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The complexity of navigating energy transitions

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We begin with legacy, scale, technology, and the principle of comparative advantage

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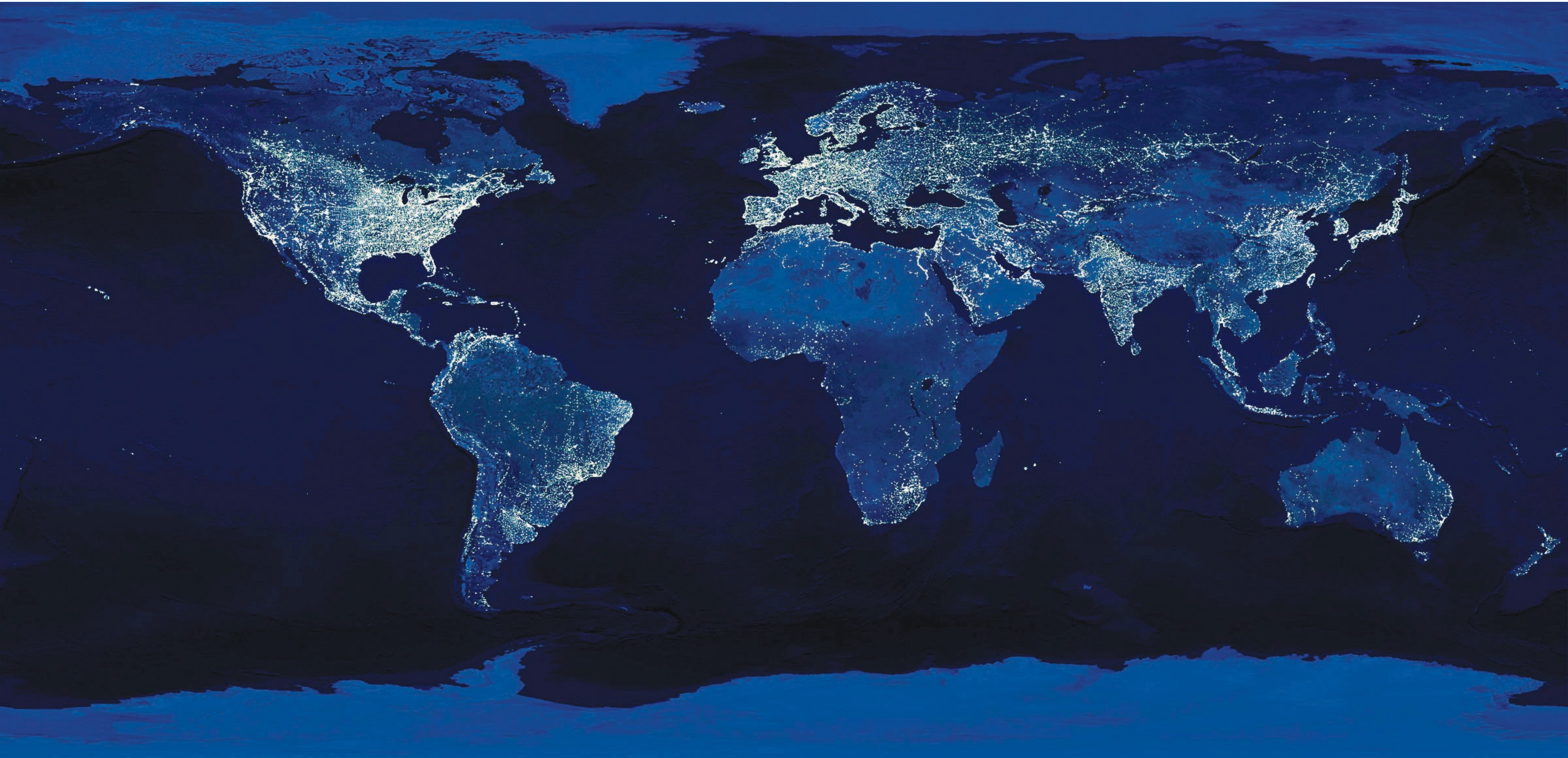

The evolving energy landscape is a developing nation story

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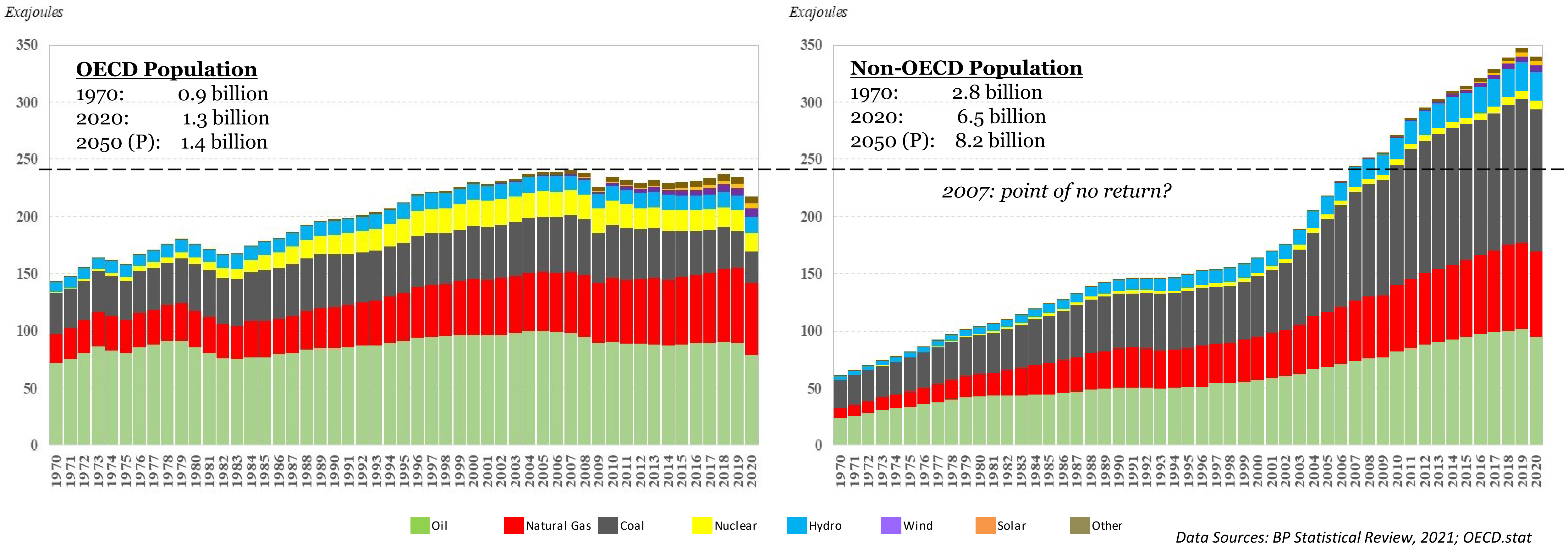
- Energy demand is rising fastest in the developing world, largely driven by hydrocarbon fuels.
  - EU is 11.8% of global demand; N. America is 20.0% of global demand; developing Asia is 36.9% of global demand.
- Projections for population and economic growth indicate this trend will likely continue.



