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Energy Transitions:
The Important Roles of Technology, Legacy, and Scale

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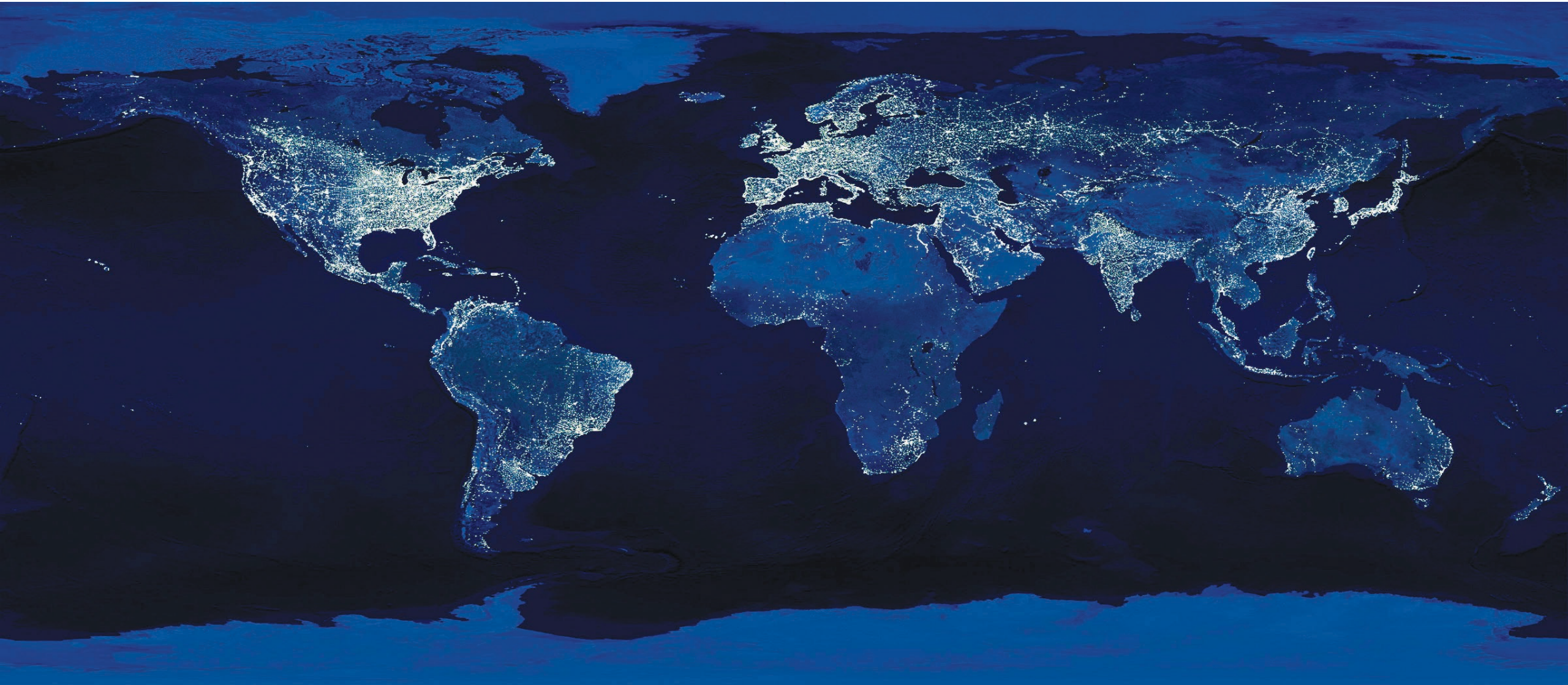
Rice University's Baker Institute

