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Supply Chains and Resource Constraints in Energy Systems

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Setting the scene: An evolving energy landscape

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How does change happen?

A key concept, that translates anywhere in the world to any technology, for understanding the pace and scale of transitions (in any industry) and the economics of technology adoption:

Coordination and the Supply Chain

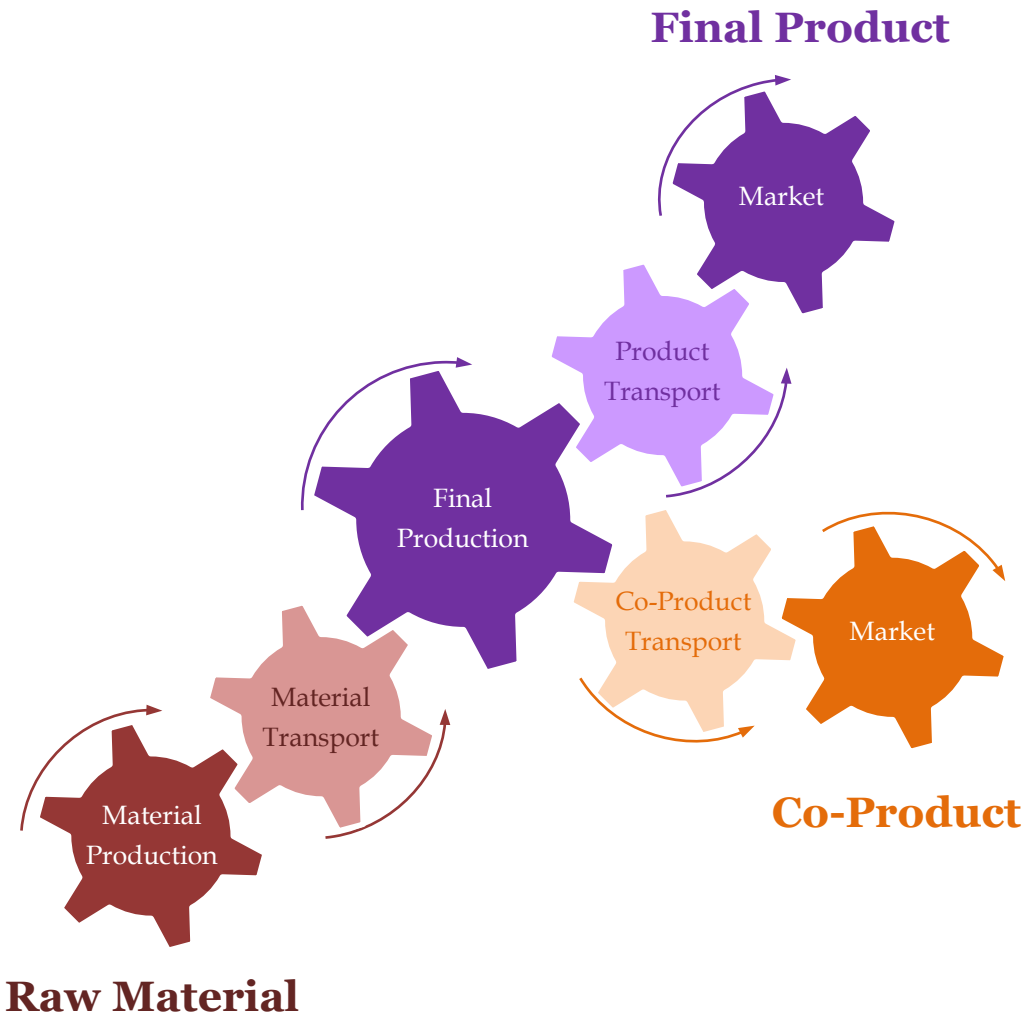
Coordination and the Supply Chain

- Every production process involves a supply chain connecting raw material inputs to a production process to deliver a final product, and potentially a co-product, to end-users. Value must be generated because capital always chases returns.

- Coordination theory plays a central role.
  - The simplest example is the prisoner's dilemma.
- Along a supply chain, if any part of the complex set of interactions breaks down, coordination failure ensues, and the commercial viability of investments at any point in the supply chain is compromised.

- What about new tech? The widget parable… 🤔

- These complexities can lead to the "valley of death" for new energy technologies.



So, what do we see across the global energy landscape?

History can provide a useful frame for understanding what will likely happen going forward…

Legacy, scale, technology and comparative advantage

The evolving energy landscape is a developing nation story

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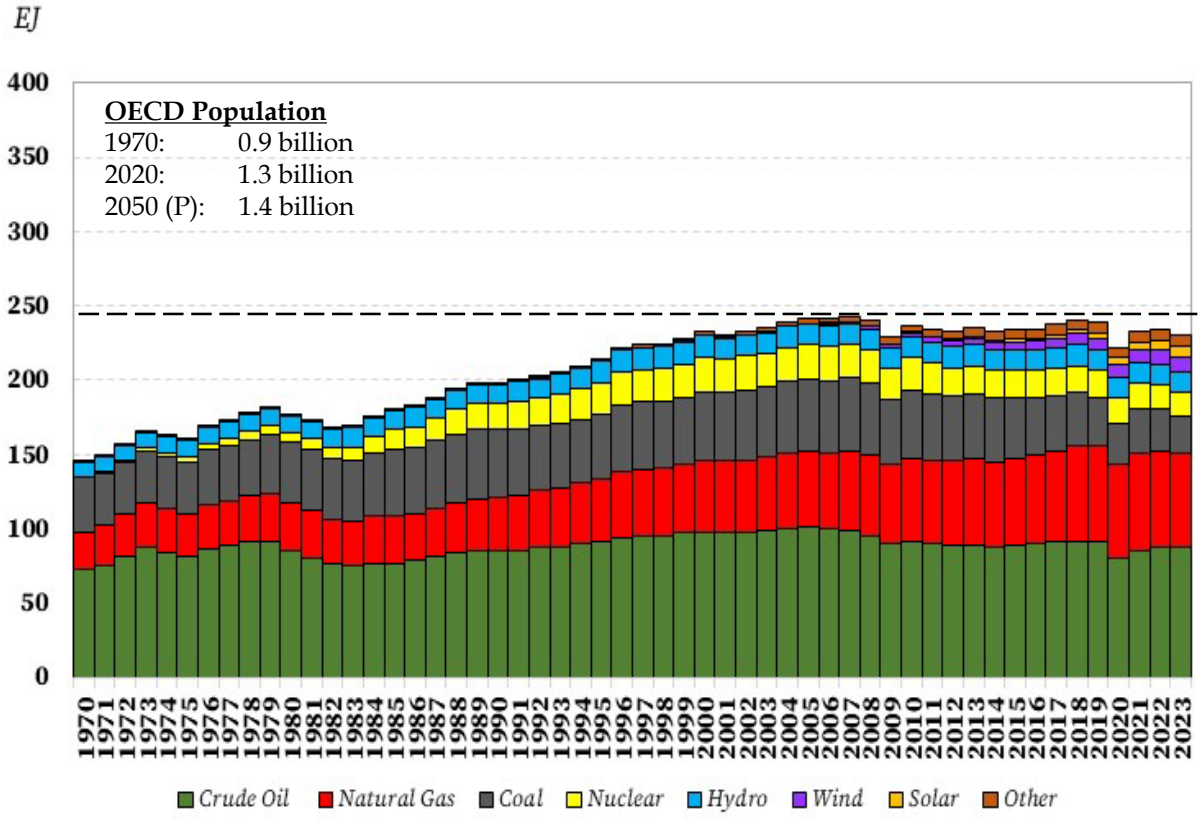
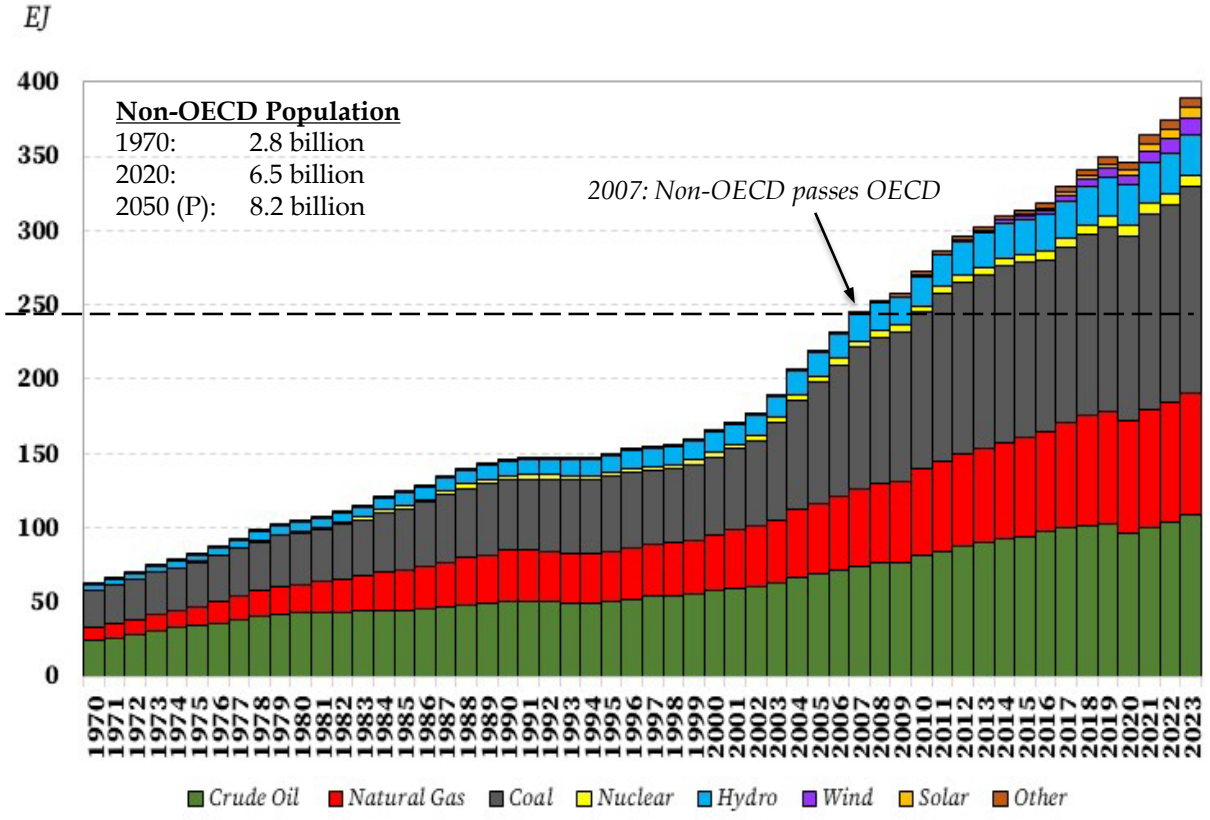
- Energy demand is rising fastest in the developing world, largely driven by hydrocarbon fuels.
  - EU is 9.1% of global demand; N. America is 18.8% of global demand; developing Asia is 39.7% of global demand.
- Projections for population and economic growth indicate this trend will likely continue.