Data Sources: BP Statistical Review, 2021; OECD.stat

The global energy landscape, the reality of "scale"

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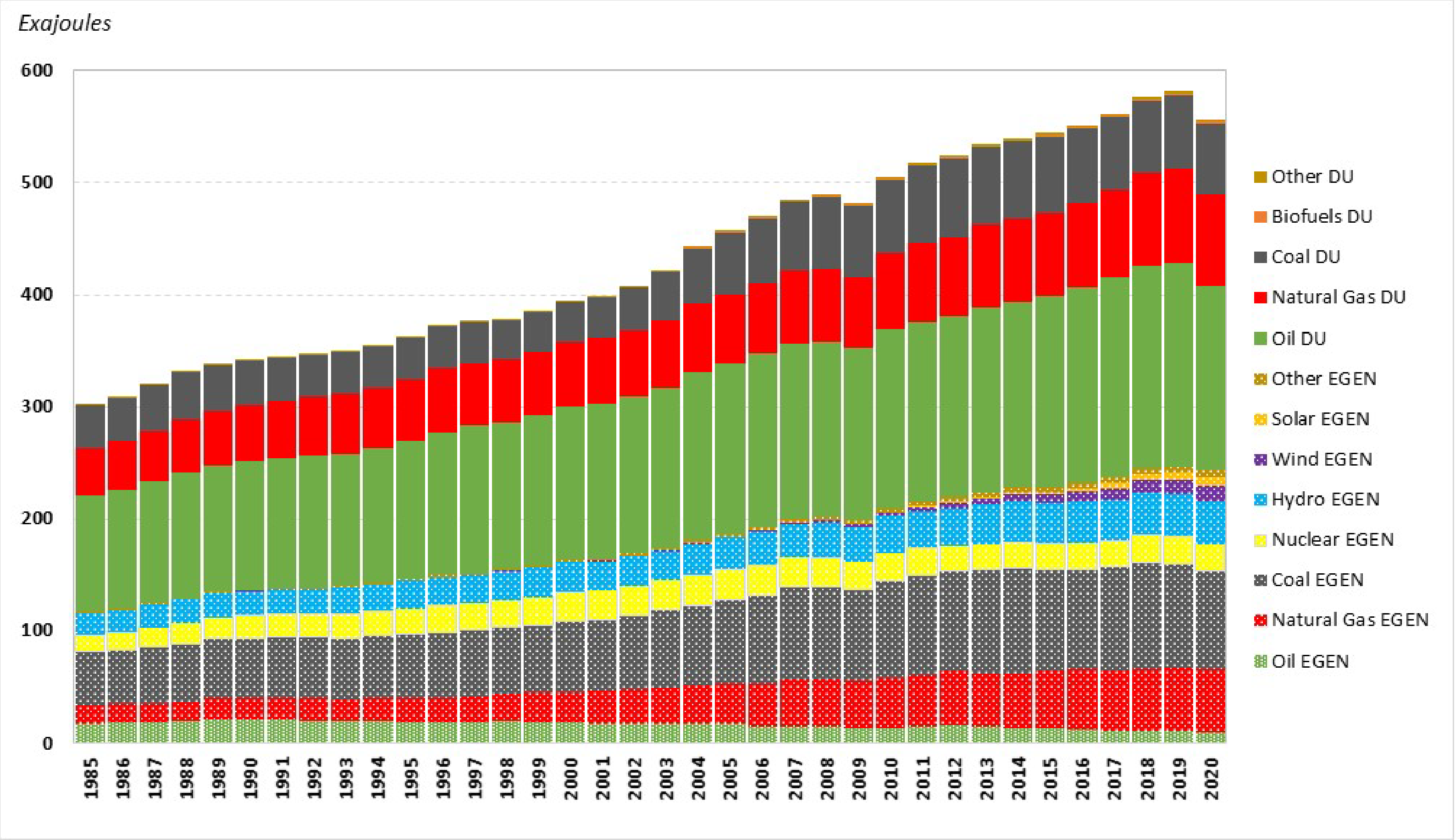
- Even with double-digit year-on-year percentage increases for wind and solar over the last 20 years, they are still a relatively small proportion of the total energy mix, 2.5% and 1.4% respectively..
- Reducing hydrocarbon demand is a challenge.
  - Total demand continues to grow. So, incumbent fuels must be displaced, and new demand simultaneously met.
  - Greater electrification is a challenge. Electricity is 43.8% of total energy.
  - With direct combustion and use, hydrocarbons remain prominent, accounting for 98.8% of all non-electric applications.