October 31, 2019

This conversation begins here…

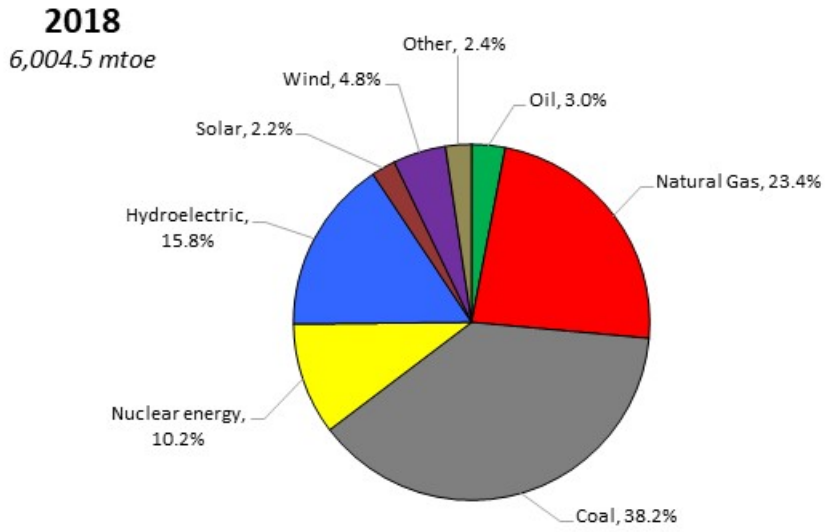


The Data Behind the Picture…

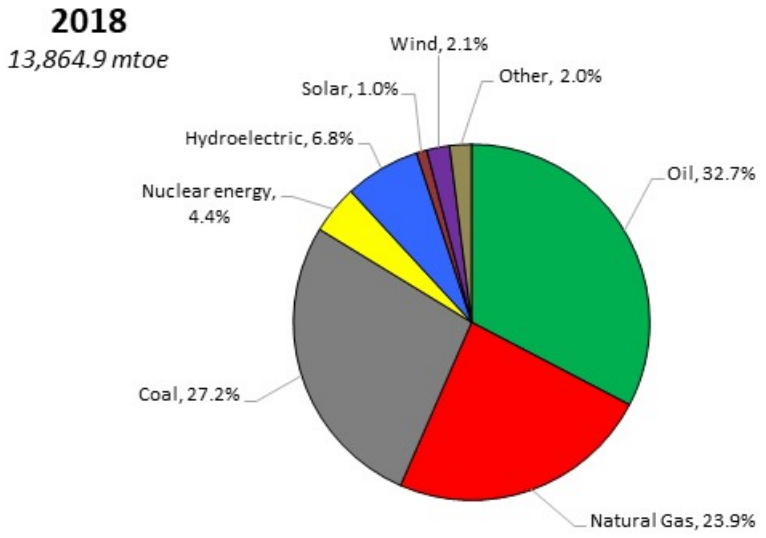
The current global energy landscape

- Renewables are a major focus of the energy transition discussion, and they are growing. In 2018, wind and solar represented 6.9% of global electric generation and 3.1% of total energy, which is up from 1.1% and 0.3%, respectively, in 2008…

Global Power Generation



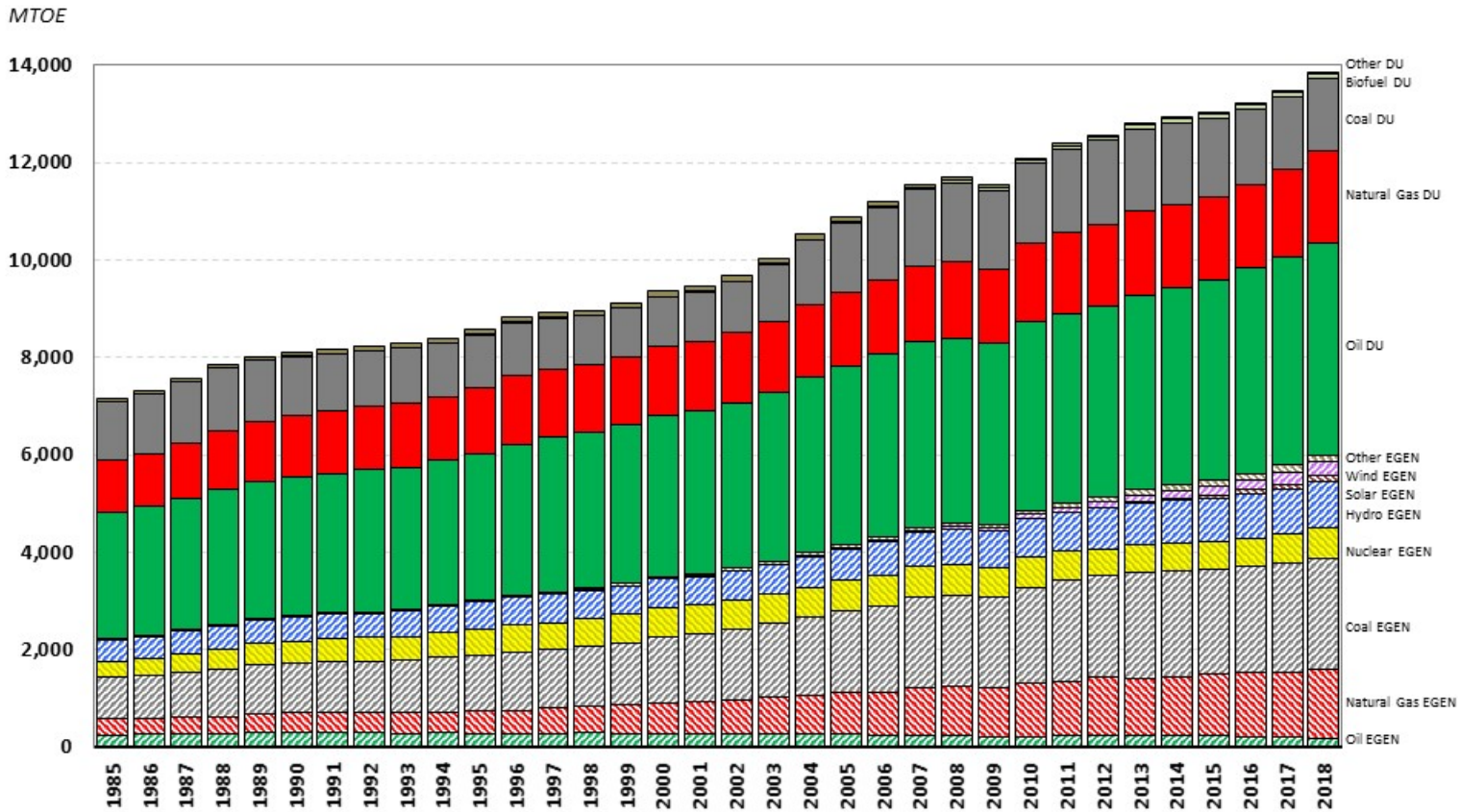
Global Primary Energy



Data Source: BP, 2019

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

- … but even with double-digit year-on-year percentage increases for the last 20 years, they are still a relatively small proportion of the total energy mix.
- Even with continued growth, the prospect for reducing hydrocarbon demand is challenging.
  - Total demand continues to grow. So, incumbent fuels must be displaced, and new demand simultaneously met.
  - Greater electrification is a challenge. Electricity is 43.3% of total energy.
  - Direct combustion of hydrocarbons remains prominent, accounting for 98.3% of non-electric energy.