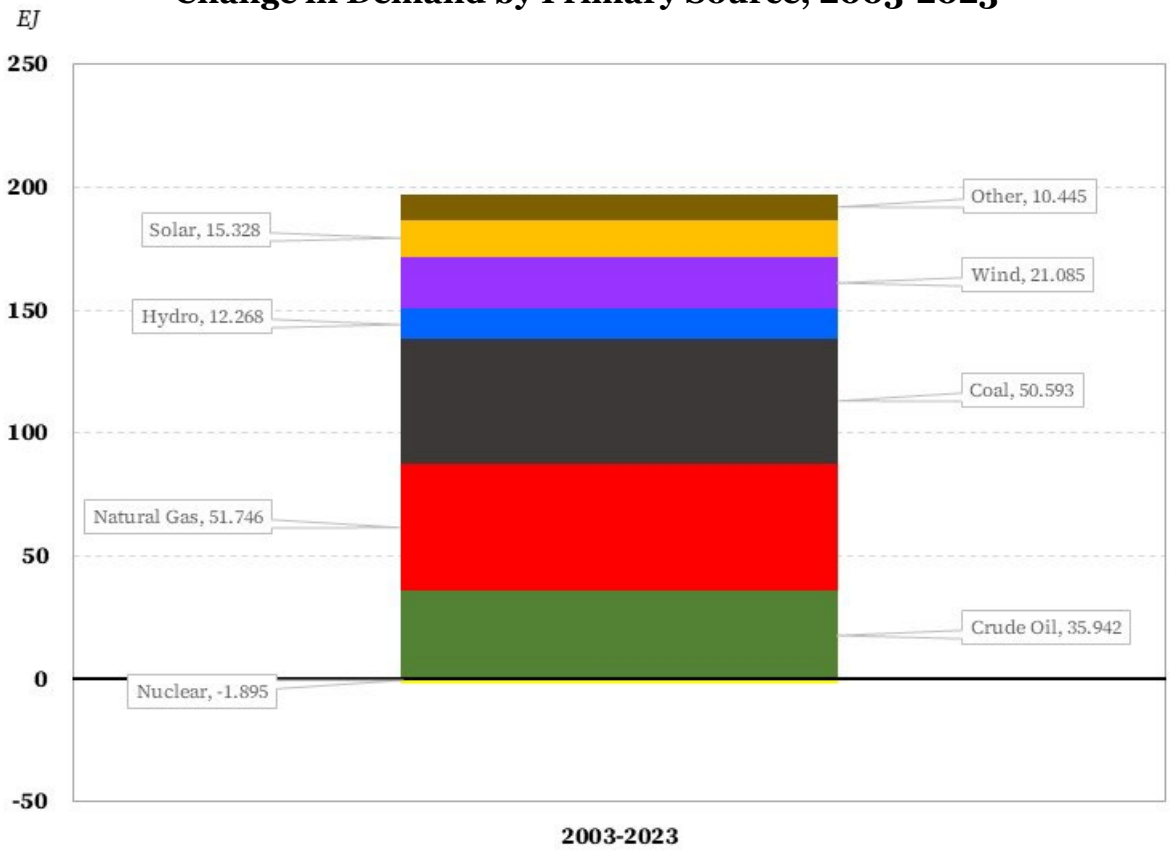


Data Sources: EI Statistical Review of World Energy, 2024; OECD.stat

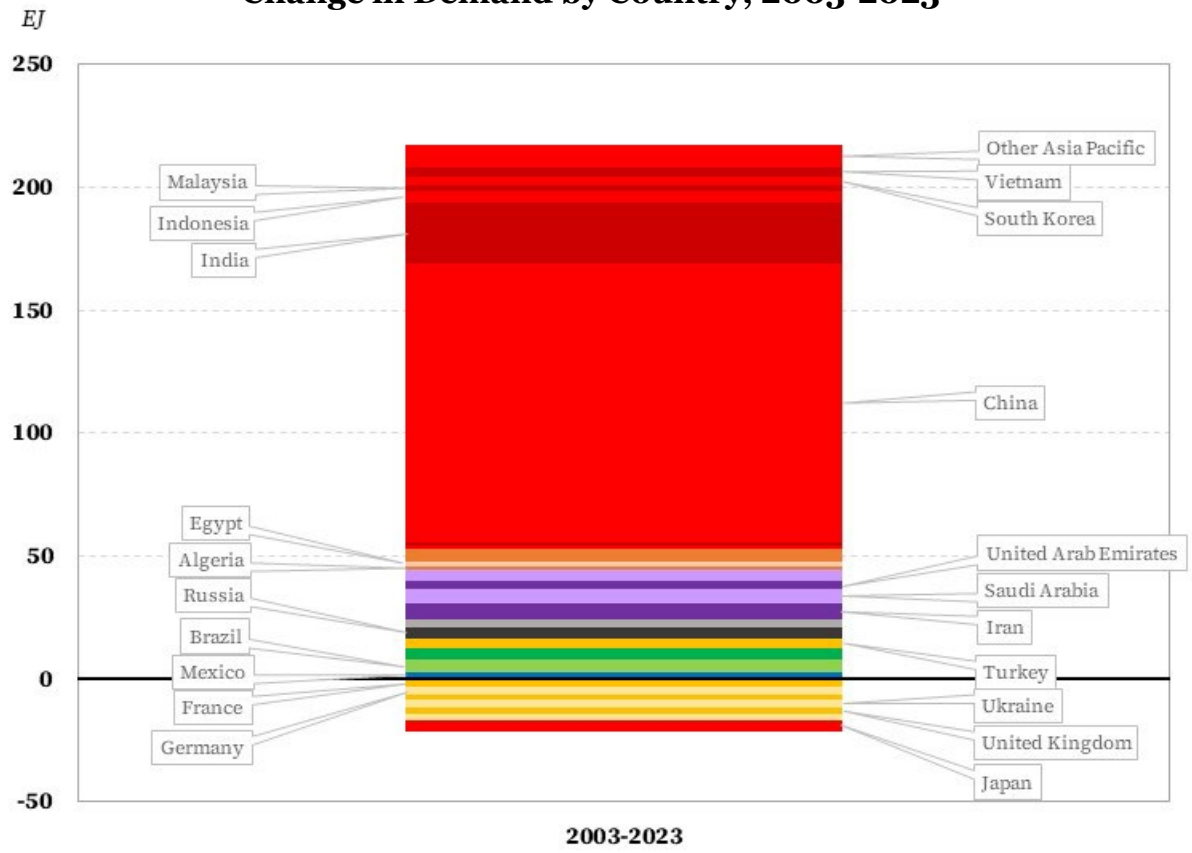
Another view: Global energy demand is expanding

- Demand has grown almost everywhere. Exceptions include most of OECD Europe, Japan, New Zealand, and the US.
- Demand by primary source has increased for energy source, except nuclear.
  - Wind and solar have increased at the highest average annual rate – 19.1% p.a. and 38.3% p.a., respectively.
  - But total demand has increased most for natural gas, coal, and crude oil.
- Developing Asia has driven increases across the energy landscape, with significant ramifications for international trade.

Change in Demand by Primary Source, 2003-2023



Change in Demand by Country, 2003-2023

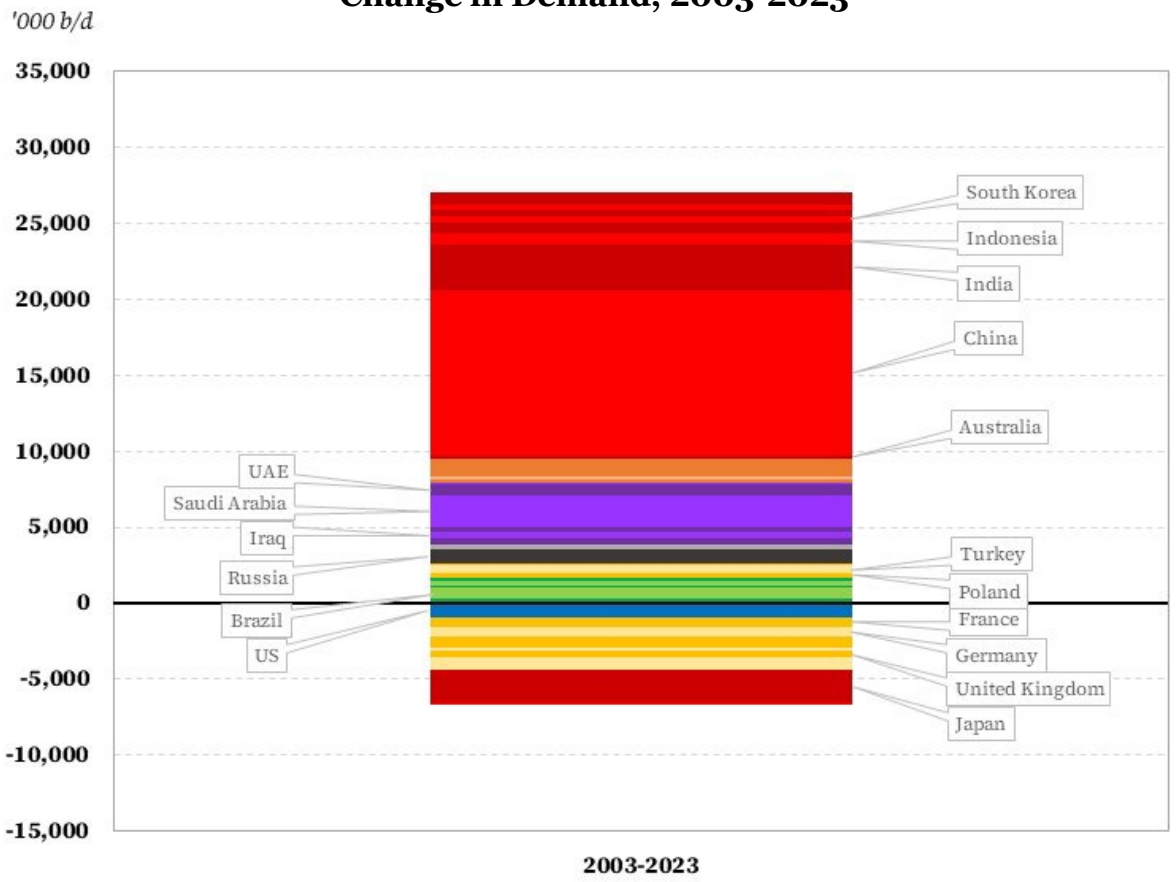


Data Source: EI Statistical Review of World Energy, 2024

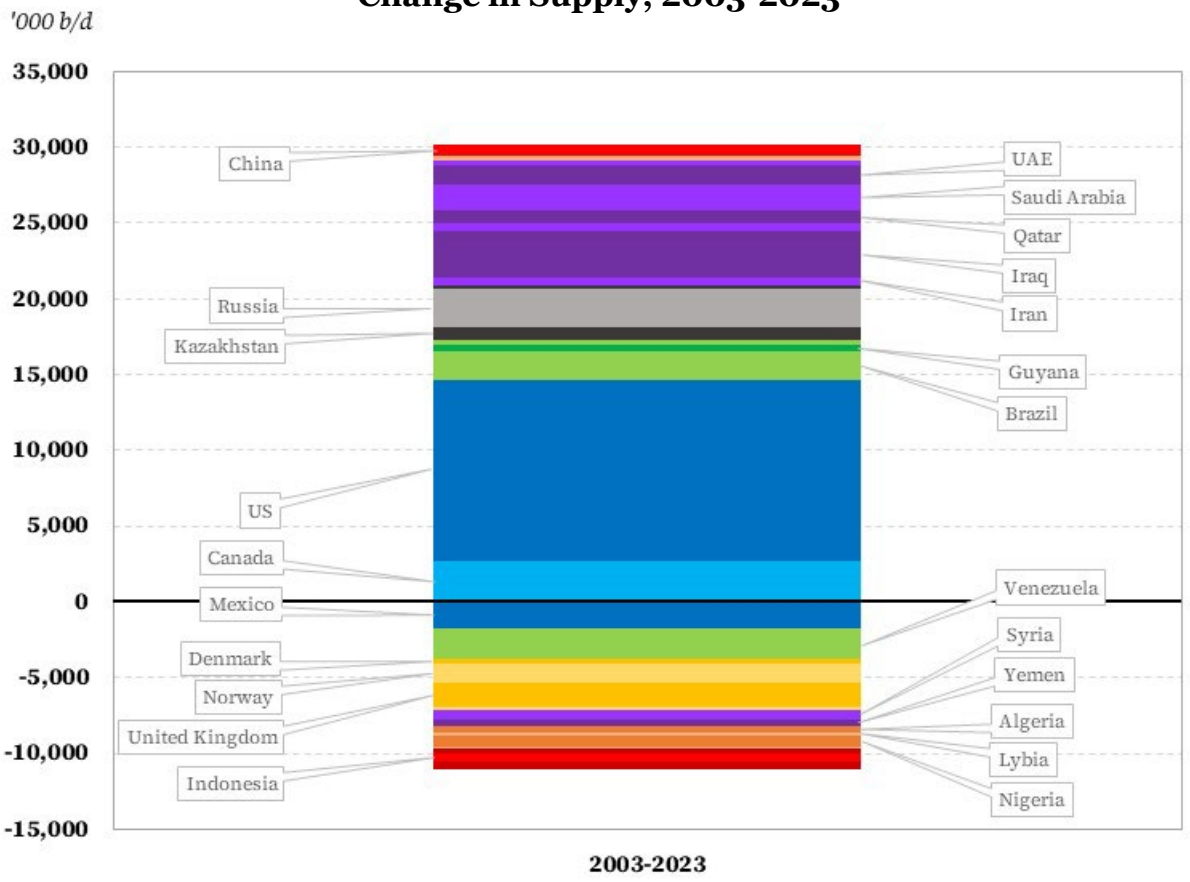
Oil: A growth story

- Demand has grown in the developing world, but it has declined in the developed world.
- Supply growth has been from “incumbent” producers, plus the emergence of the US, Canada, and Brazil.
- Above-ground issues lead supply decreases.
- Net growth over the last 20 years was 20.4 million b/d, and that includes 2020! Net growth from 1983 to 2003 was 21.9 million b/d. The average annual increase only changed from 1.09 to 1.02 million b/d.