Data Source: BP, 2021

Energy Transitions and the Roles of Legacy, Scale and Technology

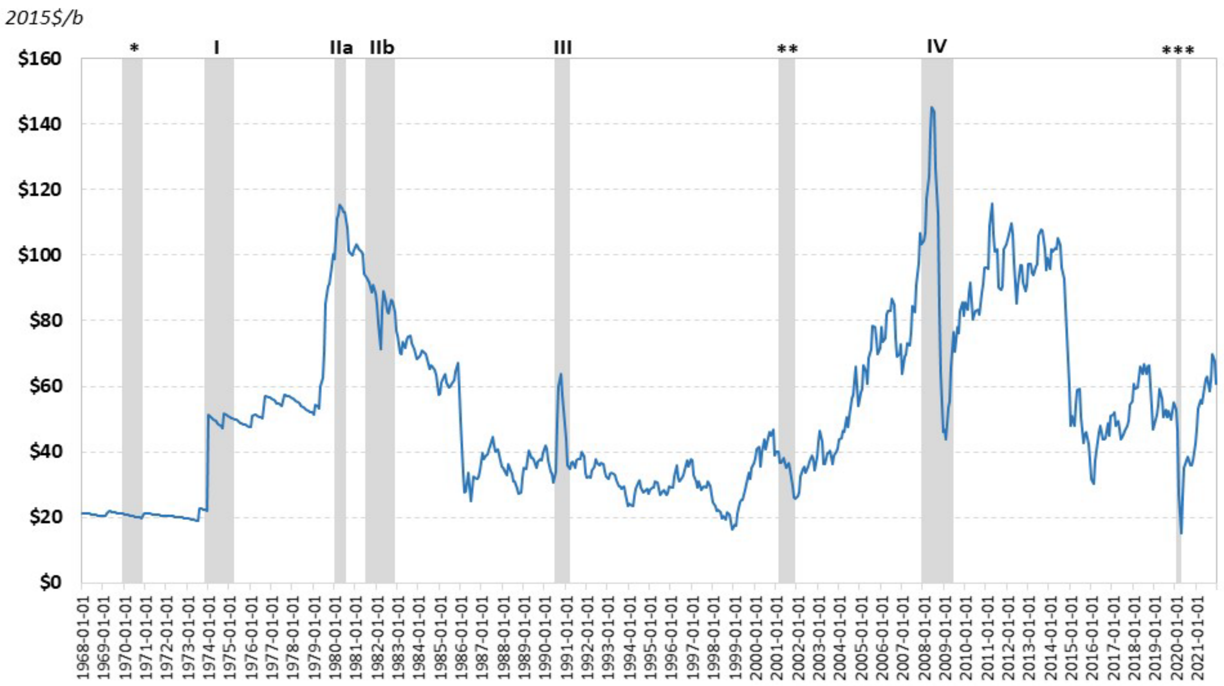
- **Energy ALWAYS transitions**, and value chains matter!
- Technology, scale and legacy are each important factors.
    - <u>Technology</u> signals how fuels will compete. Capital is the vehicle for technology deployment!
    - <u>Scale</u> matters because energy systems are large and must accommodate growth and access.
    - <u>Legacy</u> of infrastructure and energy delivery systems is the footprint for change. Legacy is different everywhere, and is defined by infrastructure.
- <u>Economics</u> 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 the value chain matter, not just the energy source… coordination theory
- Finally, <u>policy</u> and <u>geopolitics</u> shape, and are shaped, by all of the above.
- **The most impactful yet oft understated "transitions" affecting energy markets in the last 20 years have been (1) the shale revolution in the US and (2) demand growth in Asia…**
    - **(1) is tech, (2) is economic growth. Sense a theme?**

Every region is different!
Comparative advantage matters and no path is smooth.

Moreover, as everyone has been recently reminded,
energy security still matters!

Energy security: some things never change

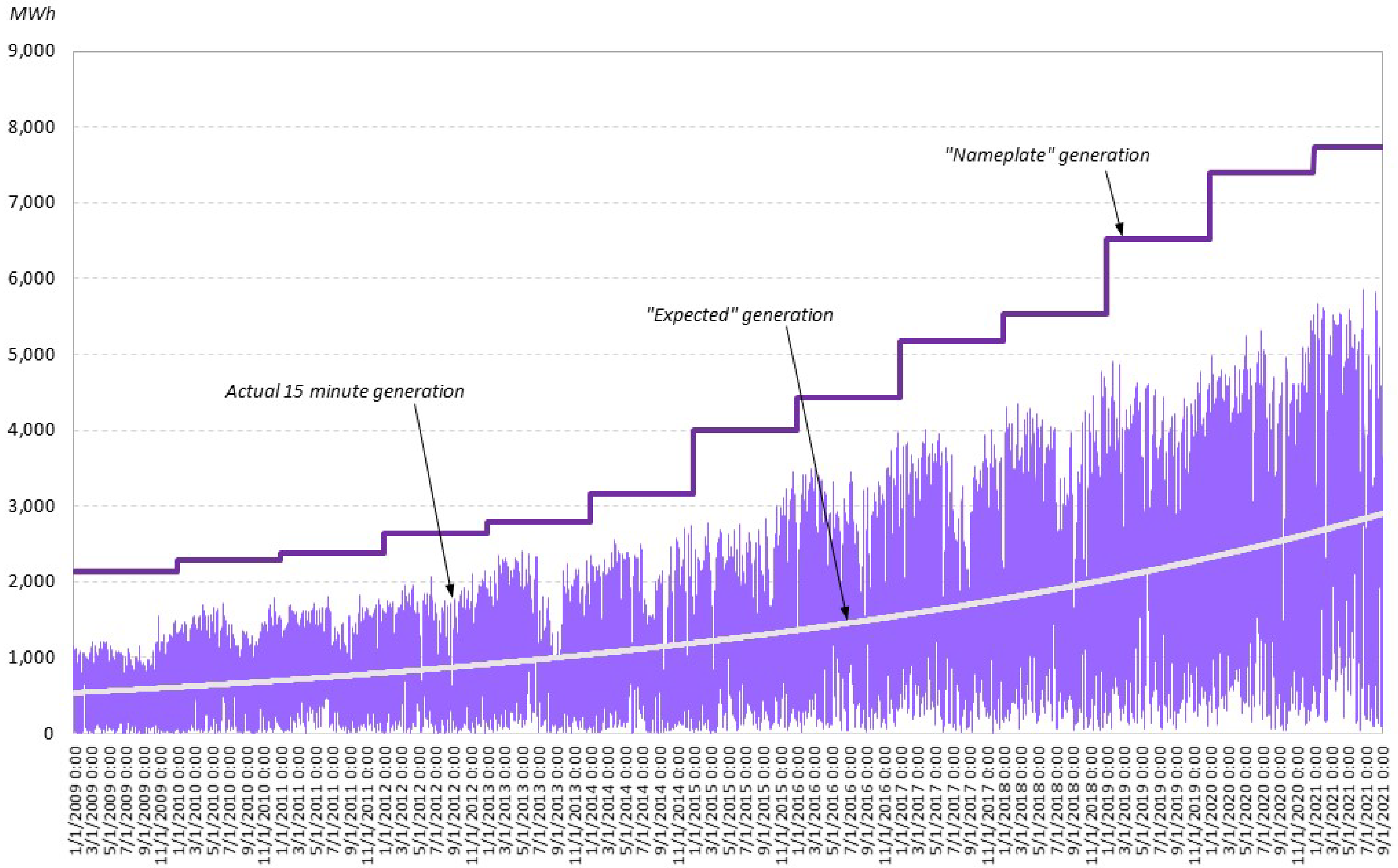
- Energy security is tied to efforts to avoid macroeconomic dislocations associated with unexpected spikes in energy price.
- COVID-related supply chain rigidities that have emerged as economies began to re-energize over the last year or so triggered a significant price increase.
- Russia's invasion of Ukraine made matters even worse as global energy markets were already tight. Recall, Brent was at $100/b two weeks prior to the invasion.
- Will the global economy slip into recession? Will COVID concerns fade? Will OPEC step up output? Will non-OPEC production respond?
- The word of the day: uncertainty!
- But, make no mistake, energy security is once again, central.



