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The complexity of energy transitions

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What the "Earth at Night" tells us…

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The evolving energy landscape is a developing nation story

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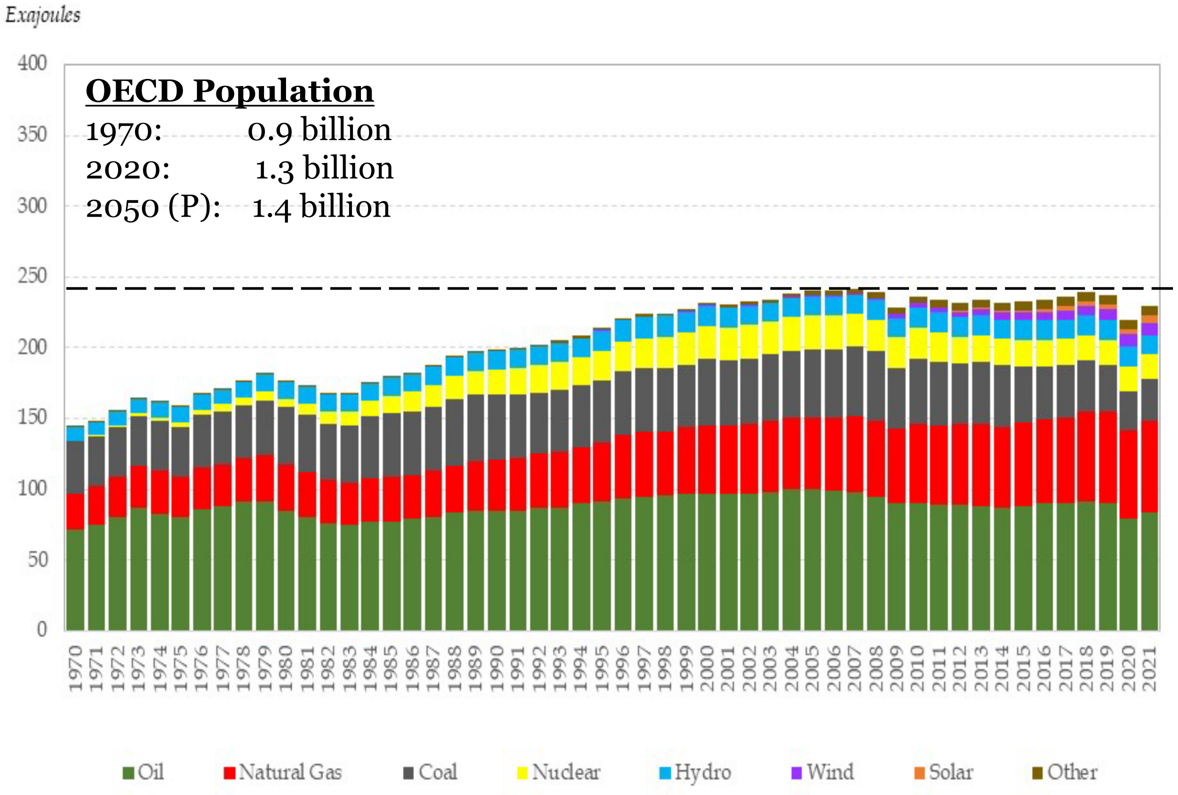
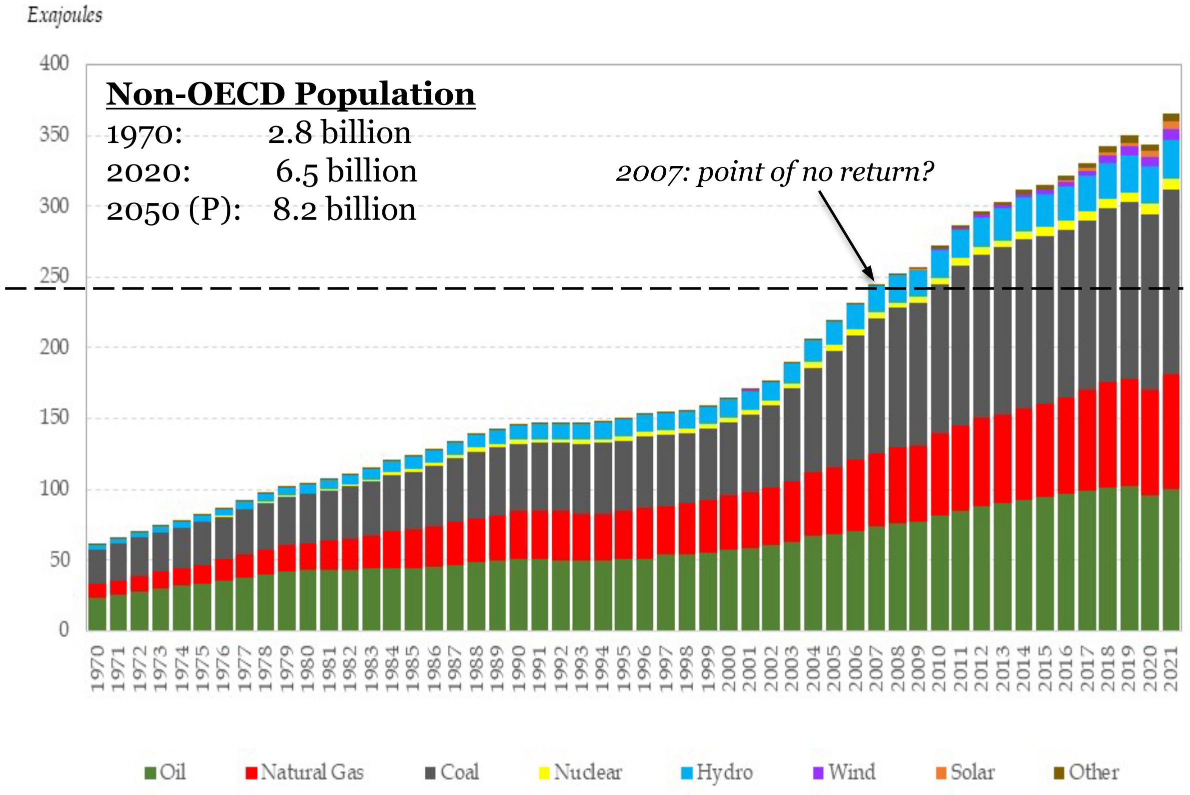
- Energy demand is rising fastest in the developing world, largely driven by hydrocarbon fuels.
  - EU is 11.8% of global demand; N. America is 20.0% of global demand; developing Asia is 36.9% of global demand.
- Projections for population and economic growth indicate this trend will likely continue.