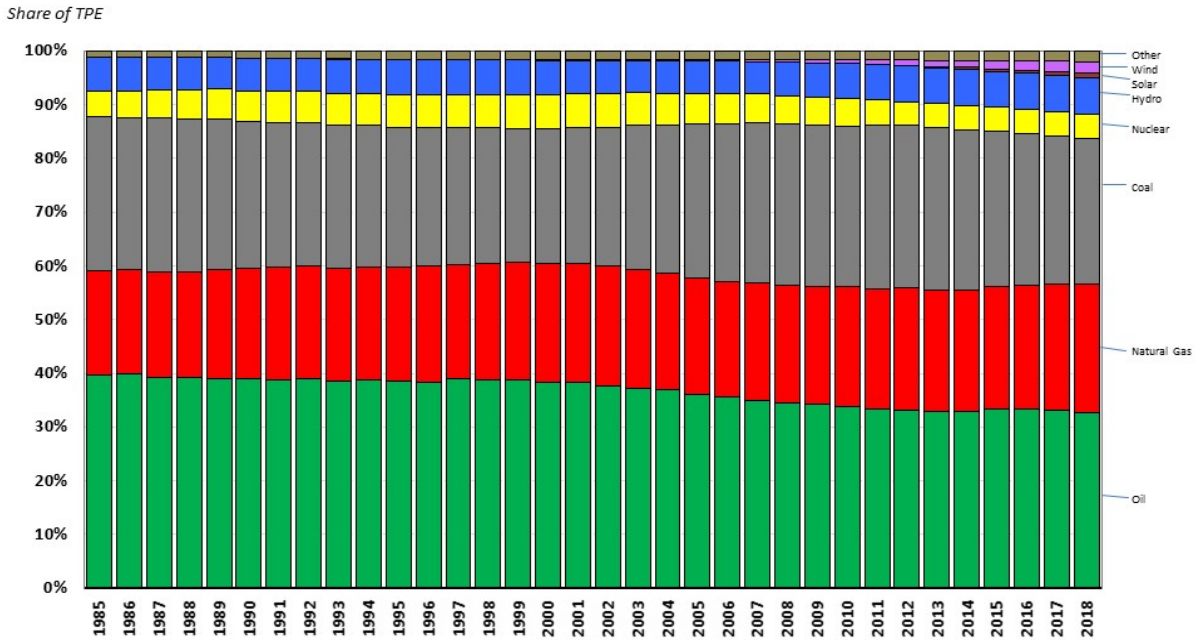


Data Source: BP, 2019

… and the implications for market shares of TPE

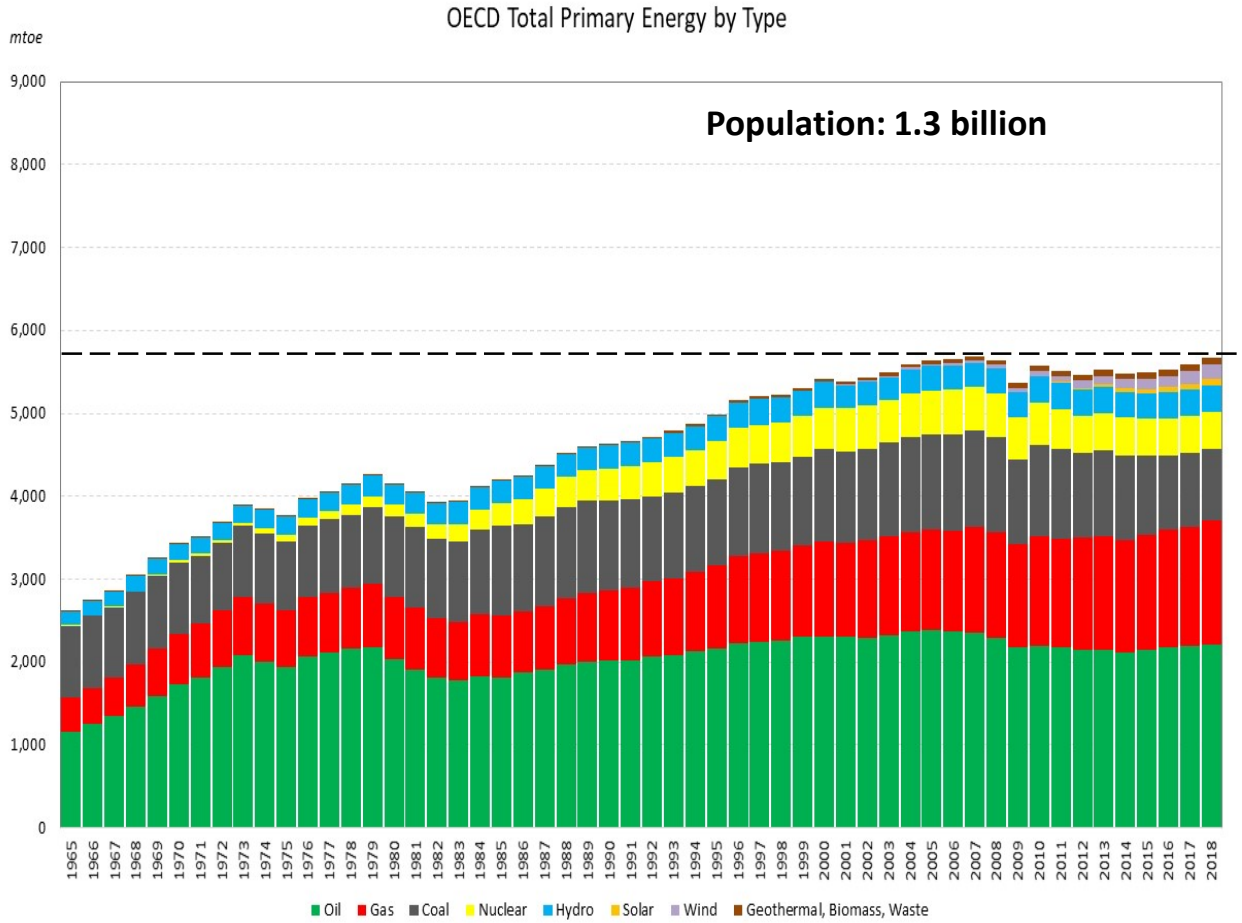
- Market shares are slow to change, especially relative to overall demand growth.
  - Coal: $28.7\%_{1985} \rightarrow 27.2\%_{2018}$; Oil: $39.4\%_{1985} \rightarrow 32.7\%_{2018}$; Natural Gas: $19.5\%_{1985} \rightarrow 23.9\%_{2018}$
  - Hydrocarbons: $87.7\%_{1985} \rightarrow 83.7\%_{2018}$
  - Total Primary Energy Demand: 7,162 $MTOE_{1985} \rightarrow$ 13,865 $MTOE_{2018}$,which is an 93.8% increase.
  - So, for hydrocarbon demand to remain flat, market shares had to fall much more (or demand not grown)…
    - Hydrocarbons: $87.7\%_{1985} \rightarrow 45.3\%_{2018}$