Key	Short explanation
*	**Mild recession**. Interest rate increased due to 60s inflation (over 5% in 1969). Ended when interest rates were lowered.
I	**The Oil Embargo**. In response to inflation pressures, price and wage freezes across major US industries were instituted, which triggered layoffs and "stagflation." Fed tried to accommodate by lowering interest rates, which led to very high inflation in the late 1970s.
IIa	**Iranian revolution** and **Iran-Iraq war** drove increases in oil price. Inflation climbed to 13.5%, which drove Fed to increase interest rates.
IIb	**"Double dip" recession**. Oil prices remained high. Fed increase interest rates to 21.5%, which quelled inflation but also shrunk GDP by 3.6% and raised unemployment to over 10%. Fiscal policy – tax cuts and defense spending – ultimately reversed the course.
III	**S&L crisis** and **Gulf War**. Mortgage lending collapsed and construction followed suit. Iraq invasion of Kuwait spikes oil price and compounds woes.
**	**"Dot-com" crash** and **9/11**. Mild recession in which Nasdaq lost 75% of its value and S&P500 lost 43% of its value. Housing boom helped end the recession.
IV	**The Great Recession** and **the Global Financial Crisis**. Perfect storm of events that included rising energy prices, and high risk moves in mortgage-backed securities by large financial institutions. S&P500 and DJIA lost half of their values. Massive fiscal support followed by quantitative easing pulled the economy out of the recession.
***	**COVID.** Pandemic-driven economic shutdown in attempt to slow spread of virus.

Electrification, renewables and challenges of intermittency

- ERCOT is a great case study for wind penetration.
- As intermittent renewable generation sources grow, their average generation grows, which accomplishes the goal of reducing emissions.
- BUT, averages are irrelevant for reliability. Extremes matter.
- Given the observed variability, sufficient dispatchable backup generation capacity is required.
- In ERCOT, this is natural gas. In other places, it may be hydro or other fossil fuels. Longer term, it may be hydrogen or long-duration storage.
- In the end, this raises the capital intensity of each MWh delivered. Cost is an issue.



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.

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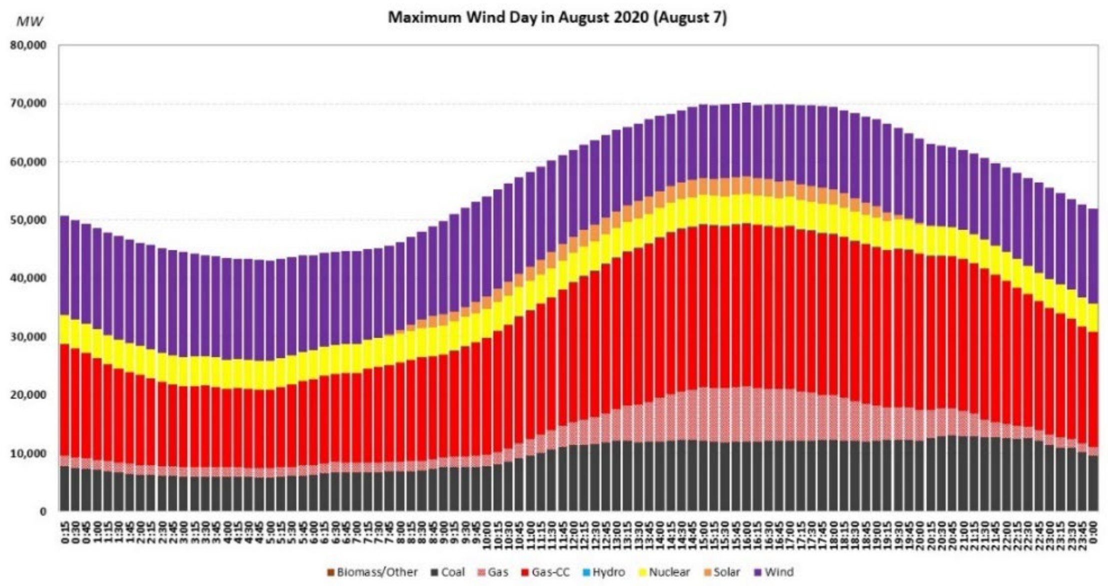
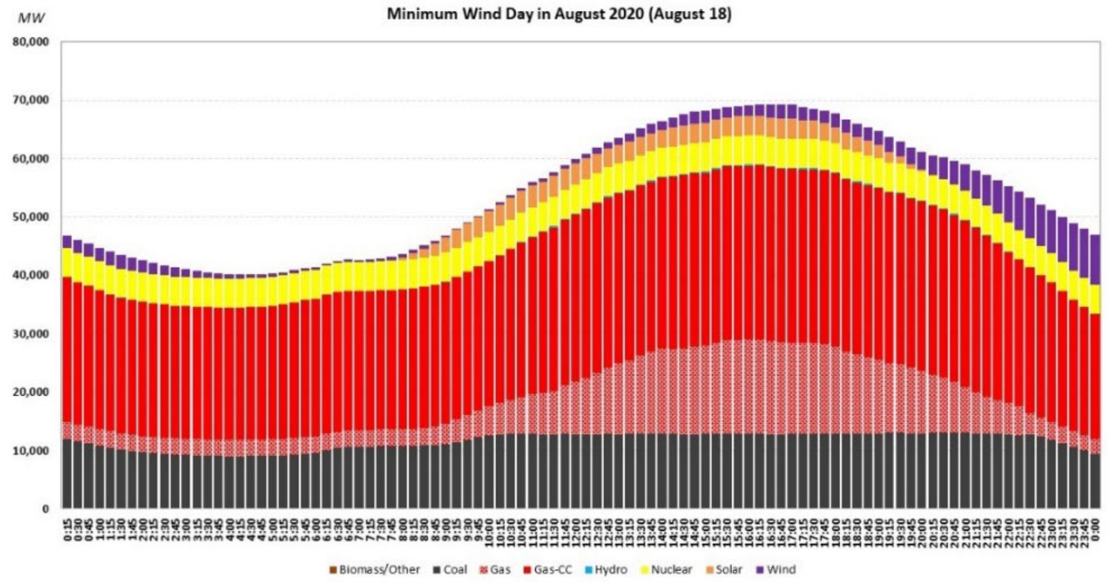
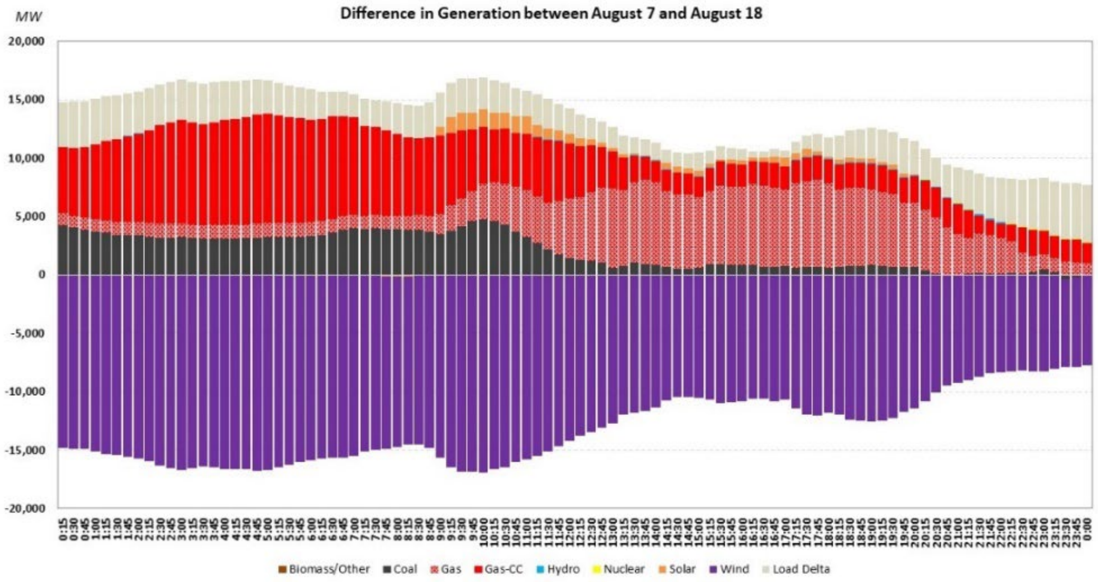
An example of why averages don't matter: Two days in ERCOT in August 2020