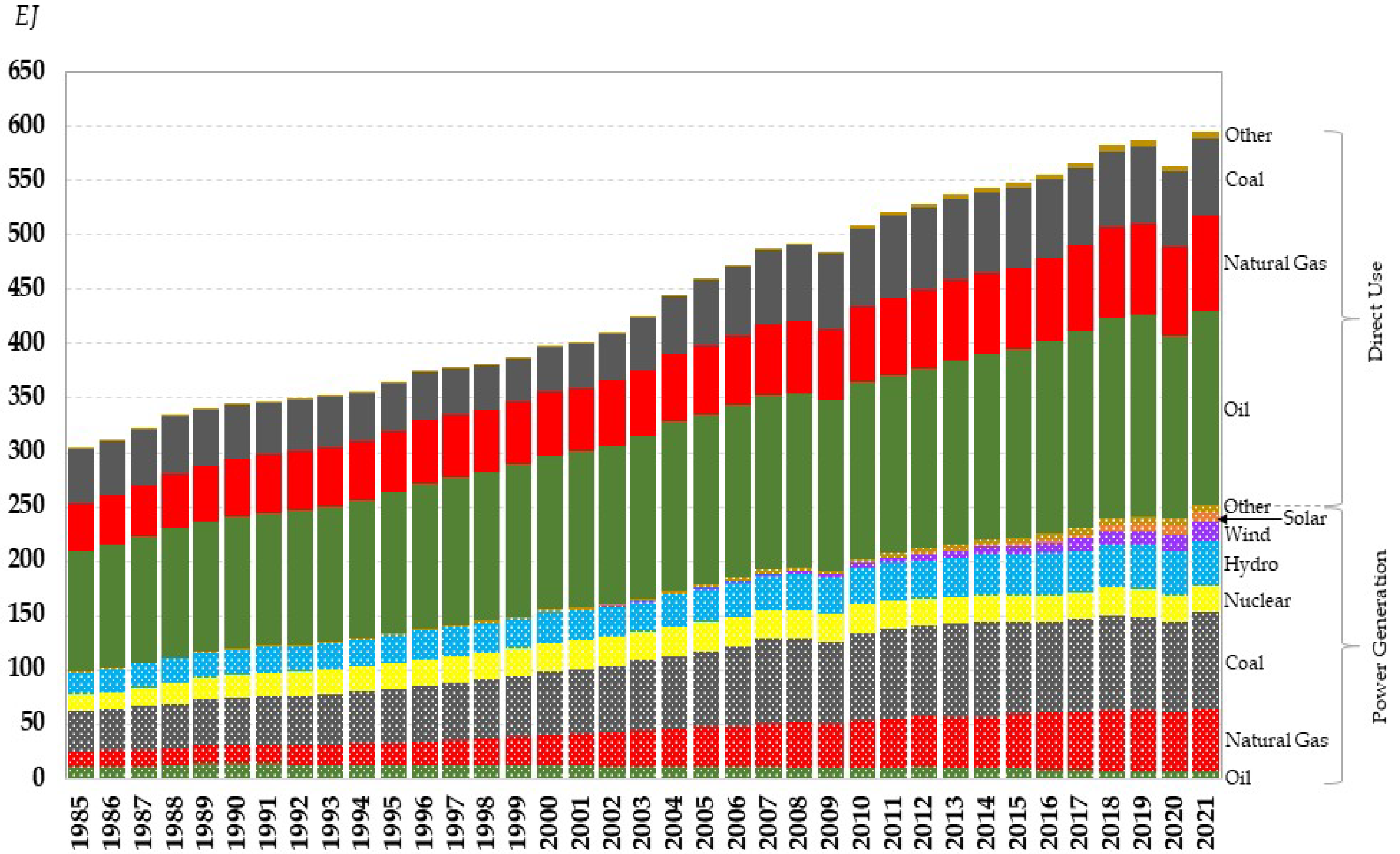




Data Sources: BP Statistical Review, 2022; OECD.stat

The global energy landscape, and the reality of "scale"

