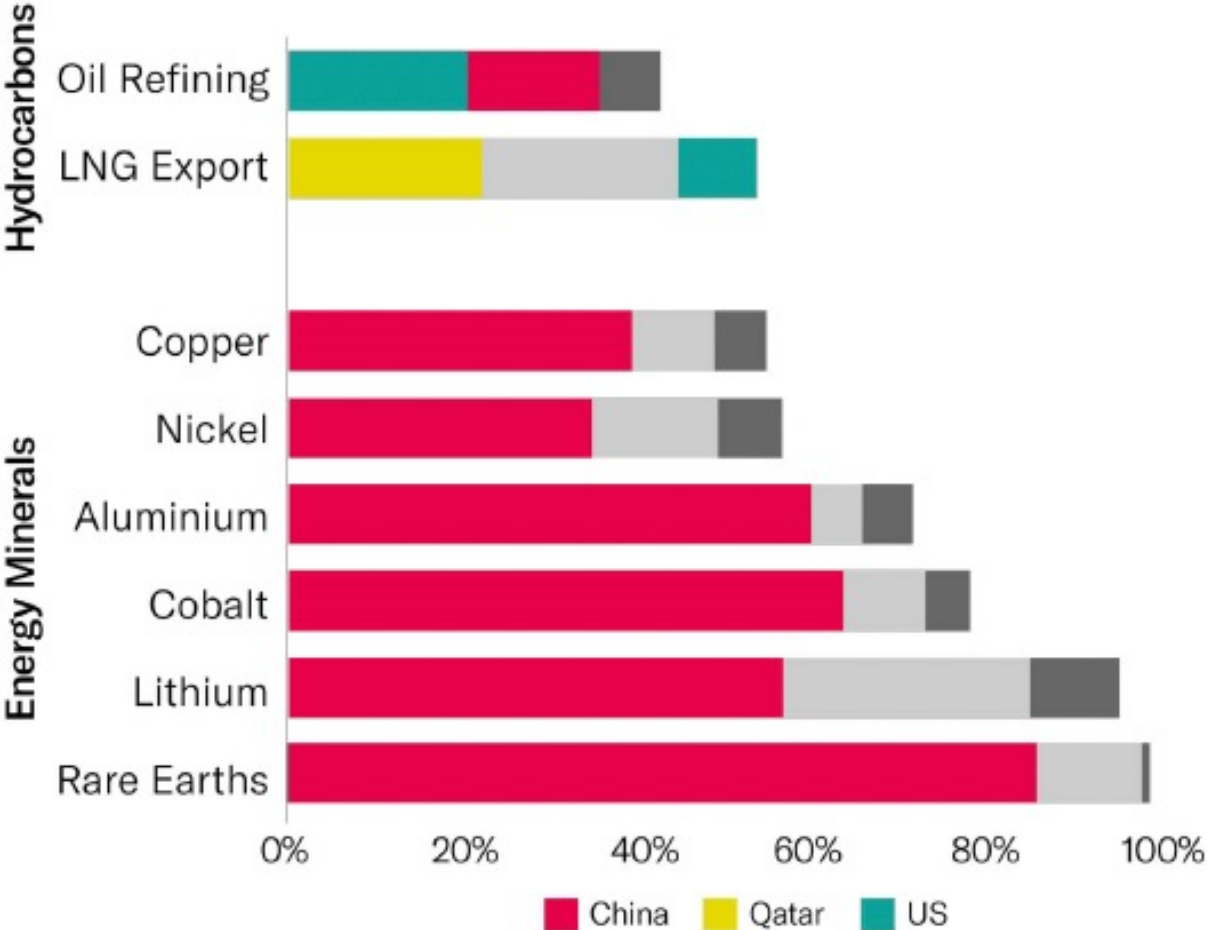


IMF: Historic Mineral Inflation

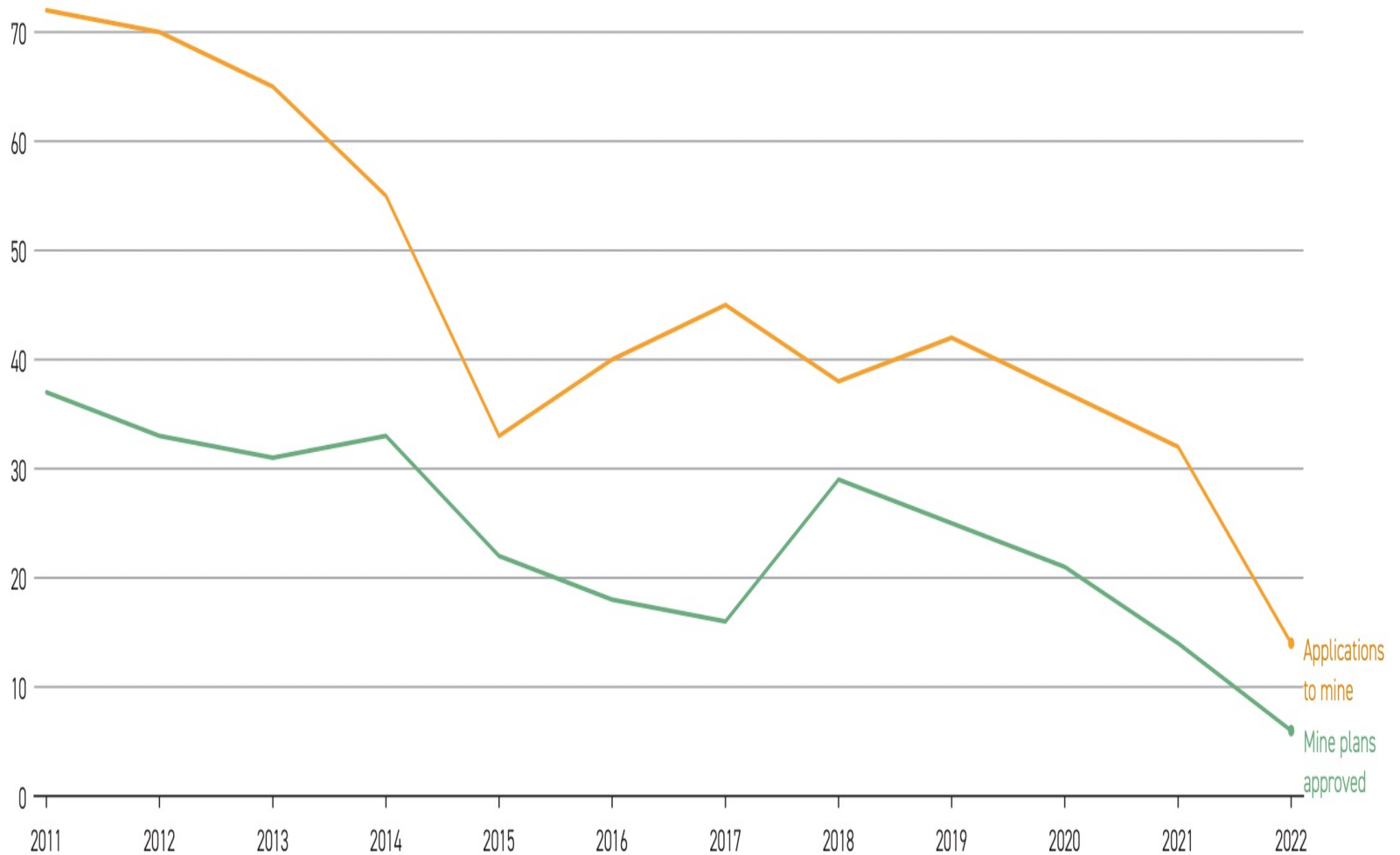


China dominates “energy minerals” supply chains

Global Share of Top Three Countries Producing Refined Products



U.S. Federal mine approvals 2010-2022



Iron Law of energy demand & prosperity

Energy use in tonnes of oil equivalent per capita