- Reliability requires multiple margins of response. Renewable deployment has been successful precisely because it has been able to leverage legacy infrastructure whose costs are already sunk.
- But, "minding the gap" will require redundancy, significant capital investment, and treating demand as a resource.



Source: ERCOT generation data from "Fuel Mix Reports" (https://www.ercot.com/gridinfo/generation).

Coordination, renewables, hydrogen and carbon capture

In general, the prospects for growth:

- are regionally differentiated,
- are tied to existing comparative advantages,
- are heavily dependent on coordination,
- will need market depth, and
- will heavily involve oil and gas!

Consider Texas to highlight the point!

Coordination Theory and the Value Chain

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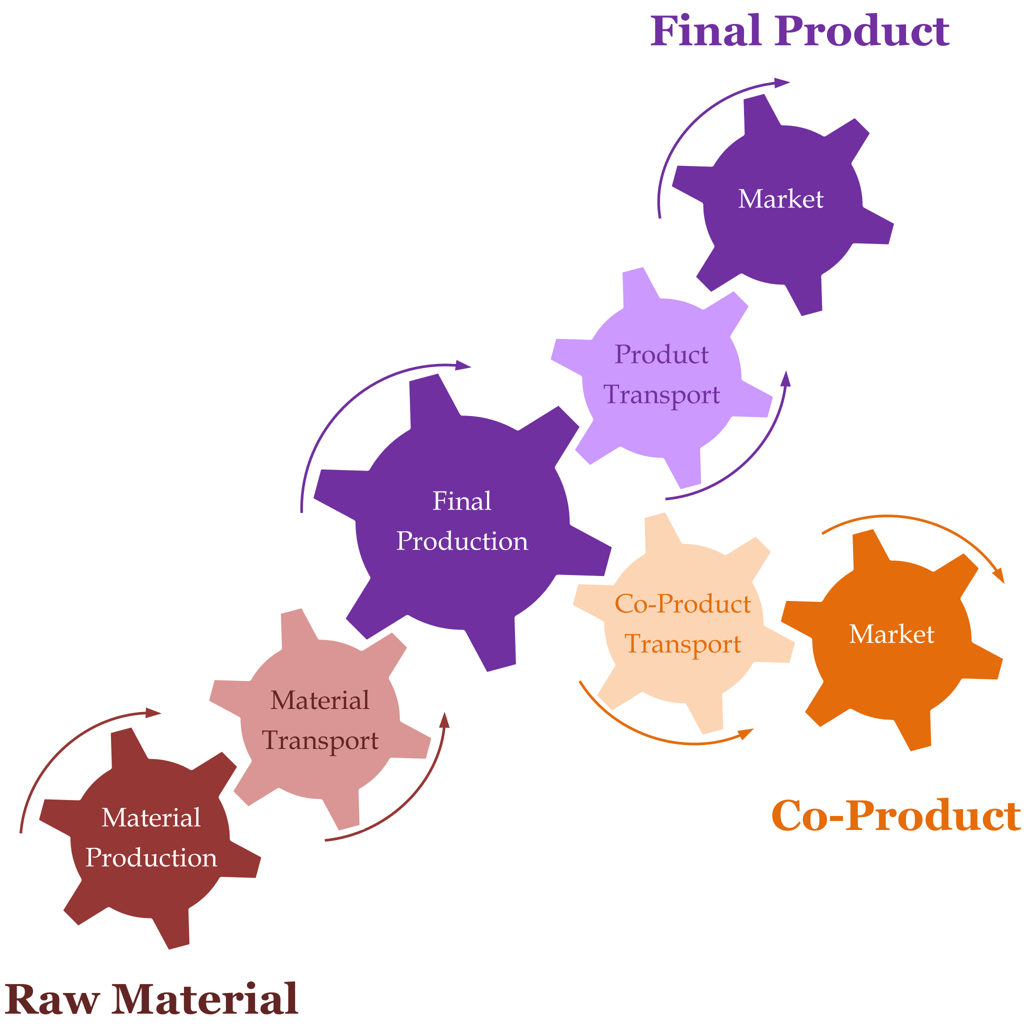
- Every production process involves a value chain associated with raw material inputs that are used in a production process to deliver a final product and potentially a co-product.
- Thus, coordination theory plays a central role.
  - The simplest example of coordination theory is the prisoner's dilemma.
- 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.