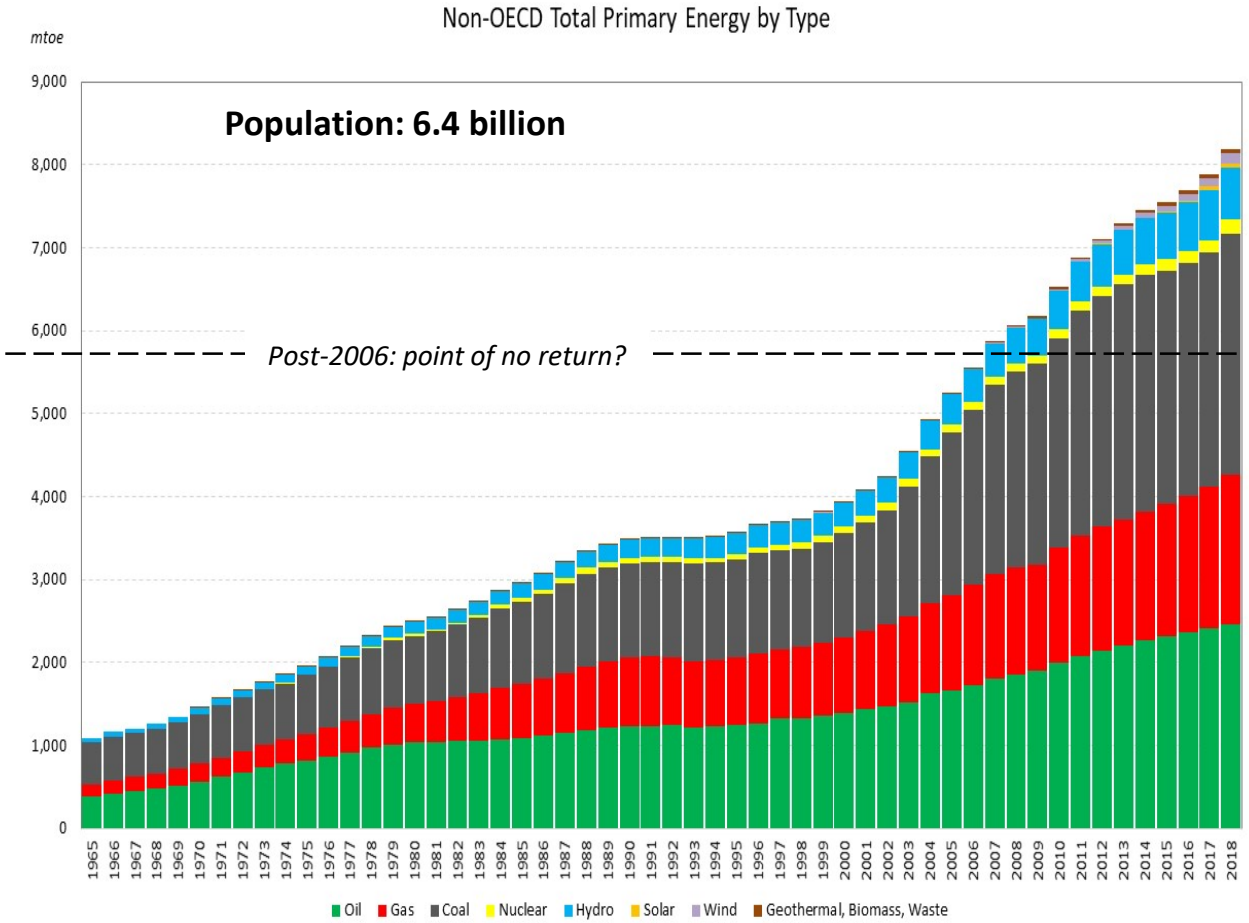
This is effectively what we are asking the world to do over the next 32 years… A major complication is most of this must come from developing nations!