Change in Demand, 2003-2023



Change in Supply, 2003-2023

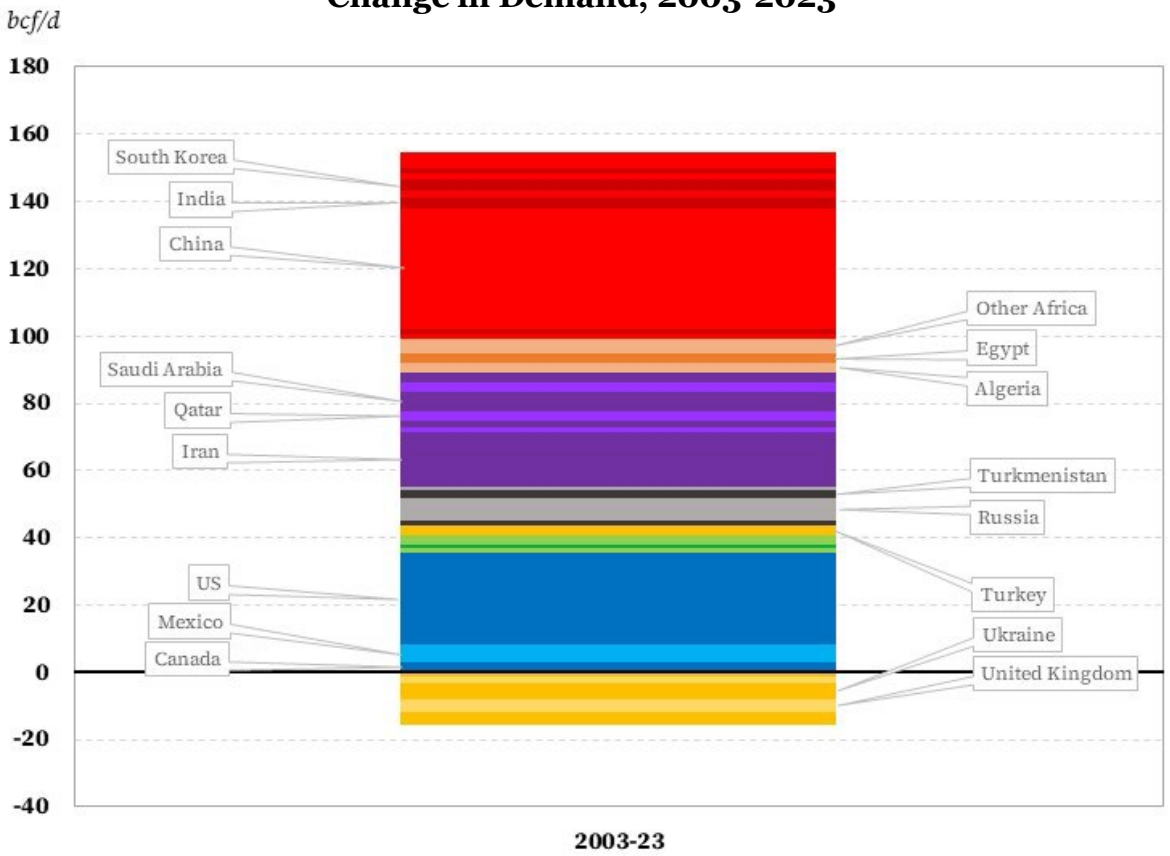


Data Source: EI Statistical Review of World Energy, 2024

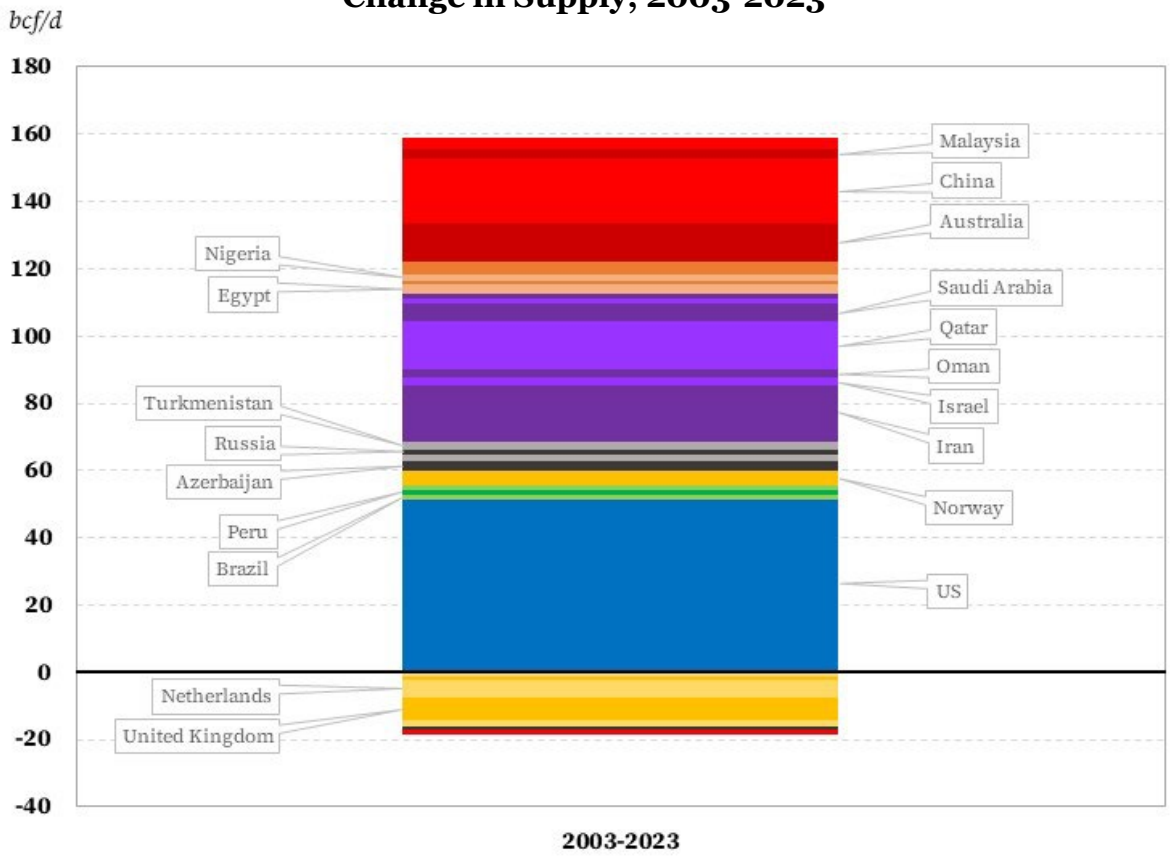
Natural gas: Another growth story

- Demand has grown everywhere, except in Europe.
- Supply declines are also led by Europe.
- Supply growth has largely been to meet local demand. Notable exceptions: US, Qatar, Australia.
- Net growth over the last 20 years has been 139 bcf/d, or a 56% increase! Net growth from 1983 to 2003 was 107 bcf/d, so although the growth rate has slowed, the net increase was larger.