Texas and the Gulf Coast Region: Green Energy

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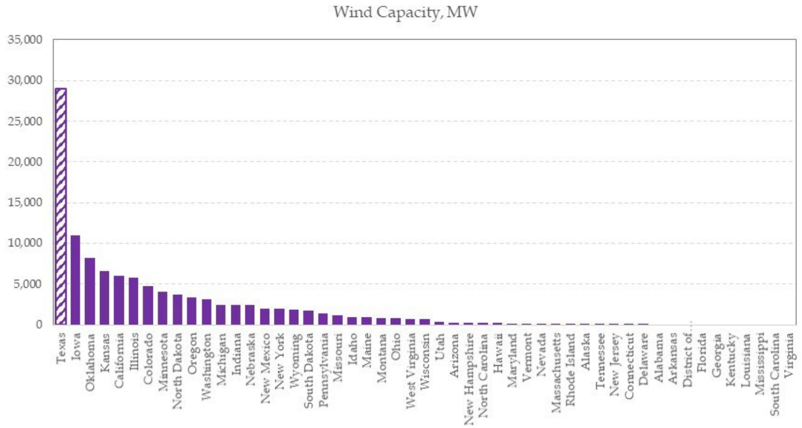
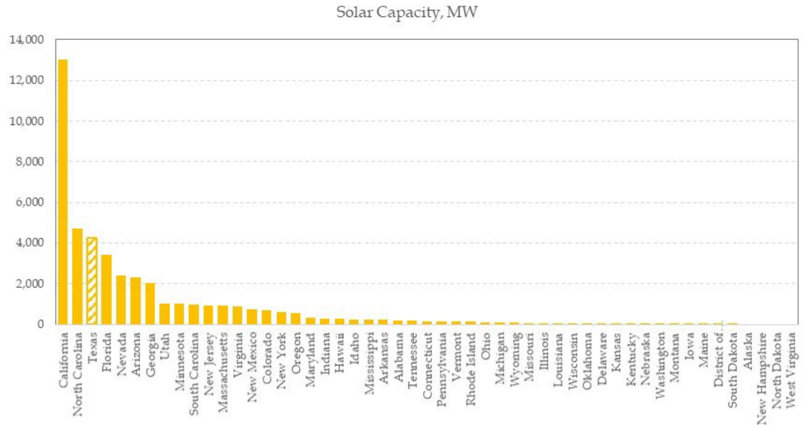
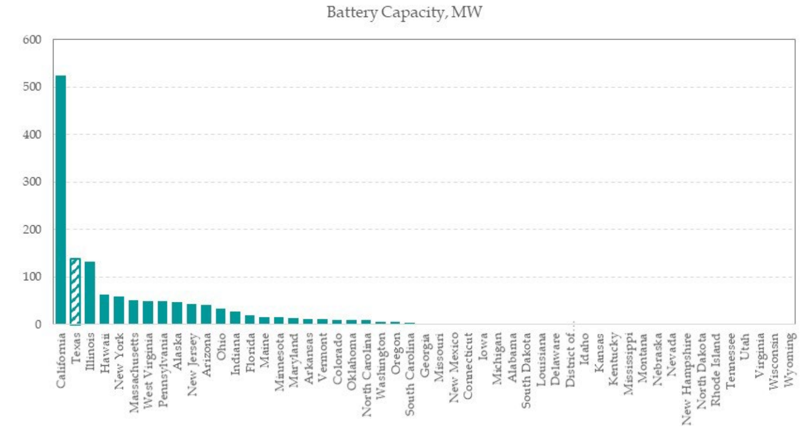
- Texas a leader in green power?
    - Yes. Wind, sun, land, a business friendly environment, and a grid to connect into.