- Even with double-digit year-on-year percentage increases for wind and solar over the last 20 years, they are still a small proportion of the total energy mix, 2.5% and 1.4%, respectively, in 2020.
- Demand continues to grow.
- Electricity is about 43% of total energy. Zero-carbon generation sources: nuclear at 10%, hydro at 16%, and wind+solar at 13%... of electricity.
- Hydrocarbons account for 61% of power generation, 99% of all non-electric energy, and 82% of all energy.
- Decarbonization will require multiple solutions, and must include *net* decarbonization of incumbent supply chains. This is the reality of scale.
- The paths will look different everywhere, and will hinge on "resource" endowments – nature, minerals, energy, human capital, etc.



Data Source: BP Statistical Review of World Energy, 2022

Of course, regional CO_2 emissions add complexity

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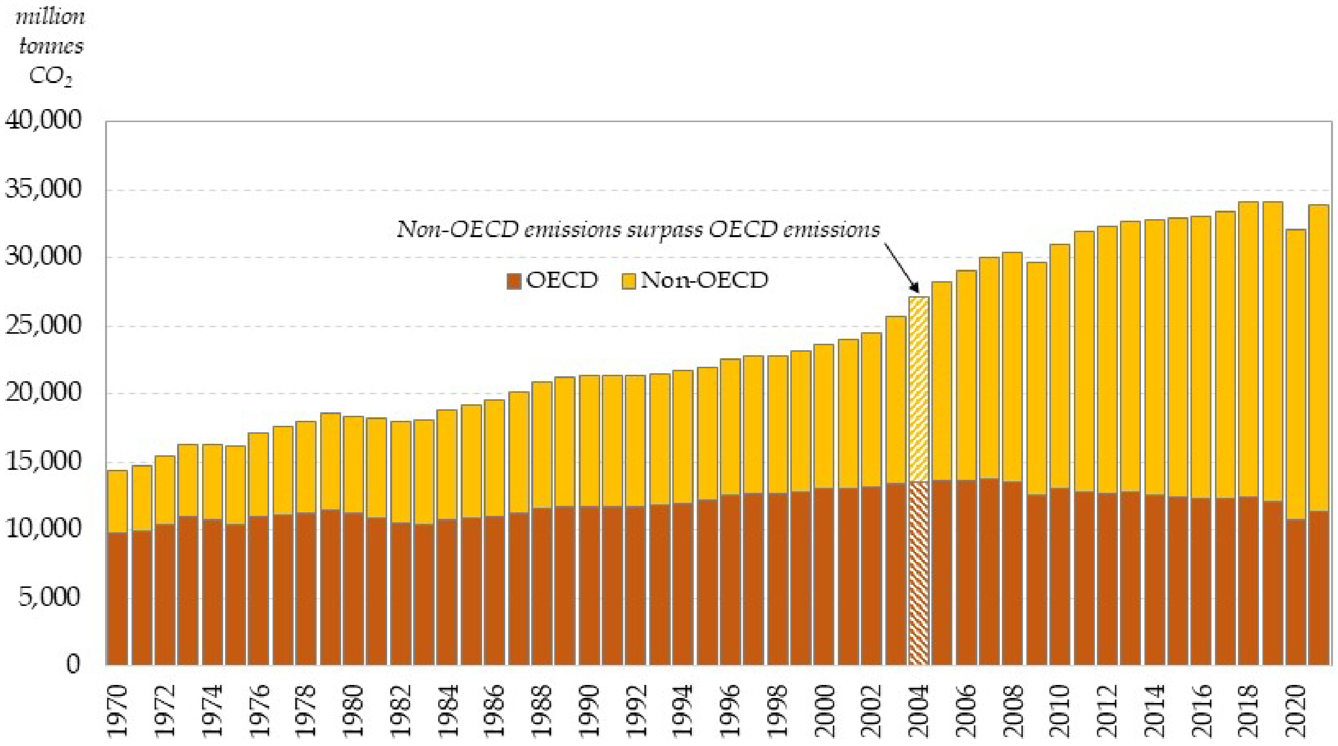
- Non-OECD emissions have grown substantially over the last 20 years. OECD emission have declined.
- Energy demand growth in developing countries will continue.
- As a matter of course, decarbonization requires a portfolio approach – carbon capture (nature-based and engineered solutions, renewables, new fuels, carbon-to-value, etc. – and there are opportunities throughout emerging value chains.



Data Source: BP Statistical Review of World Energy, 2022

What drives energy transitions?