Data Source: BP, 2019

The evolving energy landscape: A developing nation story





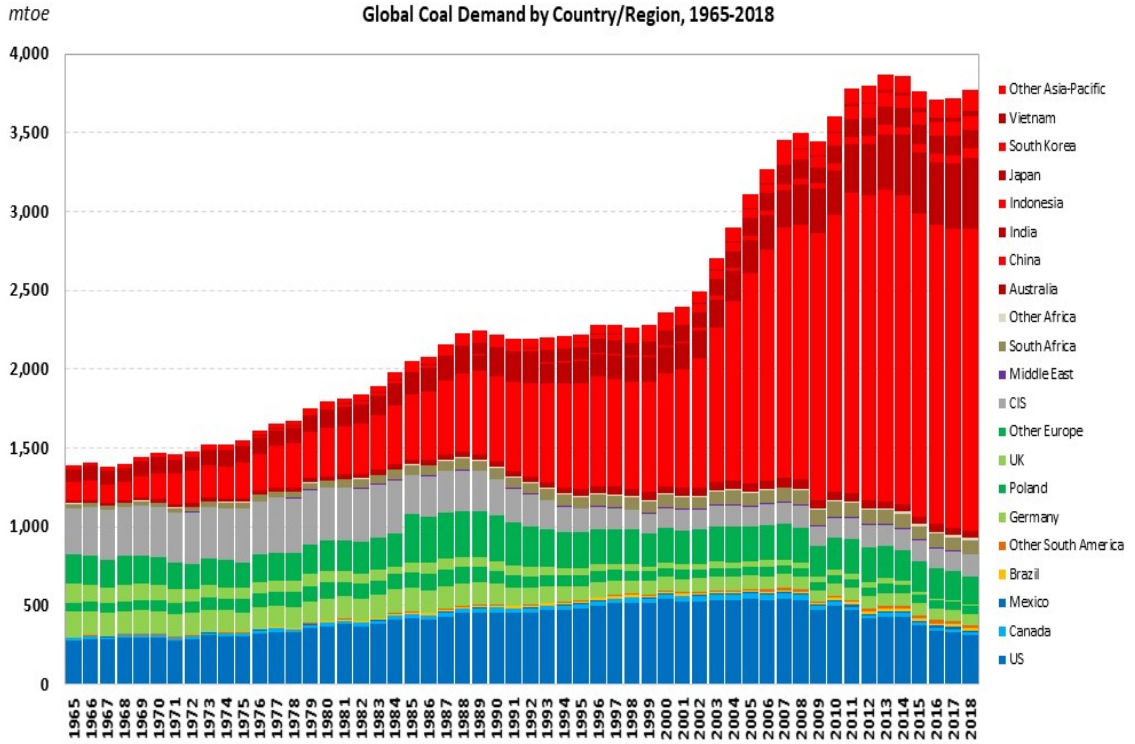
Data Source: BP, 2019

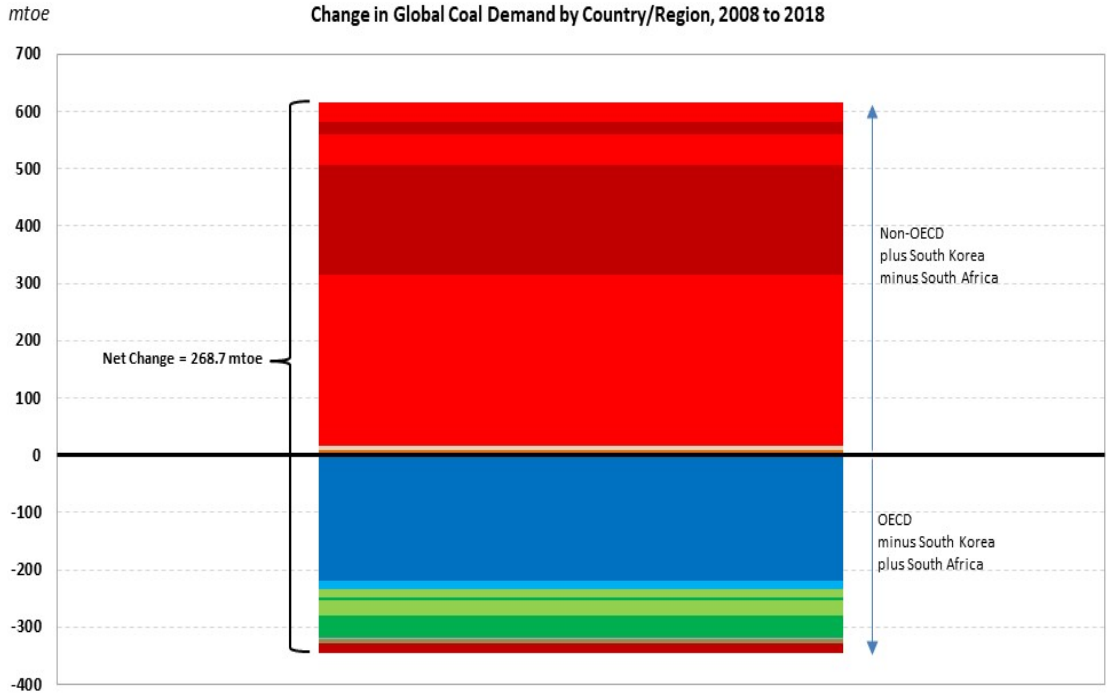
Energy Transitions
The Roles of Legacy, Scale and Technology

- **Energy ALWAYS transitions. Three important words: Legacy, Scale and Technology.**
- Technology, scale and legacy are each important factors.
  - Technology signals how fuels will ultimately compete. This can work in multiple, sometimes competing, directions by raising the efficiency of use of existing fuels *and* by introducing new competitive energy sources. Importantly, capital is a vehicle for technology deployment!
  - Scale matters because energy systems are large and must accommodate growth and expanding access.
  - Legacy of infrastructure and energy delivery systems is the footprint for change. Legacy is different everywhere – the contrasting cases of the US and China – and is set in a lumpy but continuous manner.
- Economics matter. The cost-benefit must be favorable for sustainable diffusion of new technology.
- Finally, policy and geopolitics shape, and are shaped, by all of the above.
- **The most impactful yet oft understated "transitions" affecting energy markets in the last 15 years have been the shale revolution in the US and demand growth in Asia.**

An example of where legacy, scale and technology factor prominently… Global coal demand

- US: Coal fleet expansion → late 70s to early 80s… was the largest consumer until late 90s.
- China, India, other Asia: Coal fleet expansion in waves → late 90s to …
- Asia expansion is at a different scale than occurred in the US. Technology can create substitutes and/or reduce environmental impacts. Gas displacing coal in the US is an example of technology allowing new legacies at scale.