Change in Demand, 2003-2023



Change in Supply, 2003-2023

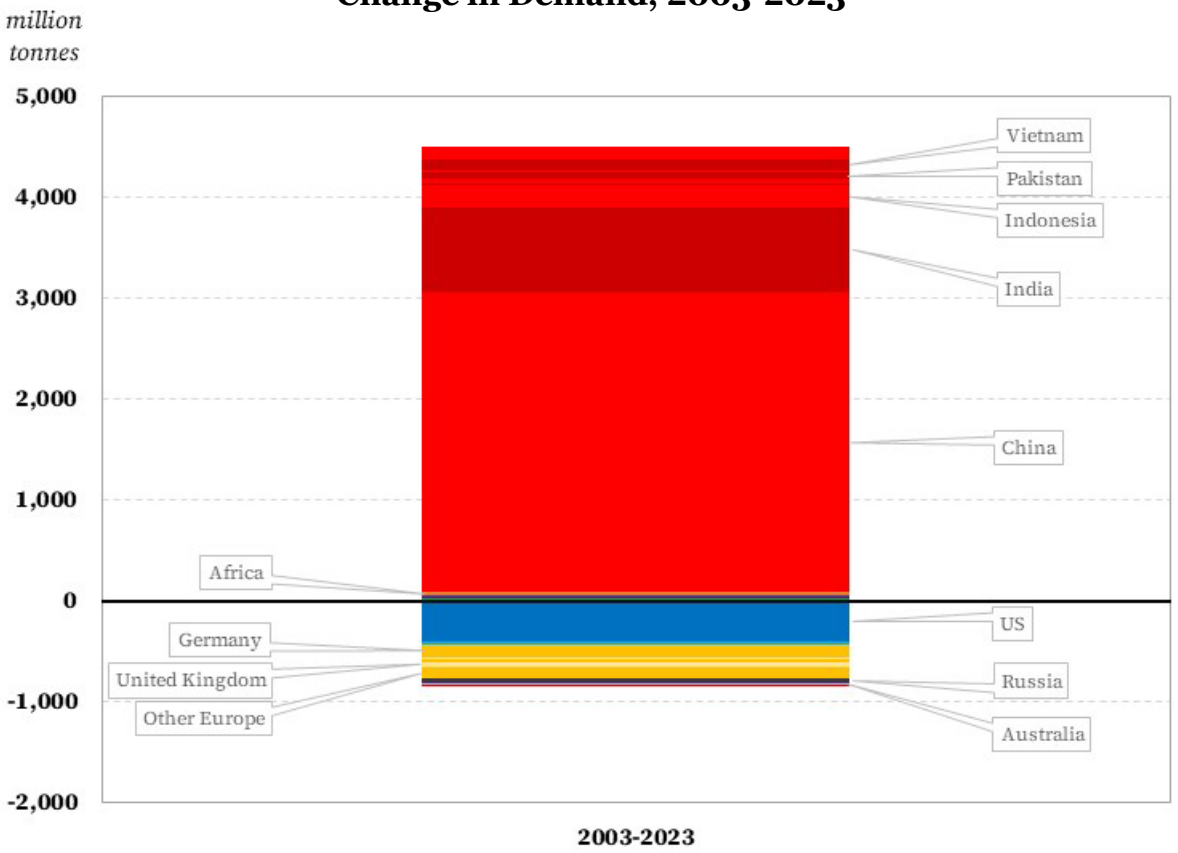


Data Source: EI Statistical Review of World Energy, 2024

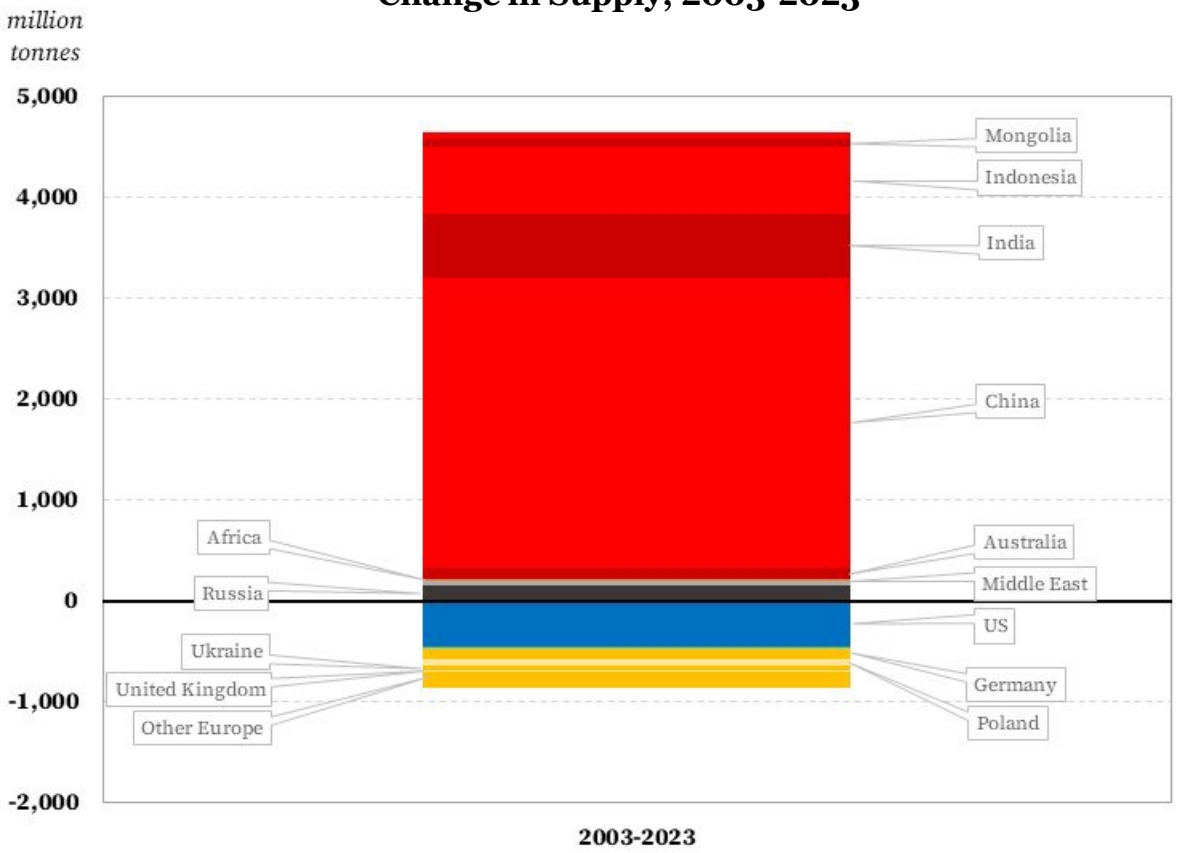
Coal: Yes, another growth story

- Growth in demand in Asia has driven the “global” increase.
- Both supply and demand have decline in Europe and North America.
- Supply growth has largely been to meet local demand, but regional trade in Asia has proven important for market balance.
- Coal demand in 2023 was 9.10 billion tonnes, the highest it has ever been. Net growth over the last 20 years has been 3.77 billion tonnes, up from 1.26 billion tonnes over 1983-2003. Growth in Asia has dramatically changed the coal landscape.

Change in Demand, 2003-2023



Change in Supply, 2003-2023



Data Source: EI Statistical Review of World Energy, 2024

Where does electrification fit? It is part of the growth story

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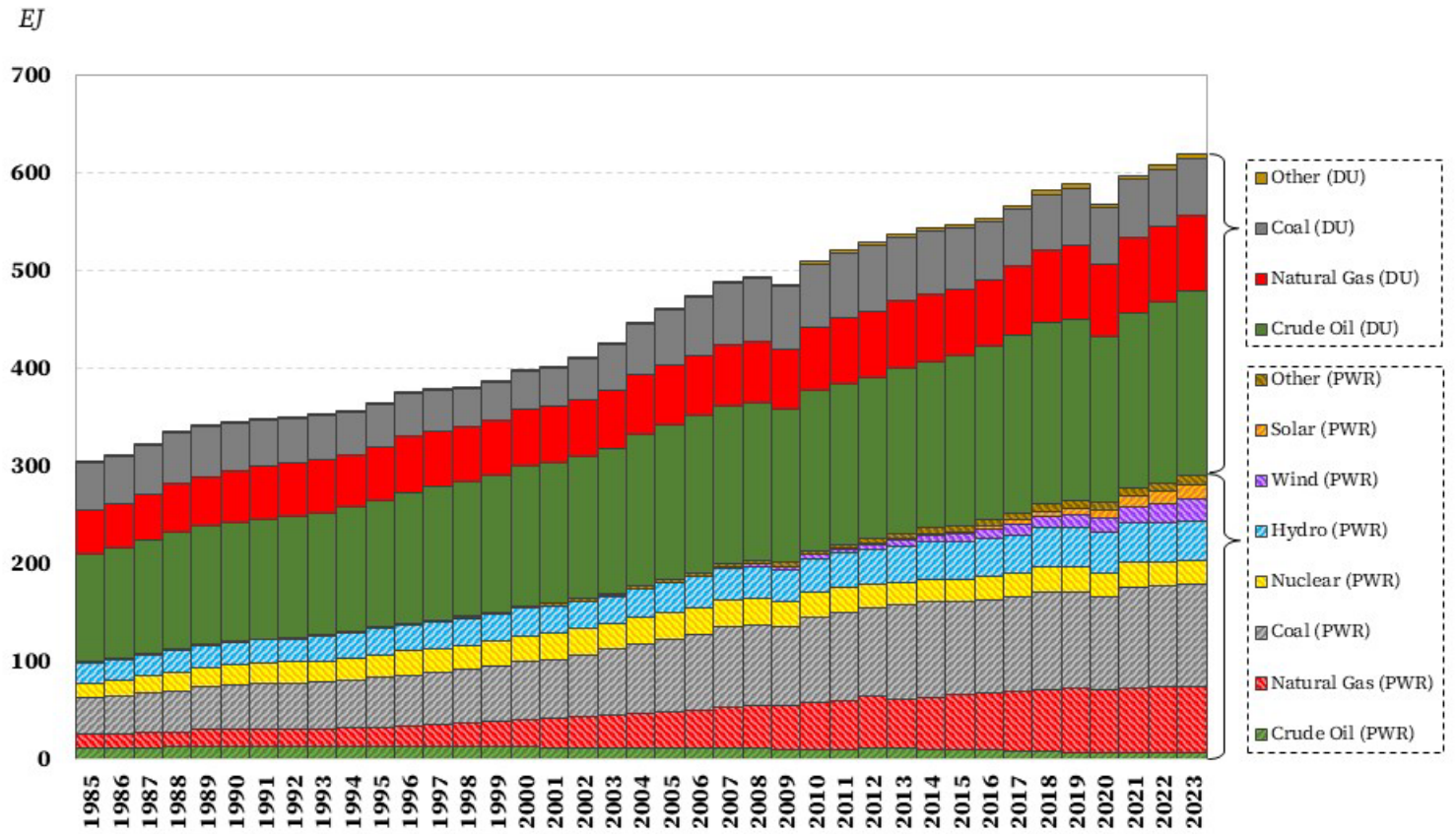
- Electricity is about 47% of total energy. Wind and solar are also a growth story over the last 20 years, but they are still a small proportion of the total energy mix, 3.5% and 2.5%, respectively, in 2023… the "101 of Scale".
- Zero-carbon generation sources account for 35% of electricity (nuclear 8.5%, hydro 13.7%, wind 7.5%, solar 5.3%).
- Hydrocarbons account for 62% of power generation, 98.5% of all non-electric energy, and 81.5% of all energy.



Data Source: EI Statistical Review of World Energy, 2024

But growth is not uniform, which opens opportunity

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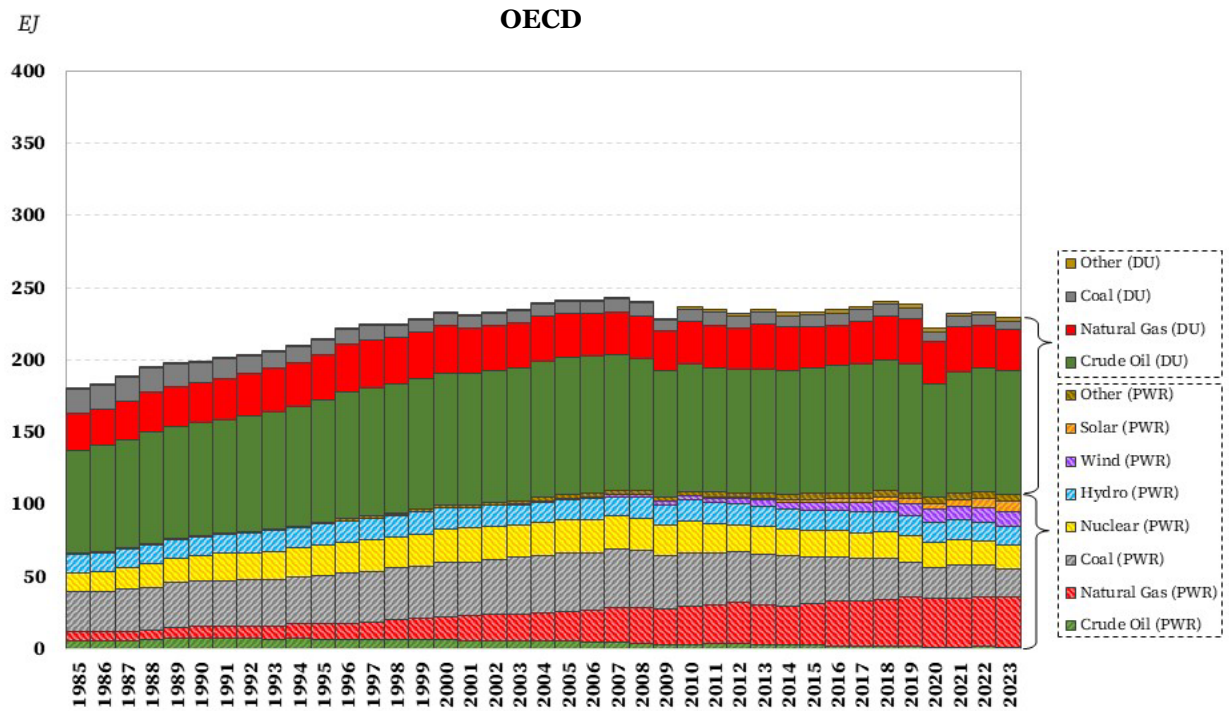
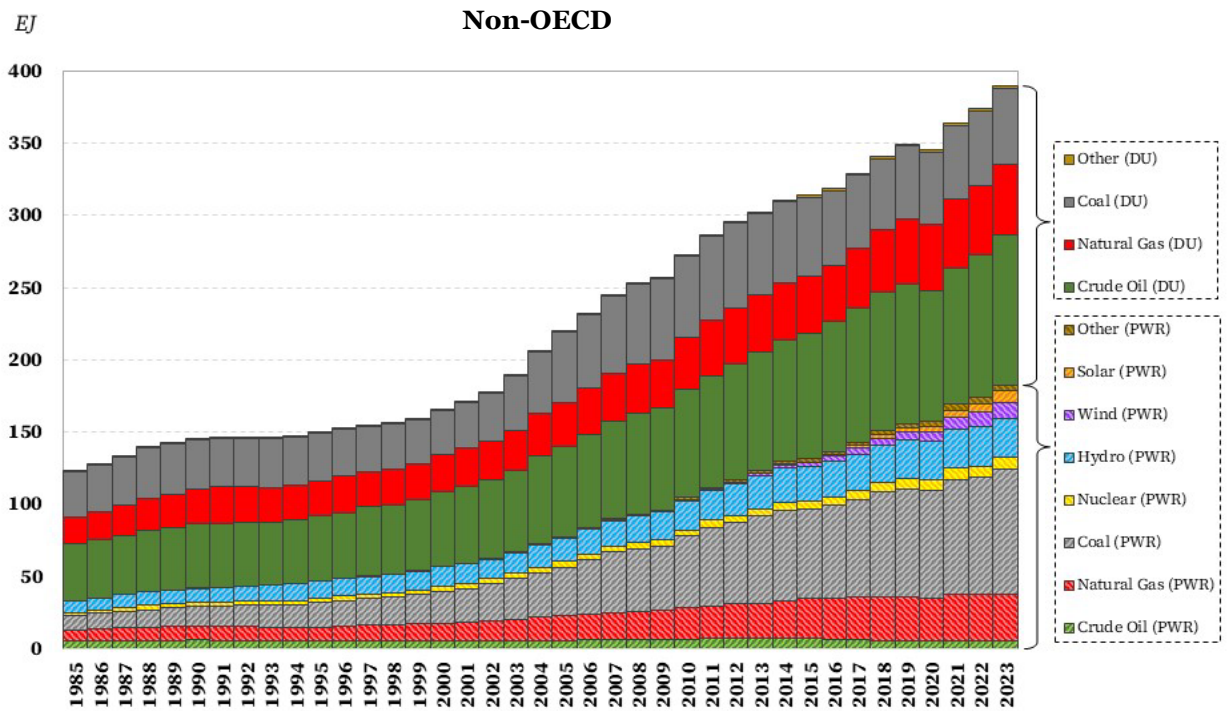
- Decarbonization requires multiple solutions, including *net* decarbonization of incumbent supply chains.
- Paths will look different everywhere and will hinge on "resource" endowments – nature, minerals, energy, human capital, etc. – opening the door for innovations along multiple chains in multiple locations.
- The future of energy will also be dictated by each region's position on the economic development ladder.
- The future is complicated by needs for infrastructure, economic growth, and incumbent energy uses.