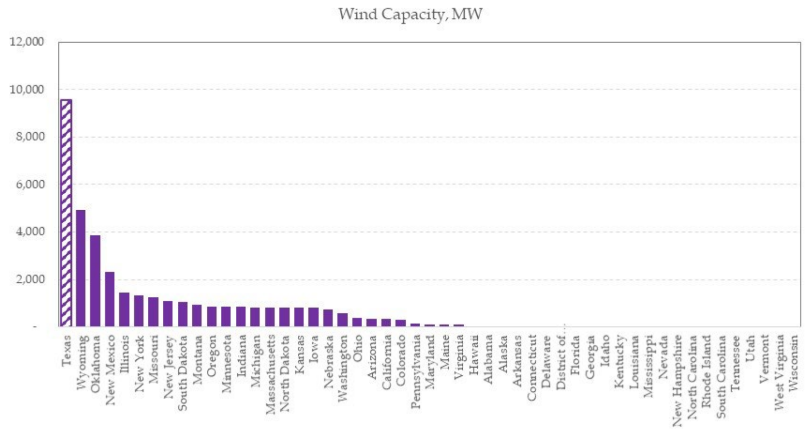
Operating Capacity

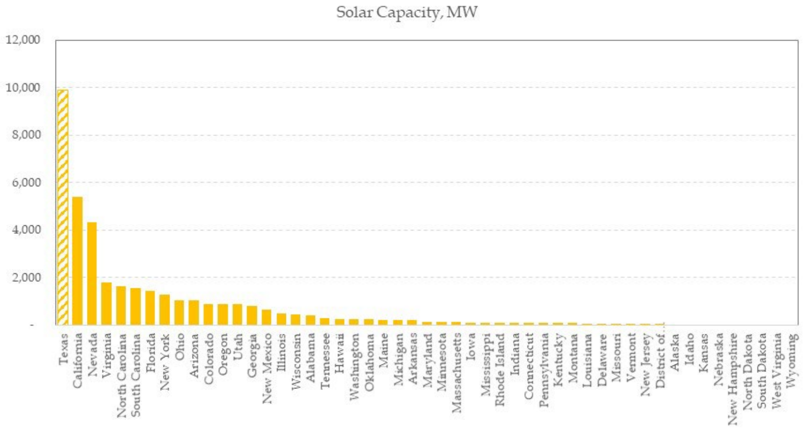


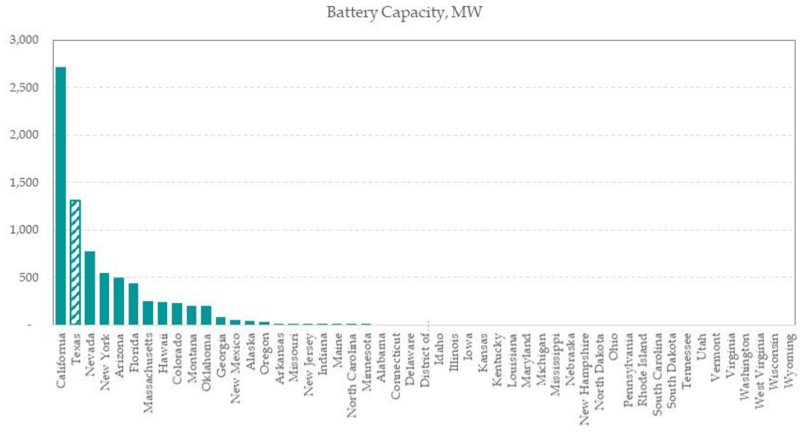




Planned Capacity







Data obtained from EIA Form 860M

The “Colors” of Hydrogen

- There are multiple technologies for producing hydrogen. Some are less carbon intensive than others, some have clear carbon-to-value propositions that alter commercial prospects, and some are better suited for regional comparative advantages than others.
- All forms of hydrogen have different value chain challenges. These include:
    - Infrastructure needs that vary by technology.
    - Some regions have legacy infrastructures that other do not.
    - Different land-use needs, industrial footprints, transport networks, societal attitudes, etc.
    - Policy and regulatory frameworks

Grey	Produced from natural gas using steam methane reforming. Most common form of hydrogen production currently in use. Results in CO_2 emissions.
Brown	Produced from gasification of fossil fuel feedstock, usually coal. Often discussed as a potential future use of coal. Results in CO_2 emissions.
White	Produced as a byproduct of an industrial process. CO_2 emissions are dependent on the industrial process.
Yellow	Produced by electrolysis using electricity from solar power. No CO_2 emissions depending on the source of power generation. Leverages existing power grid. Can be CO_2 neutral if carbon capture is deployed at sources of fossil-generated of power.
Blue	Grey or Brown hydrogen with carbon capture. CO_2 emissions are substantially reduced. Modifies existing production methods thus leveraging legacy, or existing, infrastructures.
Turquoise	Produced by methane pyrolysis with a solid carbon by-product. CO_2 emissions are substantially reduced. Leverages existing natural gas infrastructures. Opens “carbon-to-value” propositions as solid carbon can be a replacement for carbon black and used a feedstock in advanced carbon material applications.
Green	Produced by electrolysis using electricity from renewables. No CO_2 emissions.
Pink	Produced by electrolysis using nuclear power. No CO_2 emissions.

*** - This table is derived from a report by the North American Council for Freight Efficiency (https://nacfe.org/emerging-technology/electric-trucks-2/making-sense-of-heavy-duty-hydrogen-fuel-cell-tractors/). There are multiple derivatives of the color palette for hydrogen technologies. For example, yellow is sometimes associated with solar power, brown with lignite, and black with coal.*

Coordination, Hydrogen and Hubs

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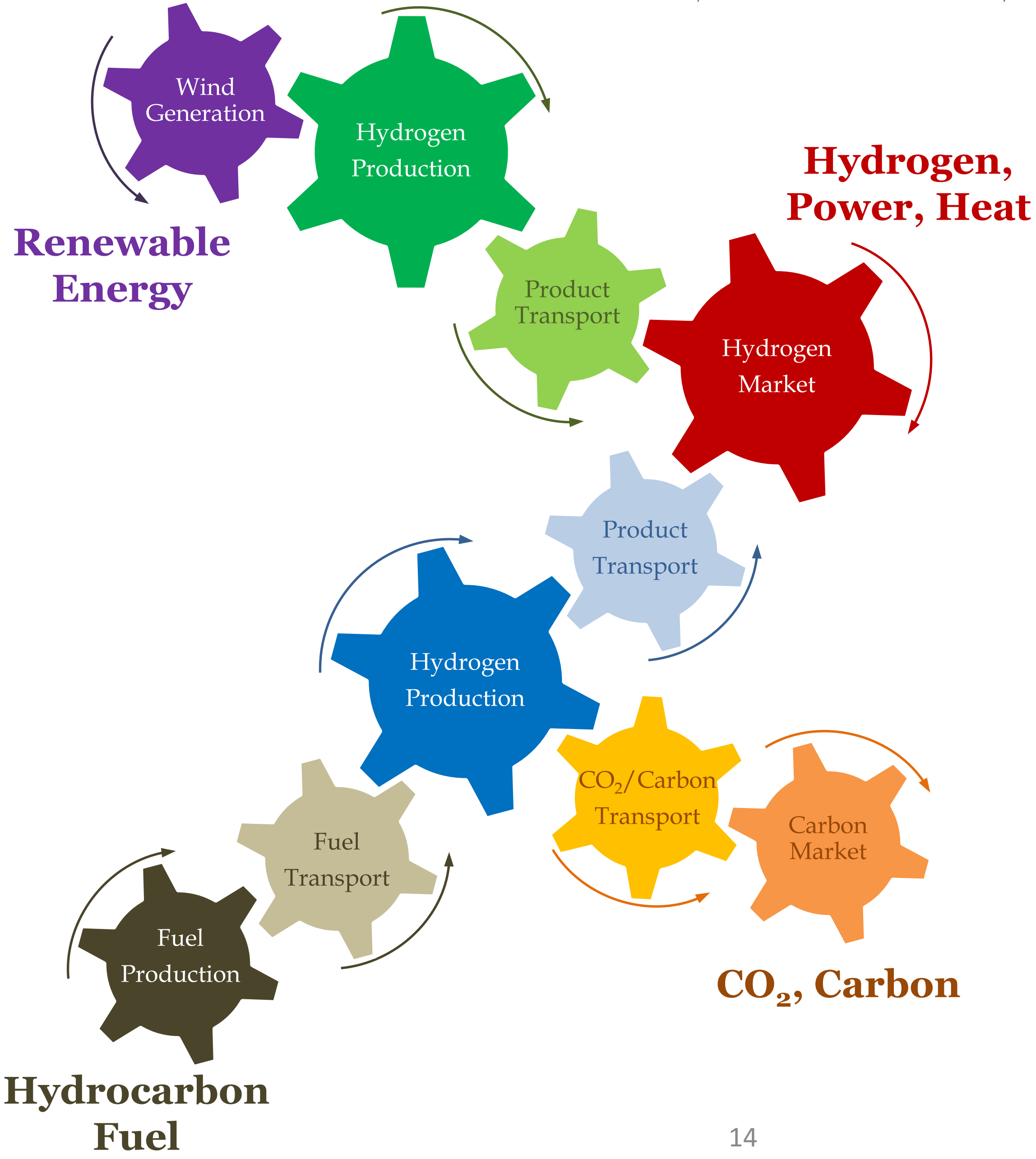
- With limited market participation, deals to support investments along the value chain must be bilateral, thus requiring identification of specific counterparty with a specific requirement. Thus, investments are highly conditional on counterparty identification.
- In the presence of a hub, investments along the value chain are de-risked because direct counterparty interaction is not needed. This facilitates investment from all players.
- In the absence of a hub, investments are limited to parties with sufficient risk tolerance, thereby diminishing the scale of the activity.
- One can think of this through the lens of real options. Investing in infrastructure is a real option. One only exercises the option when profitable. In the absence of market liquidity, a liquidity premium exists that renders the option value lower, thus reducing investment. Liquidity increases scale.