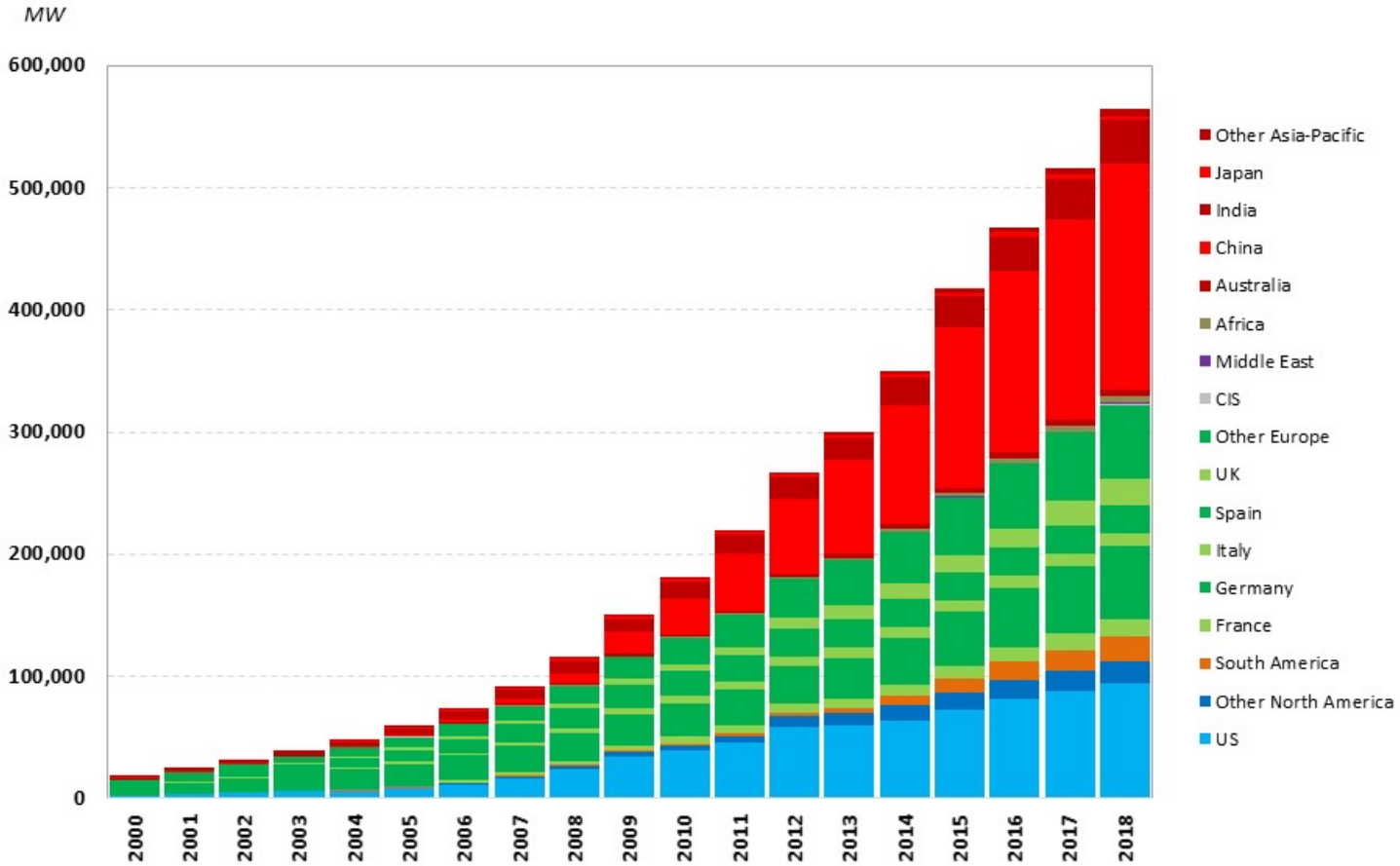
Data Source: BP, 2019

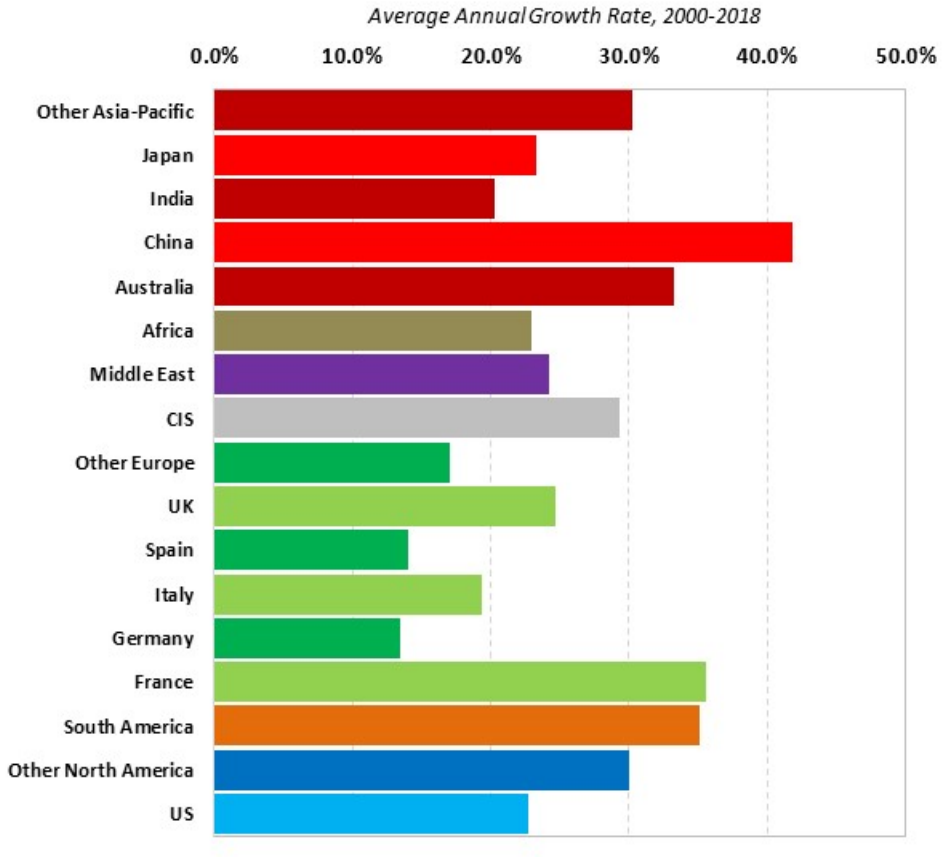
New Energy Technologies

Wind, Solar, Batteries and Electrification: What does the Future Hold?

Renewables around the World: Wind Capacity

- Wind generation capacity has expanded rapidly since 2000. Regional differences exist, but all are robust, amounting to global capacity expansion of over 547 thousand MW at an average annual growth rate of 21.4%.