Data Source: EI Statistical Review of World Energy, 2024

And, CO_2 emissions are also growing, adding complexity

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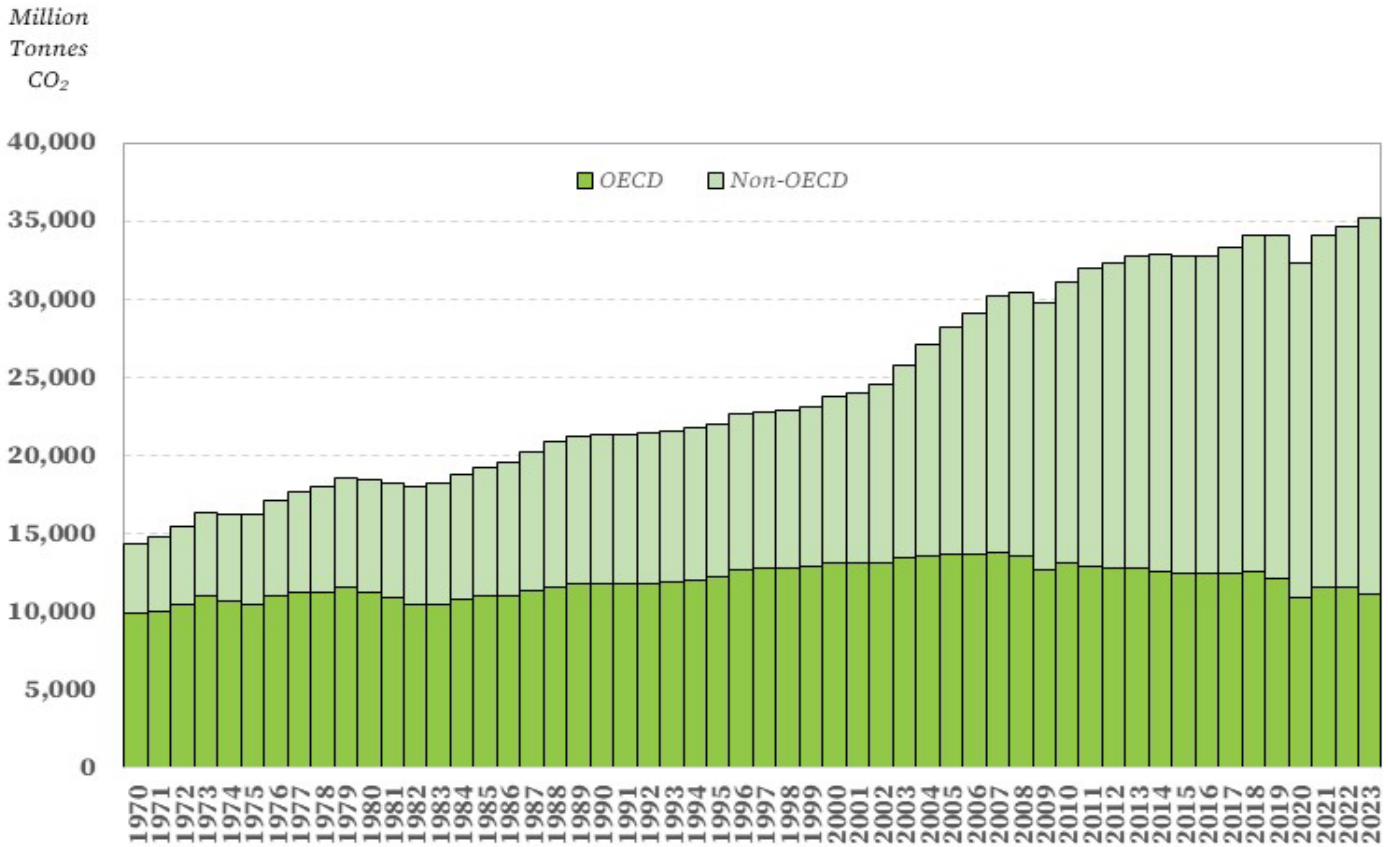
- Non-OECD emissions have grown substantially over the last 20 years. OECD emission have declined.
- Energy demand growth in developing countries will continue.
- A portfolio approach – carbon capture (nature-based and engineered solutions), renewables, new fuels, carbon-to-value, etc. – that recognizes regional differences could bring significant gains to decarbonization efforts.



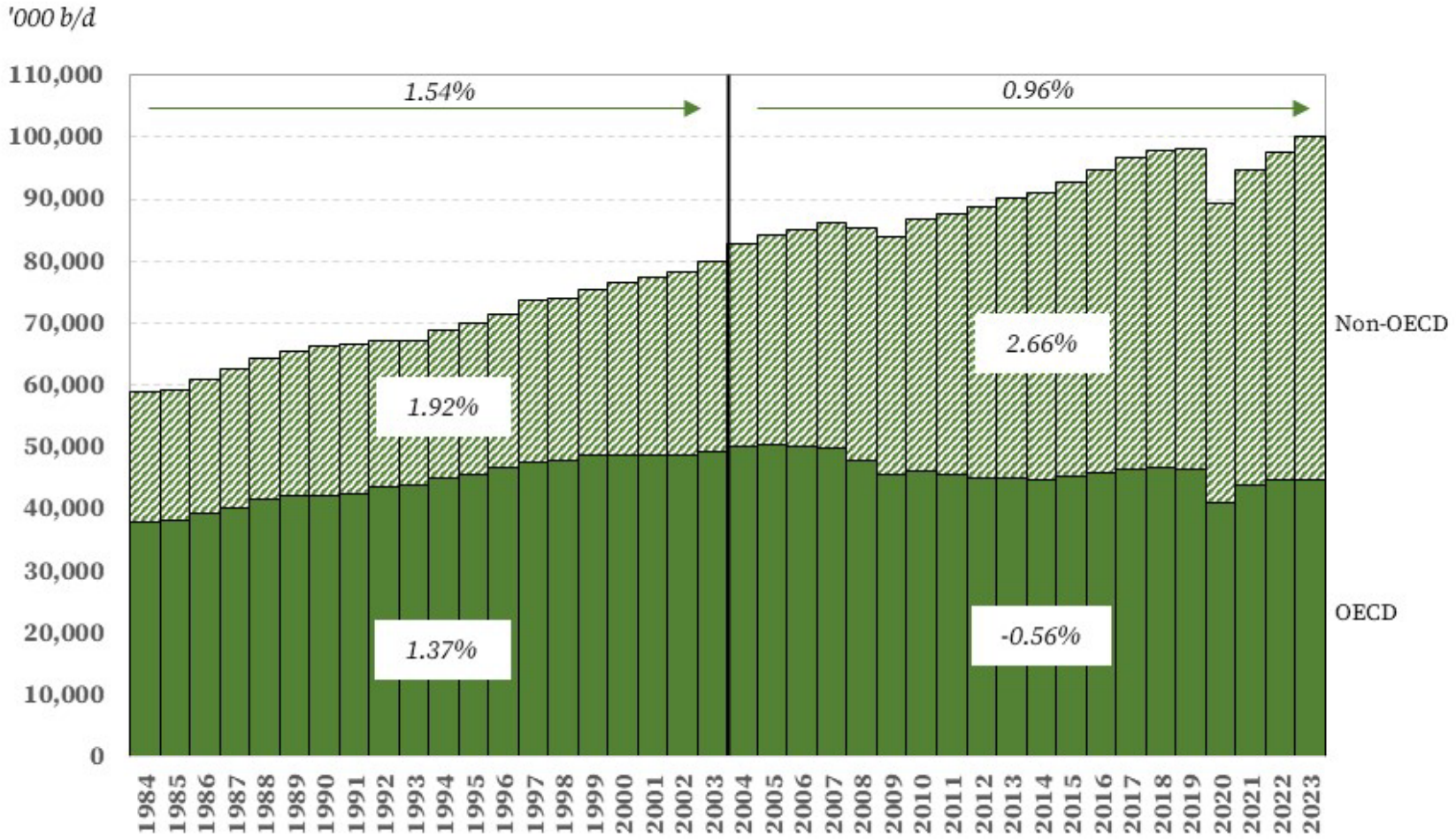
Data Source: EI Statistical Review of World Energy, 2024

Of course, geopolitics also have bearing, and they are deeply intertwined with regional economic drivers…

For example, consider the oil market

Oil demand is growing and is different regionally…

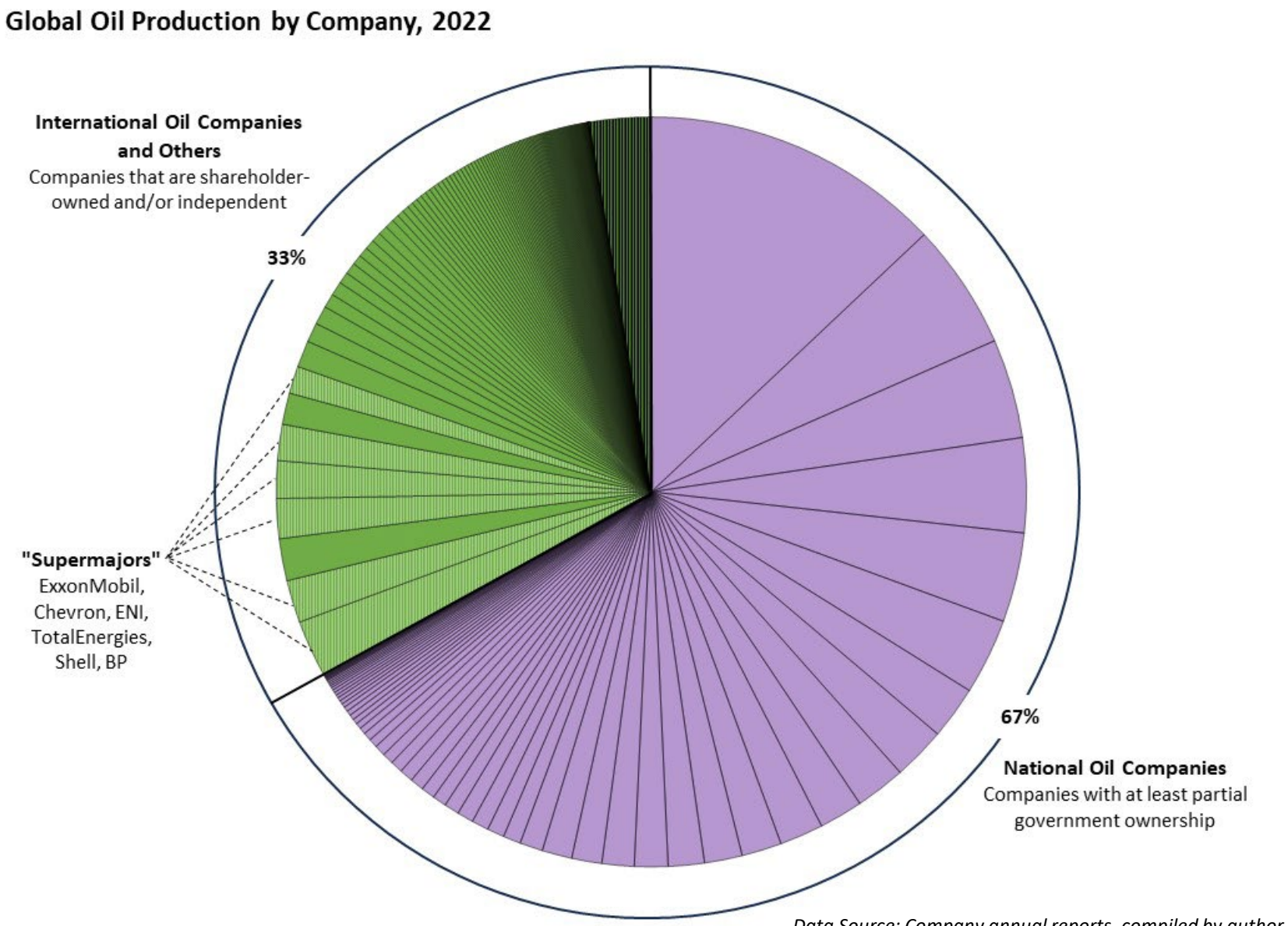
- Global oil demand growth is slowing, but that is not the whole story…
- OECD demand has declined over the past 20 years, which is a shift from the previous two decades.
- Non-OECD demand growth has accelerated.
- The future of global oil demand is a developing nation story, but that is a huge bucket. Not all developing nations are equal.
- Is a “peak” in demand imminent?