- Energy ALWAYS transitions, and value chains matter!
- **Technology**, **scale** and **legacy** are each important factors.
  - Technology signals how fuels will compete. Capital is the vehicle for technology deployment!
  - Scale matters because energy systems are large and must accommodate growth and access.
  - Legacy of infrastructure and energy delivery systems is the footprint for change. Legacy is different everywhere and is defined by infrastructure.
- Economics matter. The ***principle of comparative advantage*** is key to understanding what will happen where. Cost-benefit must be favorable for sustainable diffusion of new technology.
  - Key Point: All costs along a value chain matter, not just the energy source – ***coordination theory***. Any new technology must avoid burdensome fixed costs (barrier to entry) if it is to be successfully adopted.
- Finally, policy and geopolitics shape, and are shaped, by all of the above.
  - What's old is new again! ***Energy security*** will remain a central consideration.
- **The two largest drivers of "transitions" in energy markets in the last 20 years:**

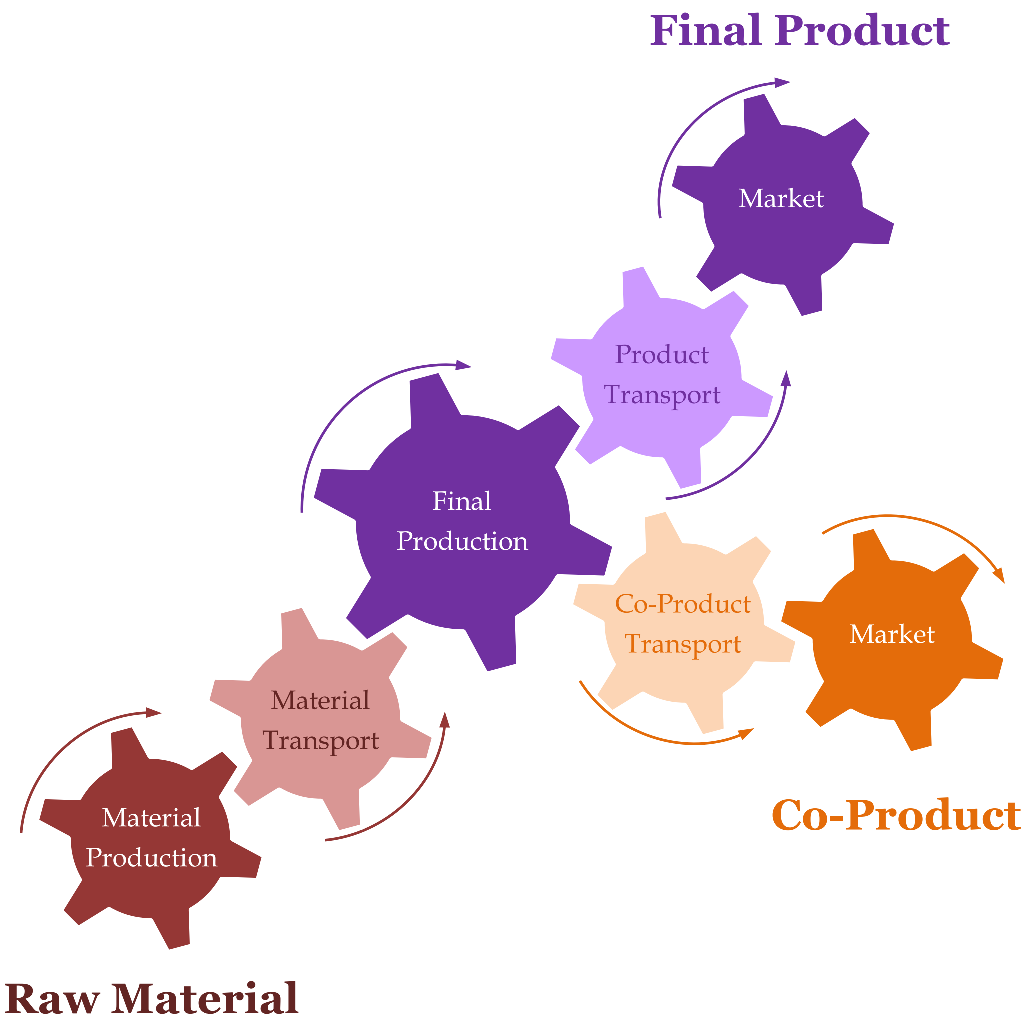
  (1) the shale revolution in the US and (2) demand growth in Asia.
  - **(1) is tech and (2) is economic growth. These two factors will shape the future as well.**

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

Coordination Theory

Coordination theory and the value chain

- Every production process involves a value chain associated with raw material inputs that are used in a production process to deliver a final product and potentially a co-product.
- Thus, coordination theory plays a central role.
  - The simplest example of coordination theory is the prisoner's dilemma.
- If any part of the value chain breaks down, coordination failure ensues. Hence, it is critical that actors along the value chain coordinate development.
- Raw materials must be produced and transported to a user. The user must have an ability to ship the final product plus any co-products to a viable marketable outlet. If any part of this complex set of interactions breaks down, the commercial viability of investments at any point is compromised.
- Note, these complexities can lead to the "valley of death" for new energy technologies.