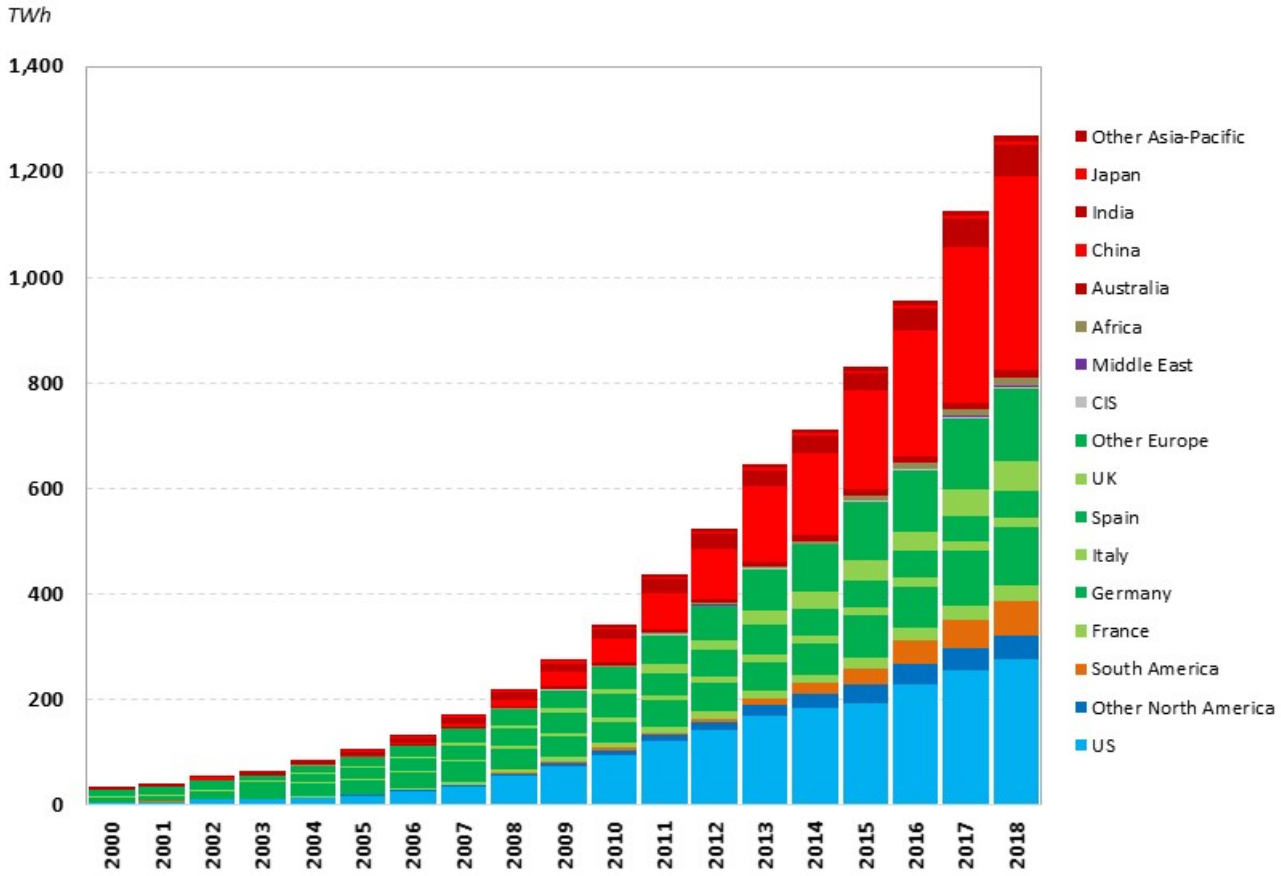


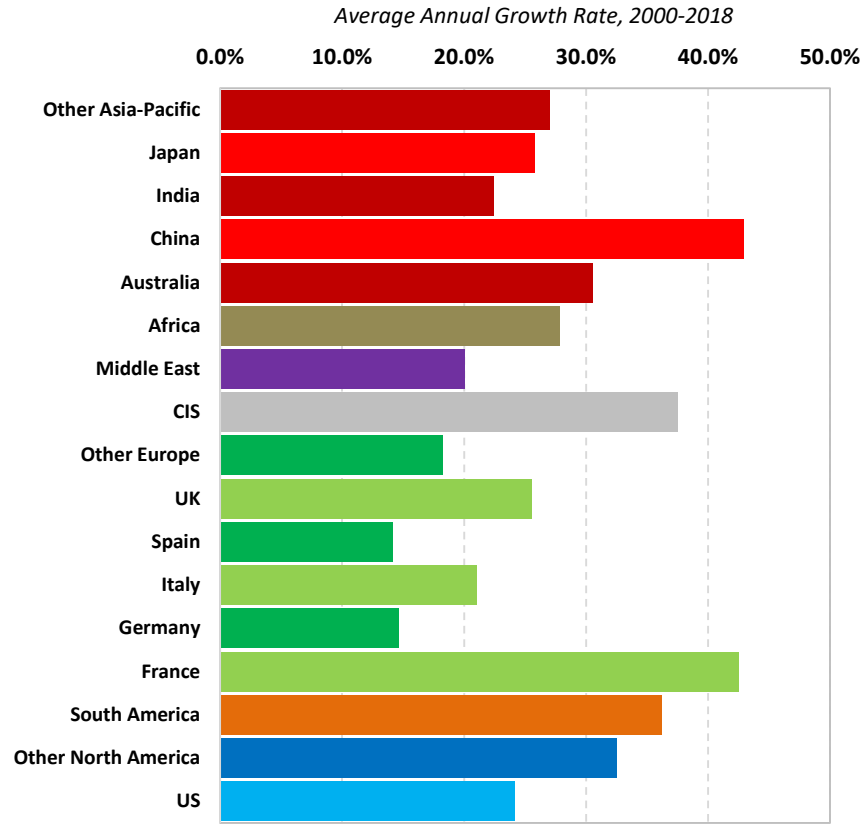


Data Source: BP, 2019

Renewables around the World: Wind Generation

- Wind generation has expanded rapidly since 2000. In 