Data Source: EI Statistical Review of World Energy, 2024

… and production is highly diverse.

- The oil market is highly diverse, but NOCs deliver the majority of production.
- Competition in the "green" makes production resilient to targeted interventions.
- The importance of oil revenues for governments makes production resilient to external pressures.
- In 2022, "supermajors" accounted for less crude oil output than the world's largest NOC: Aramco.
- Why raise this? Because market structure matters and government stake matters. It has implications for price, capital allocation, geopolitics, energy security, and energy transitions.



Data Source: Company annual reports, compiled by author

Complexity abounds!

Valuable lessons for all regions…

Comparative advantage, policy, coordination, reliability, energy choice and new technology

Green energy… consider Texas

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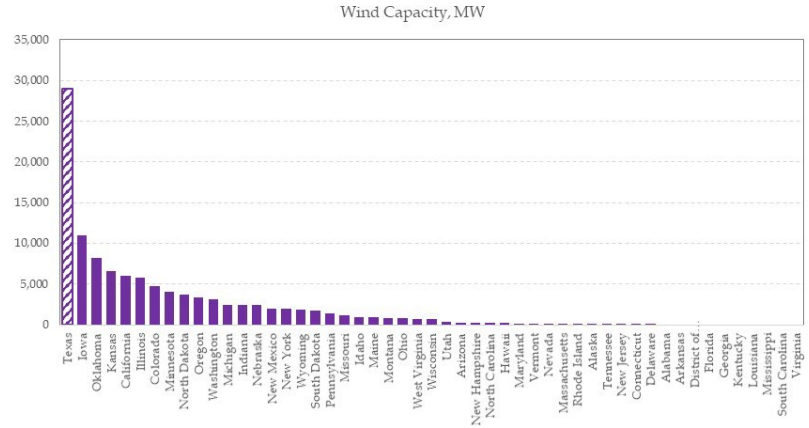
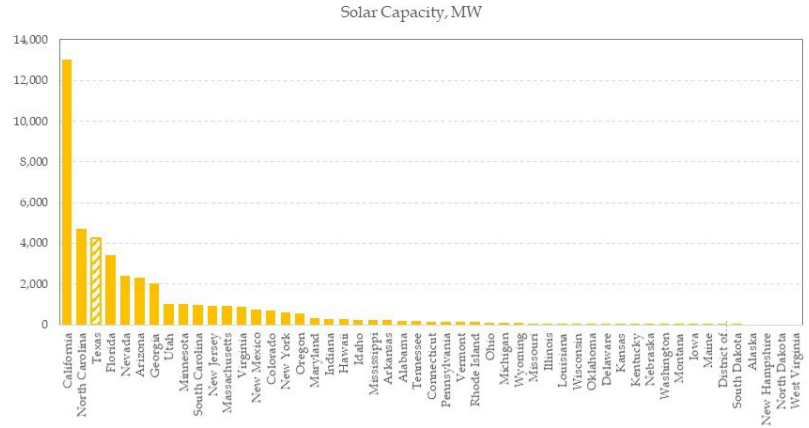
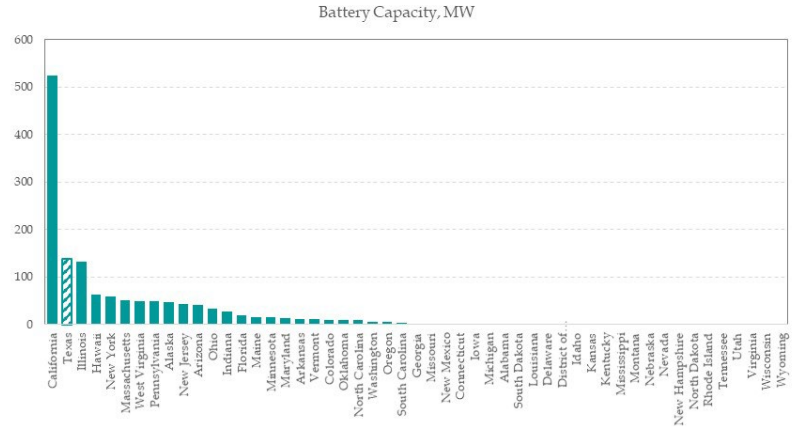
- Texas a leader in green power? Yes. Wind, sun, land, a business-friendly environment, and policy.