Consider “green” energy in Texas…

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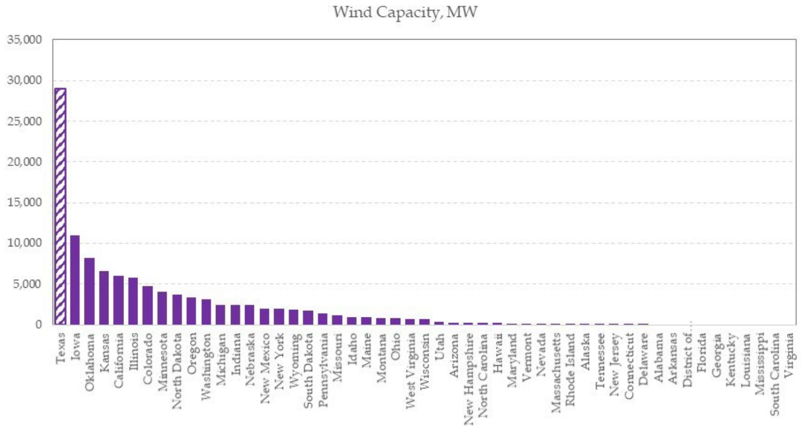
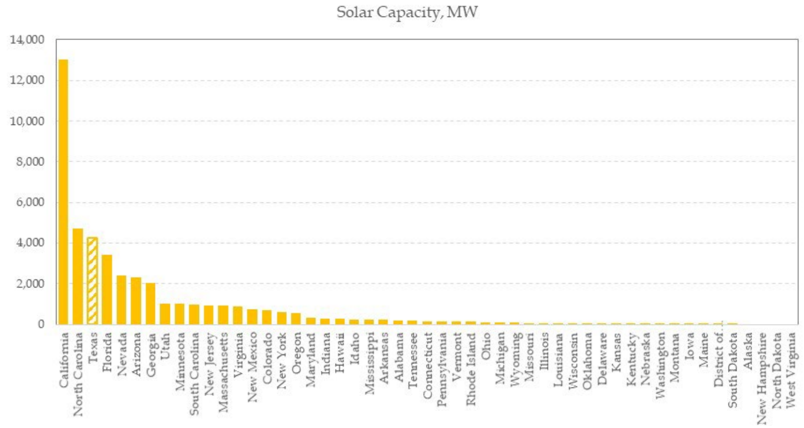
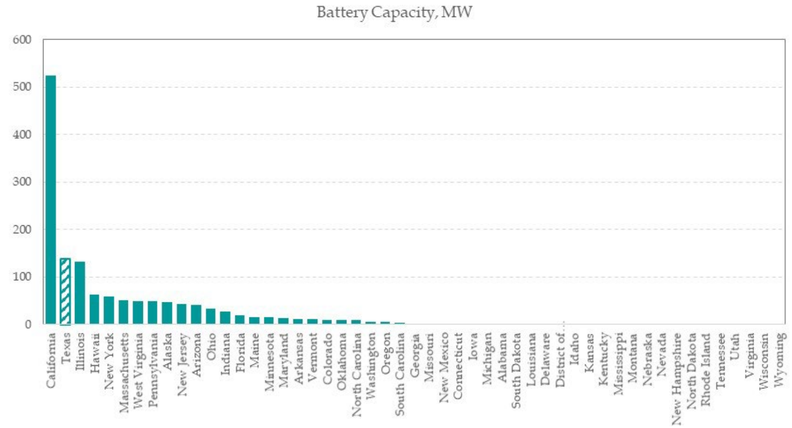
- Texas a leader in green power? Yes. Wind, sun, land and a business-friendly environment.