Texas and the Gulf Coast Region: Carbon Capture

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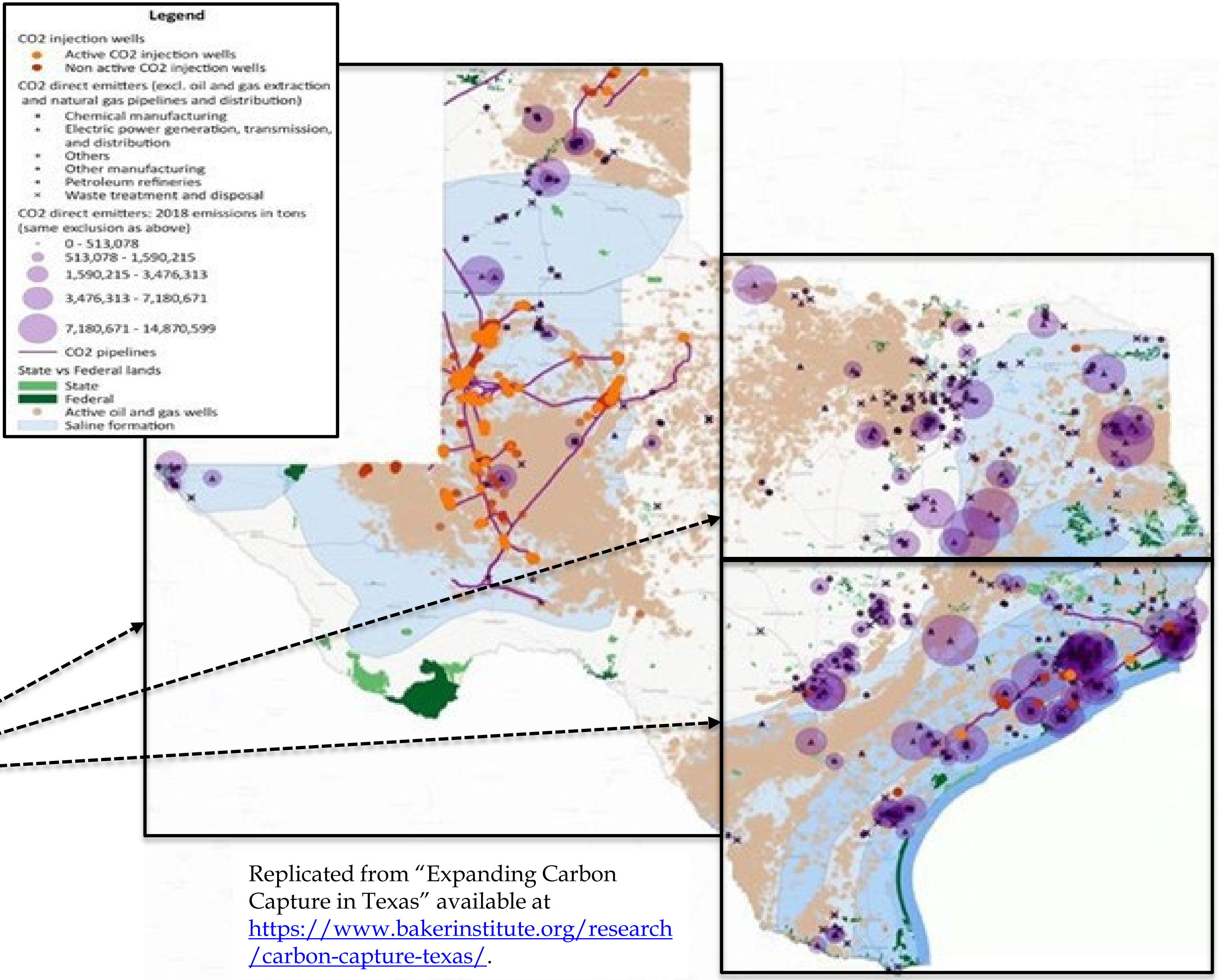
- Texas a leader in carbon capture?
- Significant industrial and power generation CO_2 emissions
  - 24% of US energy-related emissions from industry
  - 12% of US energy-related emissions from power generation
- Comparative advantages:
  - Large CO_2 footprint
  - Supply chain logistics and management expertise
  - Engineering and subsurface expertise
  - Geologic endowment
  - Business-friendly
- <u>Regionally distinct differences</u>. There are challenges, but the opportunities are multifaceted.



Replicated from "Expanding Carbon Capture in Texas" available at https://www.bakerinstitute.org/research/carbon-capture-texas/.

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