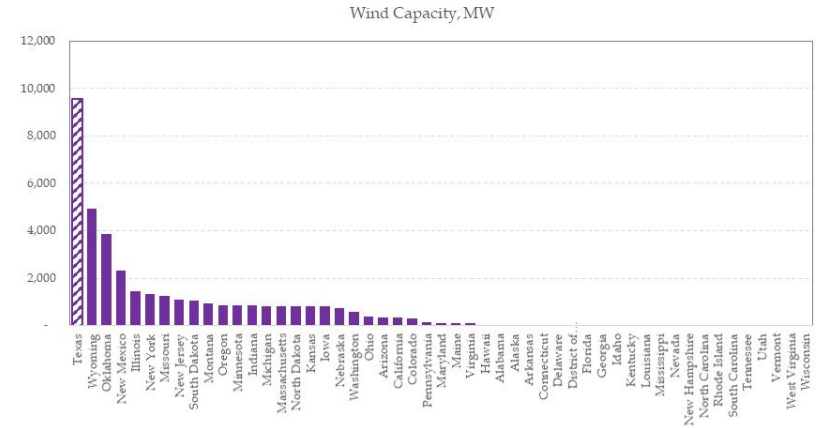
Operating Capacity

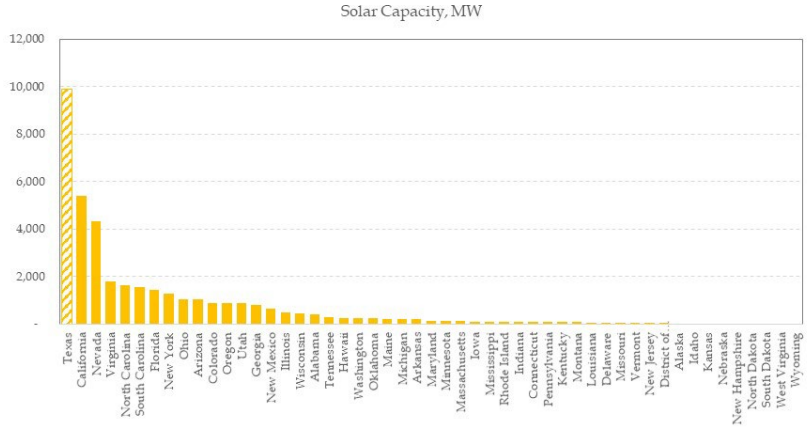


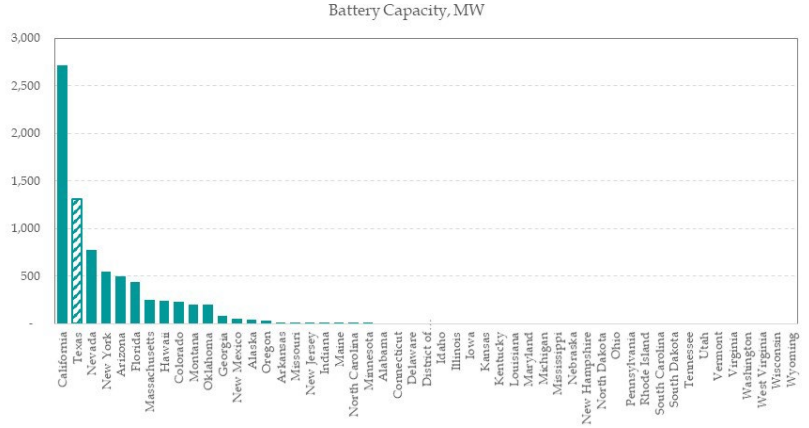




Planned Capacity

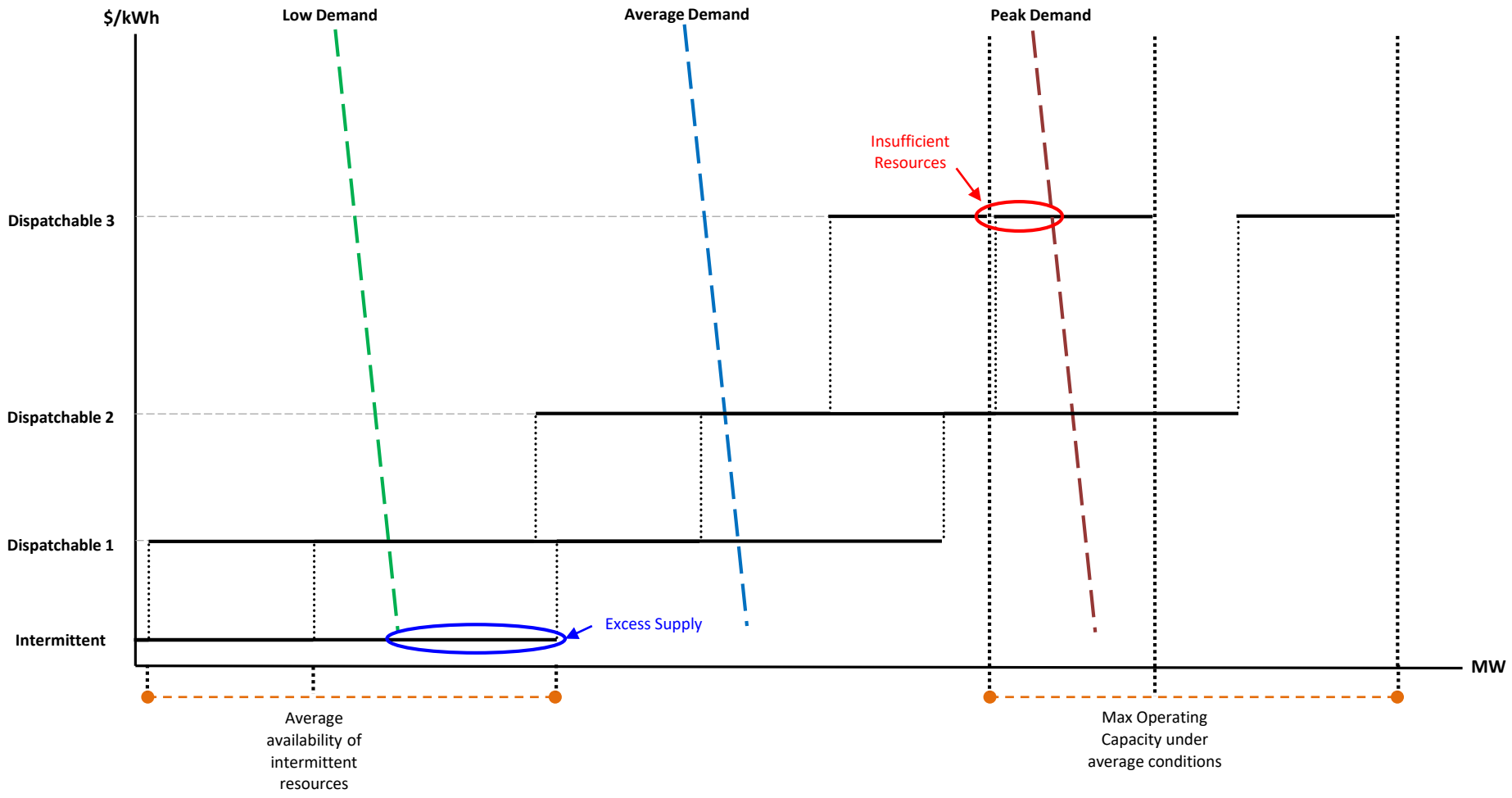






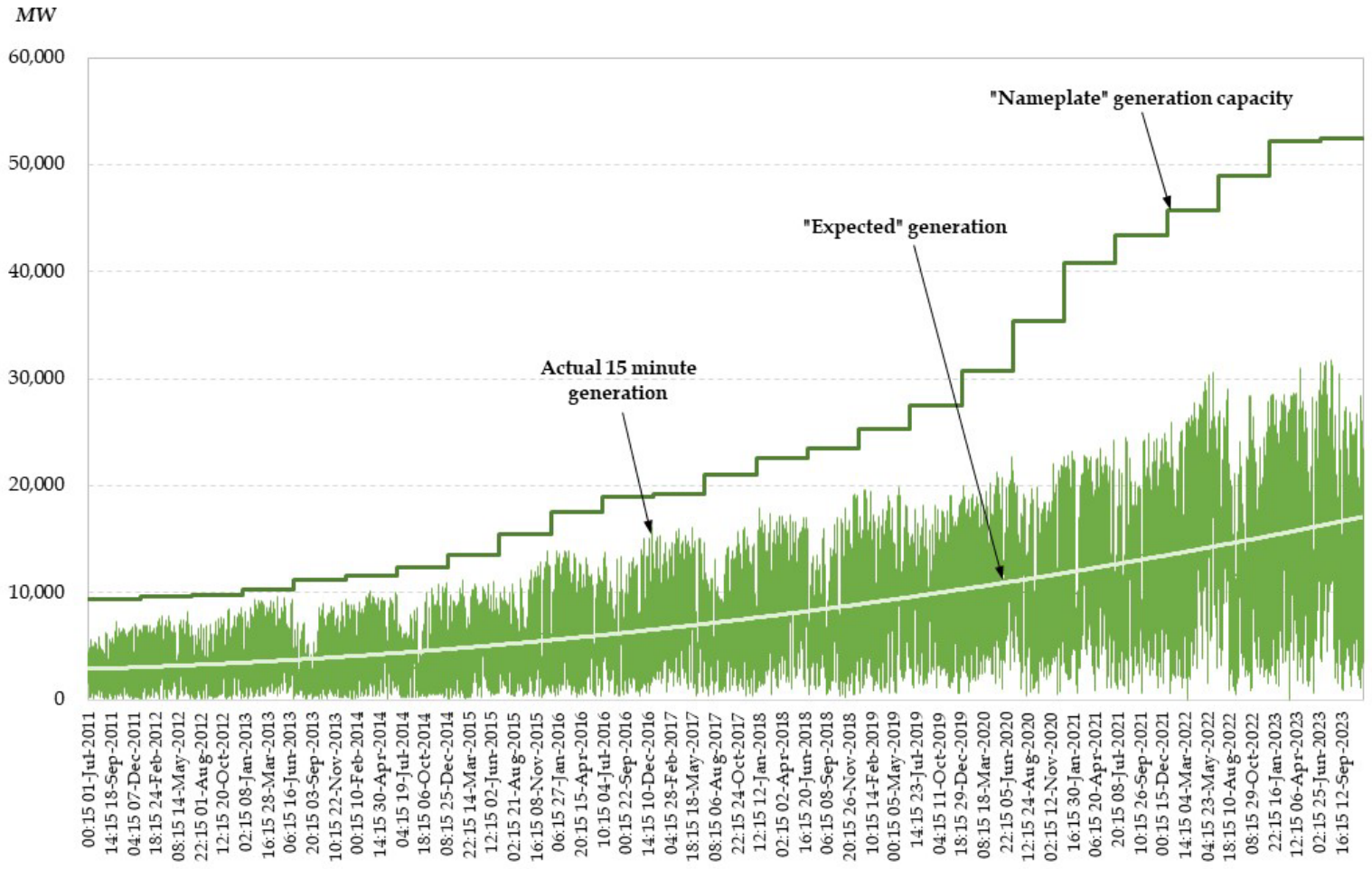
Data obtained from EIA Form 860M

But what do intermittent resources do on a grid?



We see this in ERCOT, which presents challenges

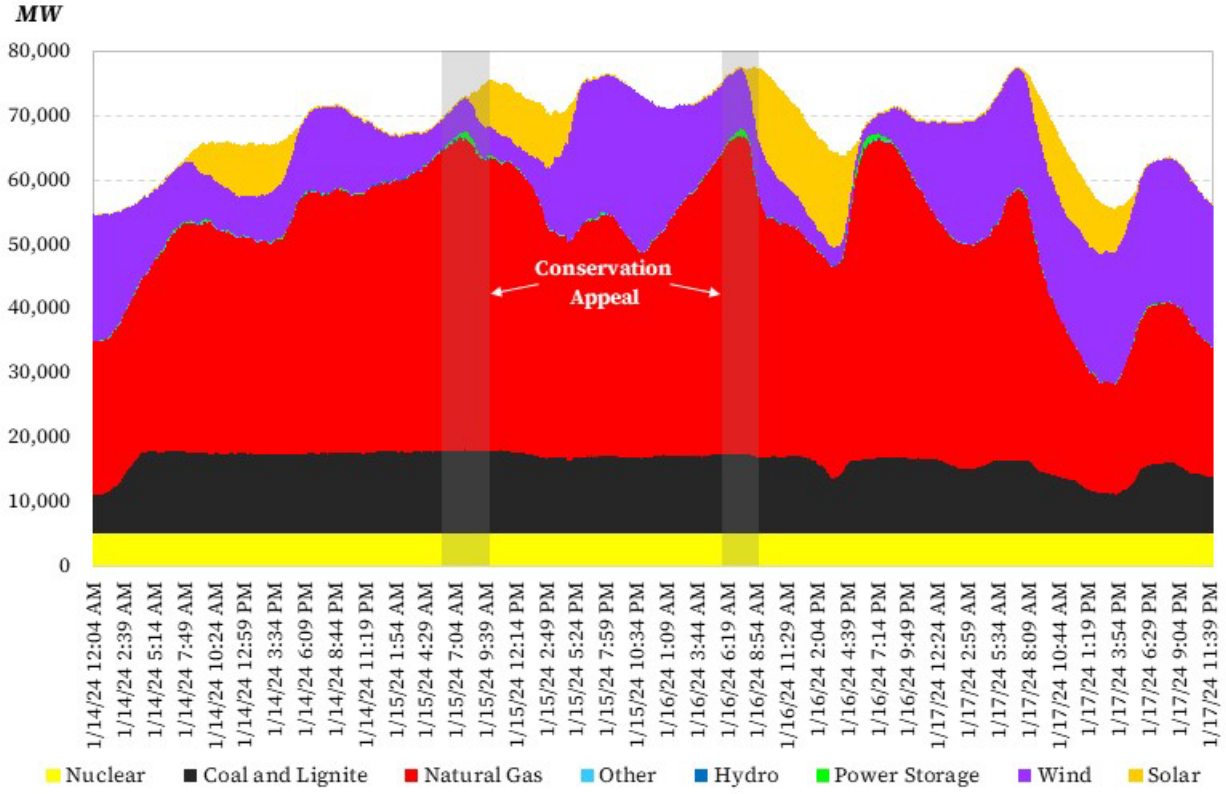
- As wind and solar generation *capacity* grows, the average generation grows, which reduces emissions, all else equal.
- But averages are irrelevant for **reliability**. Extremes matter.
- Given the observed variability, sufficient dispatchable backup capacity is required.
- In the end, this raises the capital intensity of each MWh delivered, which presents an economic hurdle associated with cost.
- **Reliability matters. Its value must be priced to ensure sufficient redundancy is available to the grid.**
  - This is nothing new! Grids have always needed sufficient "insurance" against unexpected outages.

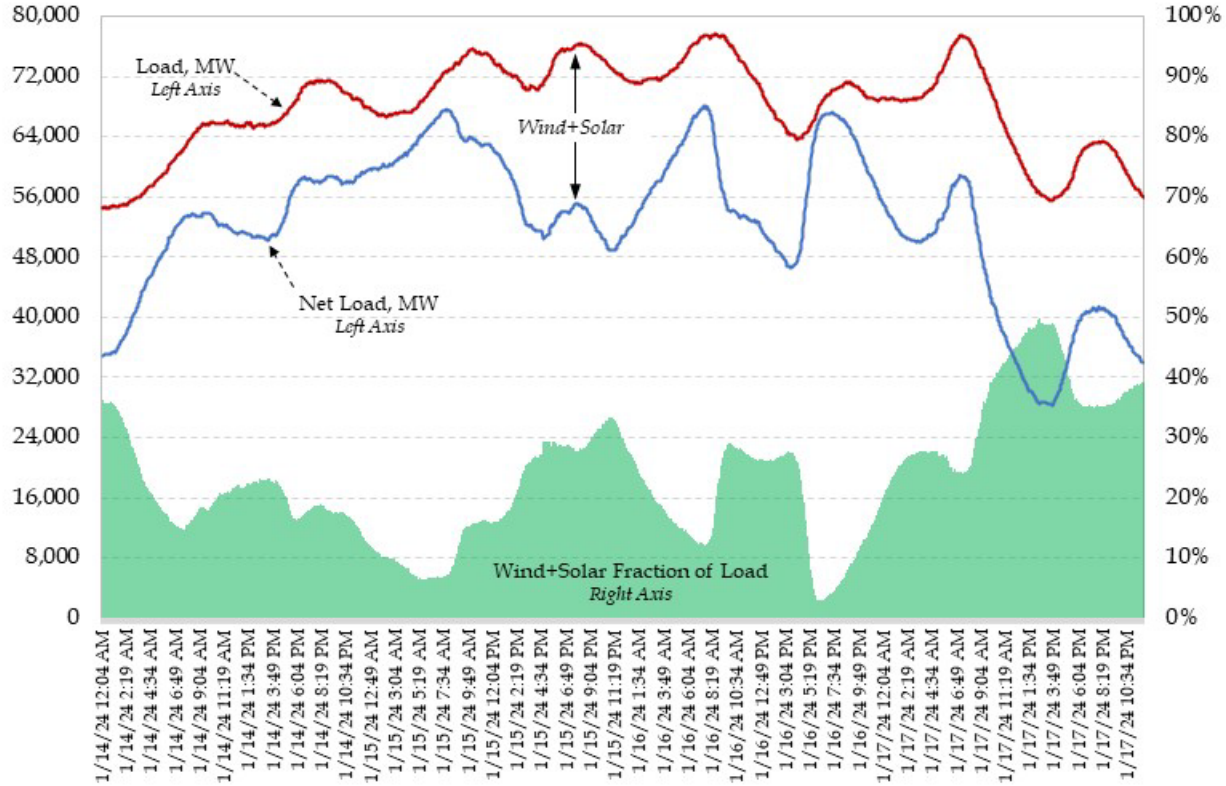


Source: Data compiled from ERCOT. "Expected" generation is the best fit over time to the actual 15-minute generation and is only for illustration. Resource planning utilizes seasonally rated capacity, which is different by season.