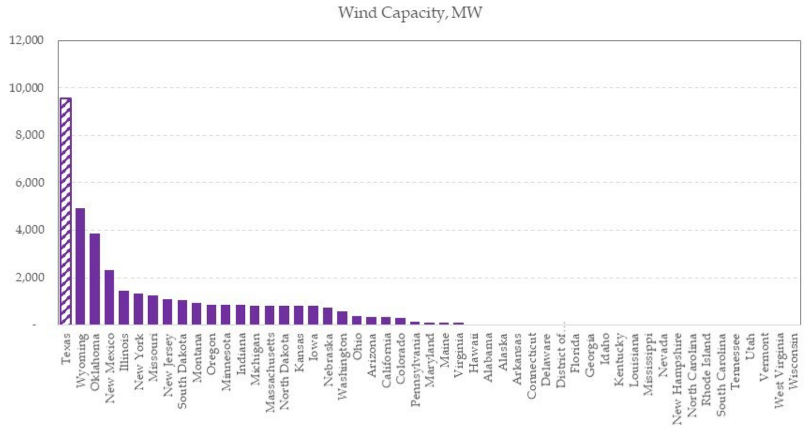
Operating Capacity

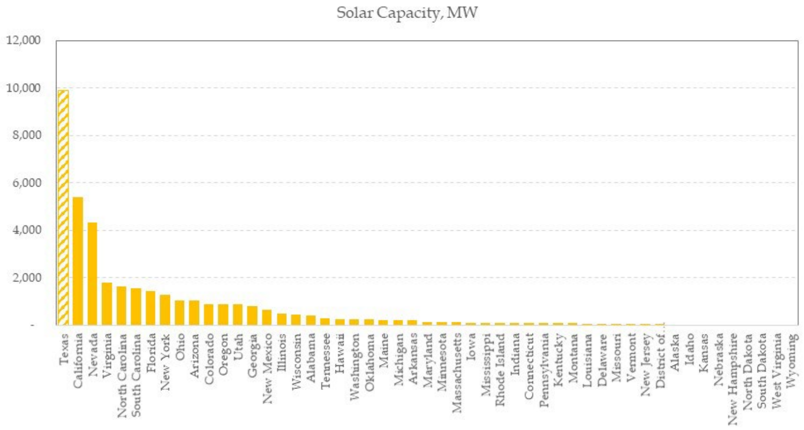


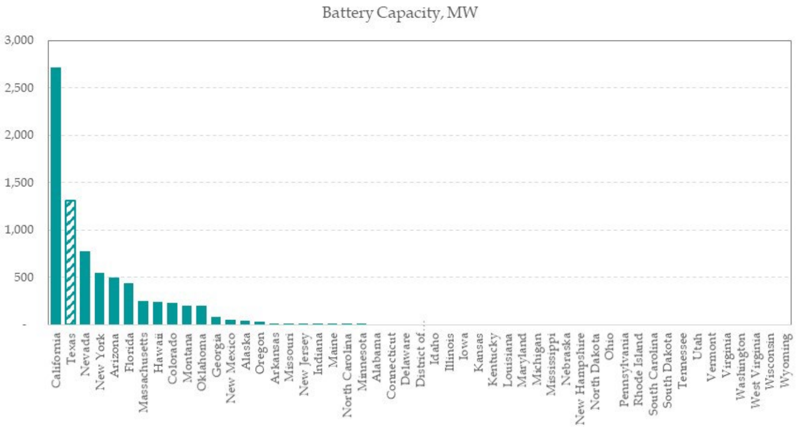




Planned Capacity



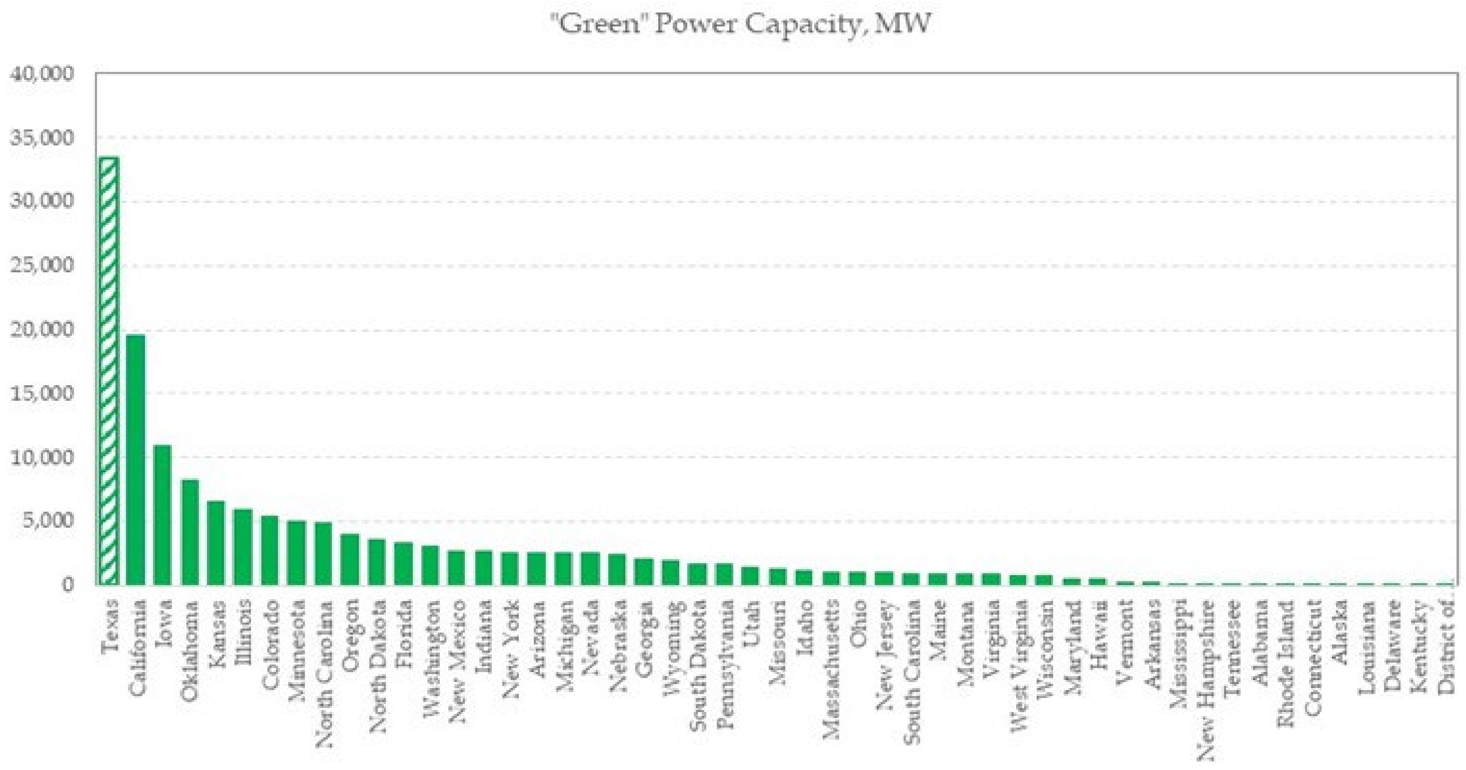




Data obtained from EIA Form 860M

… as an example of coordination theory at work…

- Texas power generation market. #1 in wind capacity (26% of US), #2 in battery capacity (10% of US), and #3 in solar capacity (10% of US). Total MWs of installed "green" capacity → #1 in the US.
  - Senate Bill 7 (1999), tax incentives at the Federal, State and local levels, all matter.
  - But growth was impeded until investment in the Competitive Renewable Energy Zones (CREZ) happened.
- Coordination theory at work. The CREZ was a $7 billion investment approved by the Texas PUC and completed in 2013. Costs are rolled into wholesale rates.
- The CREZ provided transmission, which allowed access to a liquid market. This de-risked investment in renewable capacity and supported significant expansion.
- Other energy options, such as hydrogen and carbon capture, will follow suit. Market liquidity is an enabler.



… but intermittency is a challenge (consider ERCOT).

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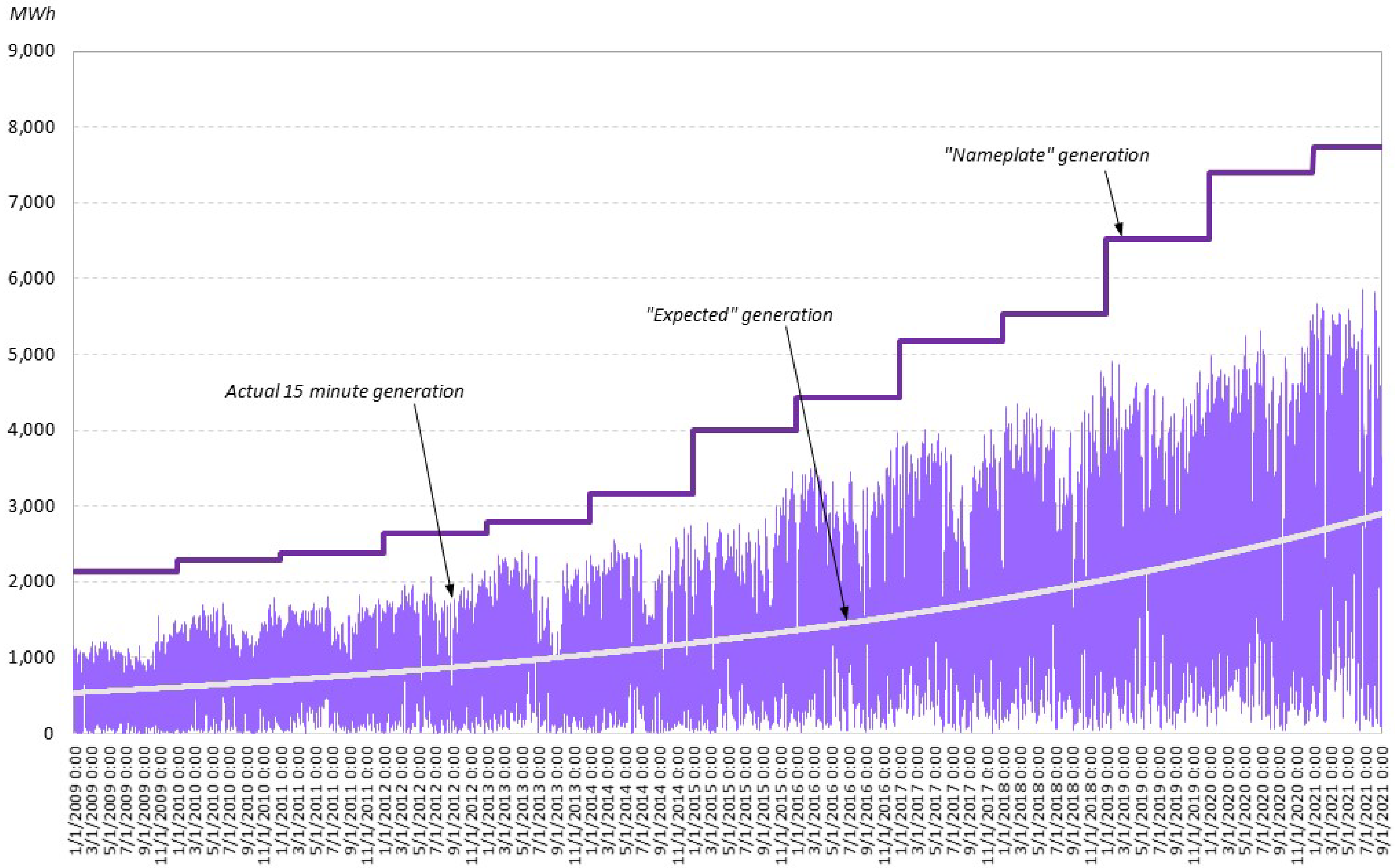
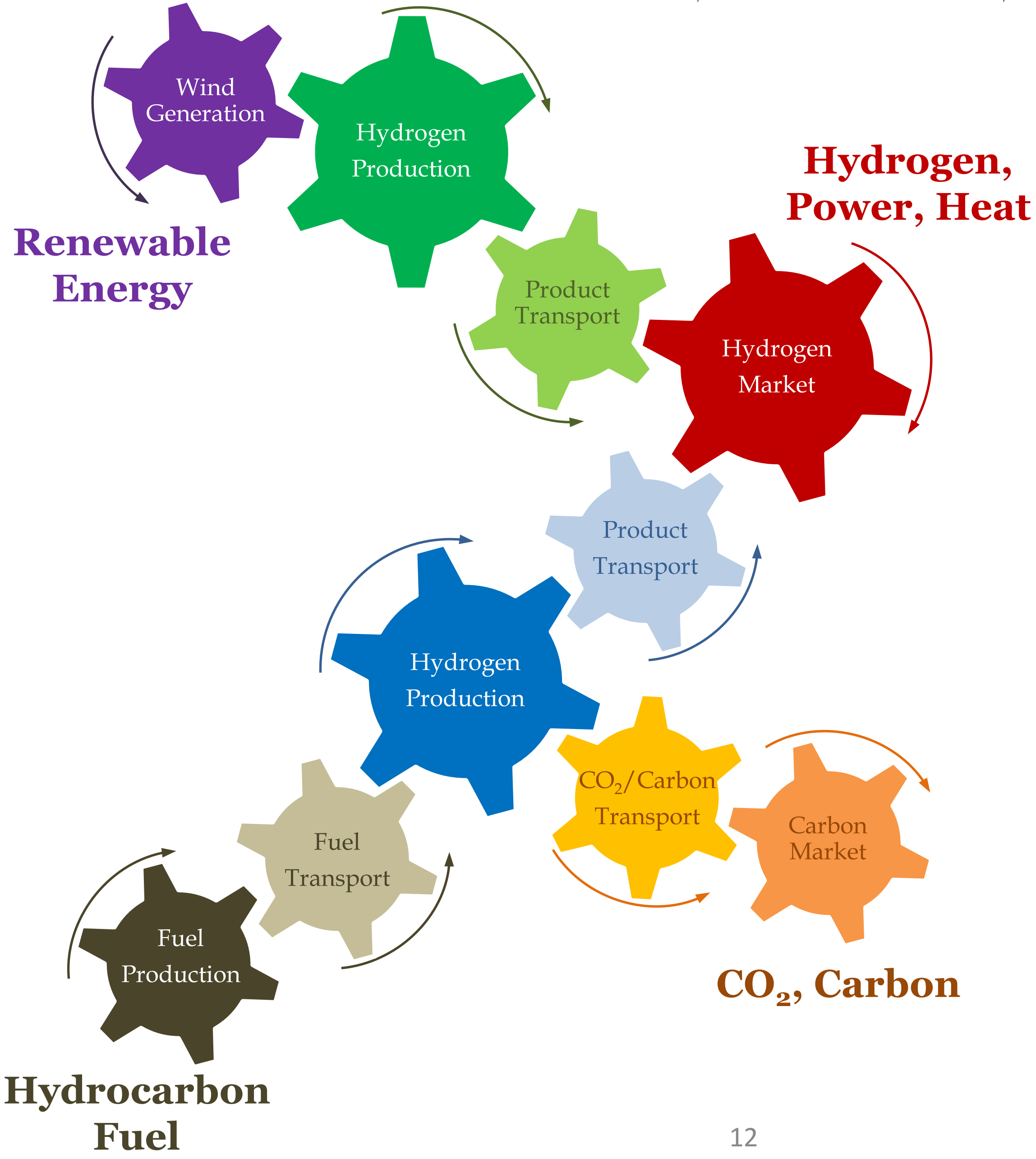
- As wind generation *capacity* grows, the average generation grows, which reduces emissions, all else equal.
- BUT averages are irrelevant for **reliability**. Extremes matter.
- Given the observed variability, sufficient dispatchable backup generation capacity is required… <u>coordination for reliability</u>!
- In the end, this raises the capital intensity of each MWh delivered, which raises 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!



Source: Data compiled from ERCOT. "Expected" generation is the best fit over time to the actual 15-minute generation and is only for illustration. "Nameplate" generation converts the annual average wind capacity, in MWs, to MWhs assuming it is 100% utilized every 15 minutes. Resource planning utilizes seasonally rated capacity, which is different by season.

Coordination, hydrogen and hubs

- With limited market participation, deals to support investments along the value chain must be bilateral, requiring identification of a counterparty with a specific requirement. So, investments are conditional on counterparty identification.
- **Transparency** and **liquidity** are needed!
- Investing in infrastructure is a "real option" that one only exercises the option when profitable. In the absence of market depth, a liquidity premium exists that renders option value lower, thus reducing investment. Market depth (or liquidity) increases scale because it lowers transaction cost.
- As pointed out in a recent Baker Institute study (https://www.bakerinstitute.org/research/developing-robust-hydrogen-market-Texas), the concept of hubs is in most national and regional strategies for hydrogen. However, almost none address market design.



Let "the future of energy" begin…

Good luck!

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