Lessons from the January 2024 freeze in ERCOT

- Stable grids can exercise multiple margins of response, i.e., resource optionality, transmission, demand response, etc.
- Renewable deployment has been able to leverage legacy infrastructure whose costs are already sunk.
- What does continued expansion of intermittent resources mean? System flexibility must grow!
- Reliability is a function of peak demands, redundancy in generation, and dispatchability.
- Going forward, *growth* in load along with *innovation* in dispatchability and load management will have significant bearing.





Data compiled from ERCOT dashboard in 5-minute increments (https://www.ercot.com/gridmktinfo/dashboards); author calculations

Some final thoughts to color everything…

Forecasting is an inexact science, and consensus is a dangerous place to be.

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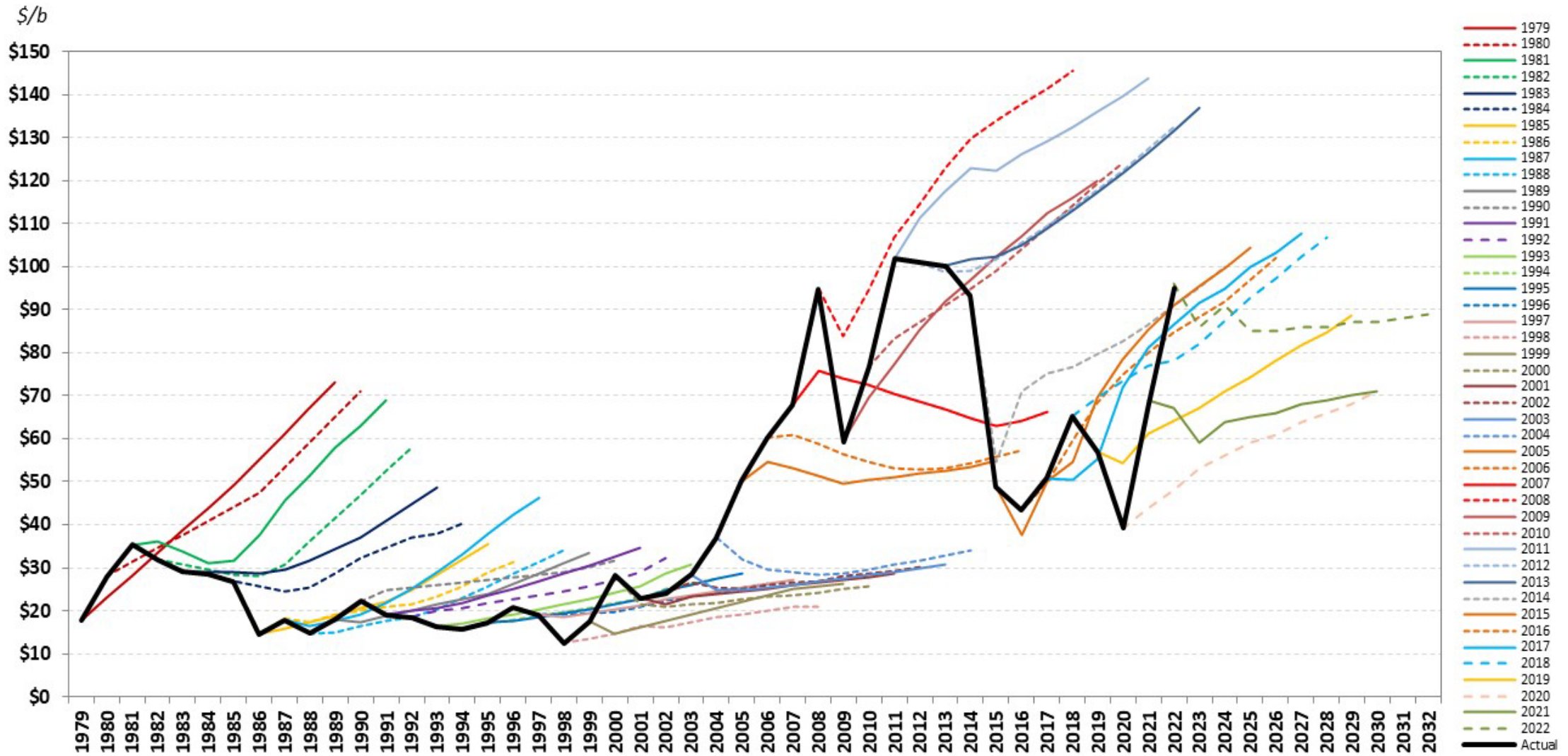

Data Source: EIA Annual Energy Outlook, www.eia.gov

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Despite our best efforts, we have no idea what will happen…

… but we do know there will be trade-offs…

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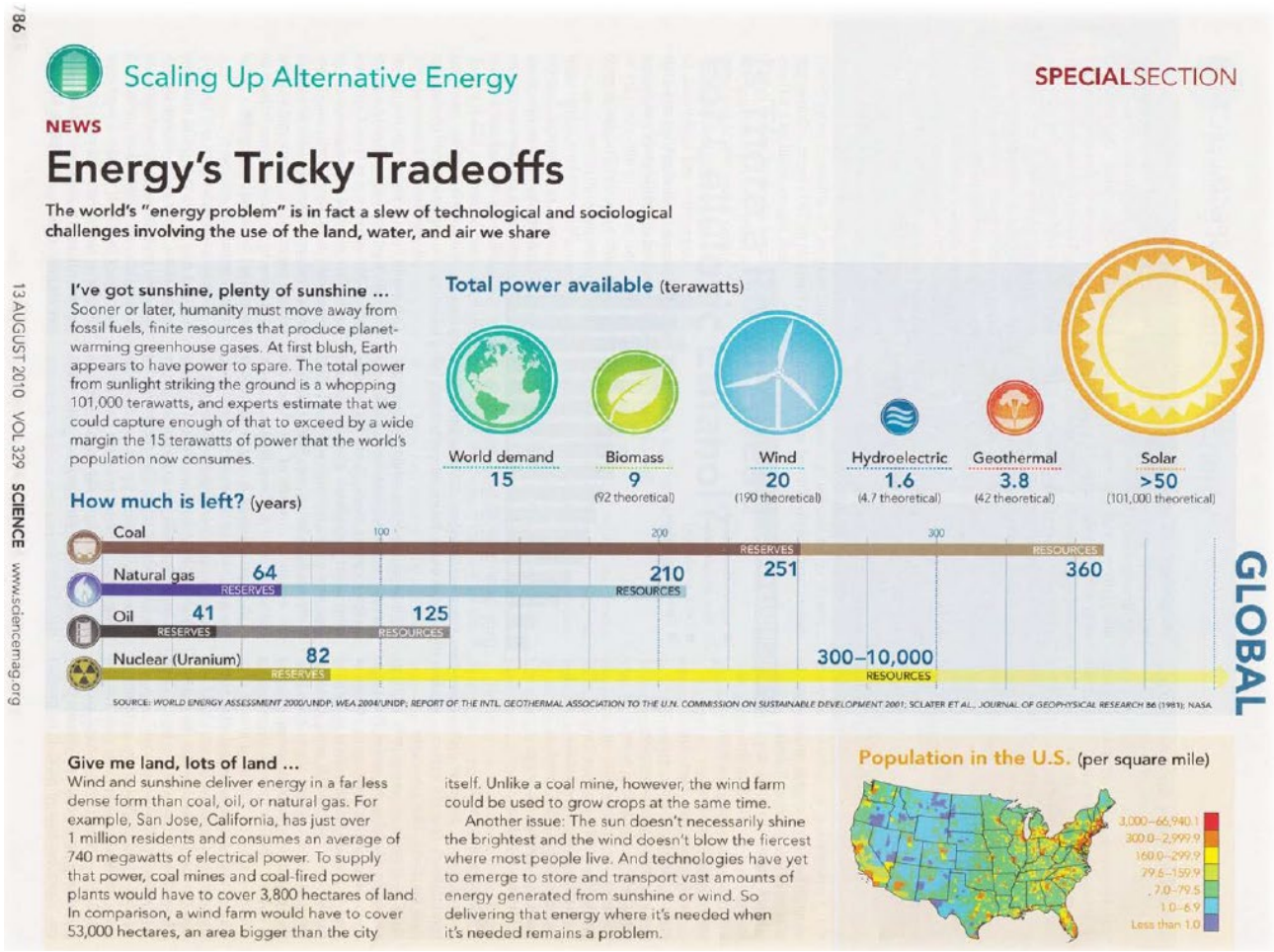

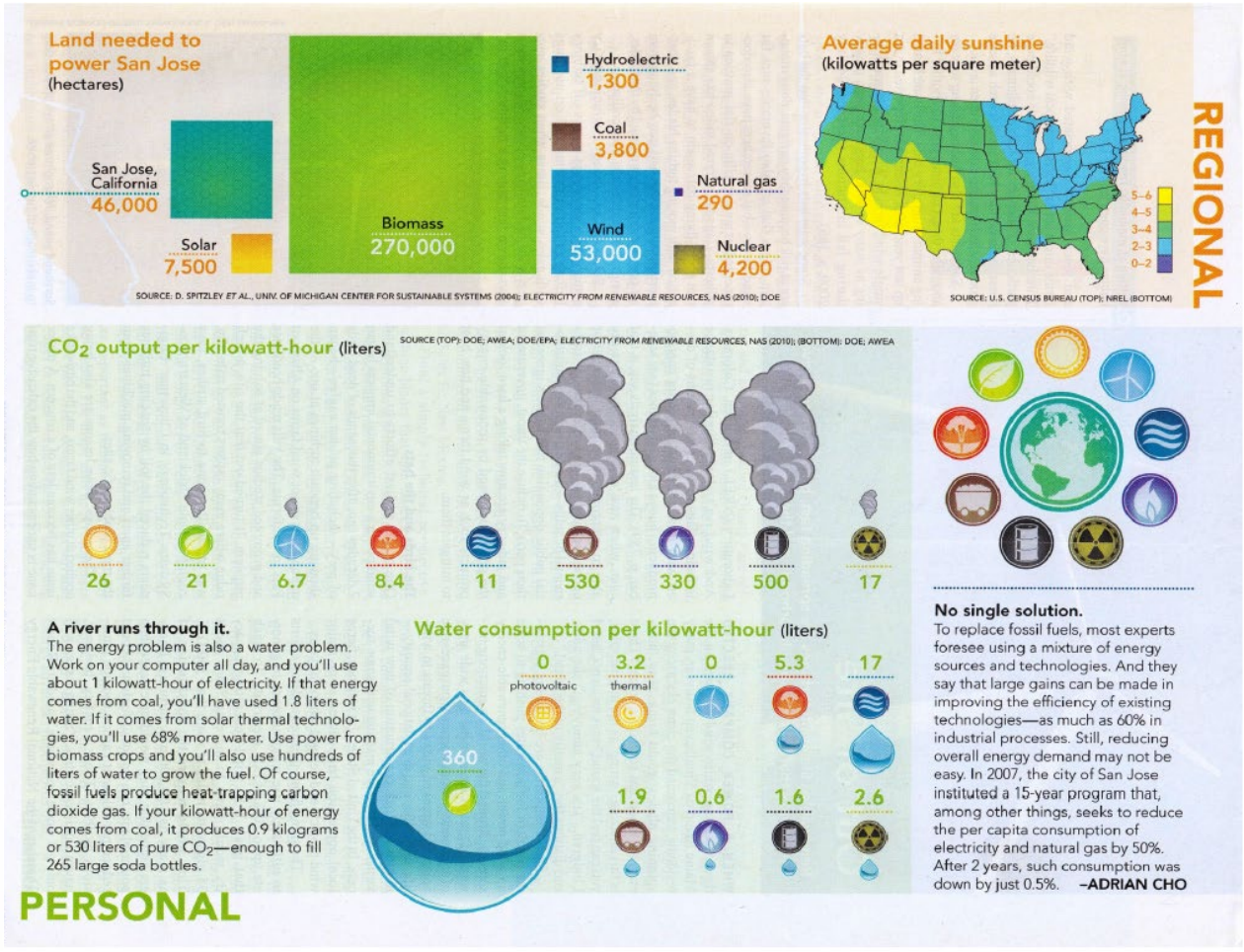

… bringing tremendous opportunities for innovation.

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