2018, wind accounted for 1,270 TWhs of generation equating to an average annual growth rate of 22.8% since 2000. Average load factors: 20% to 37%; with global average at 26%.

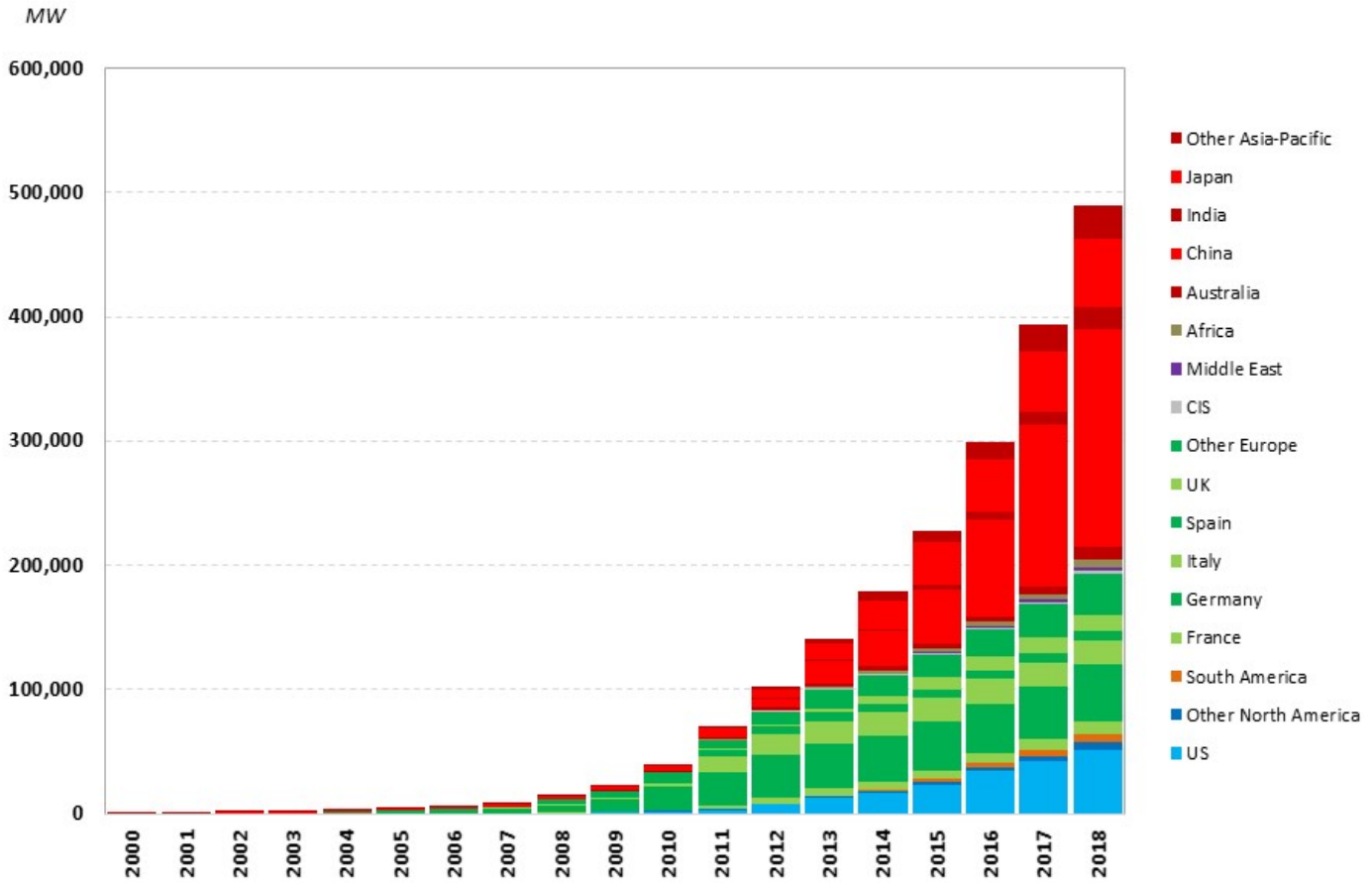


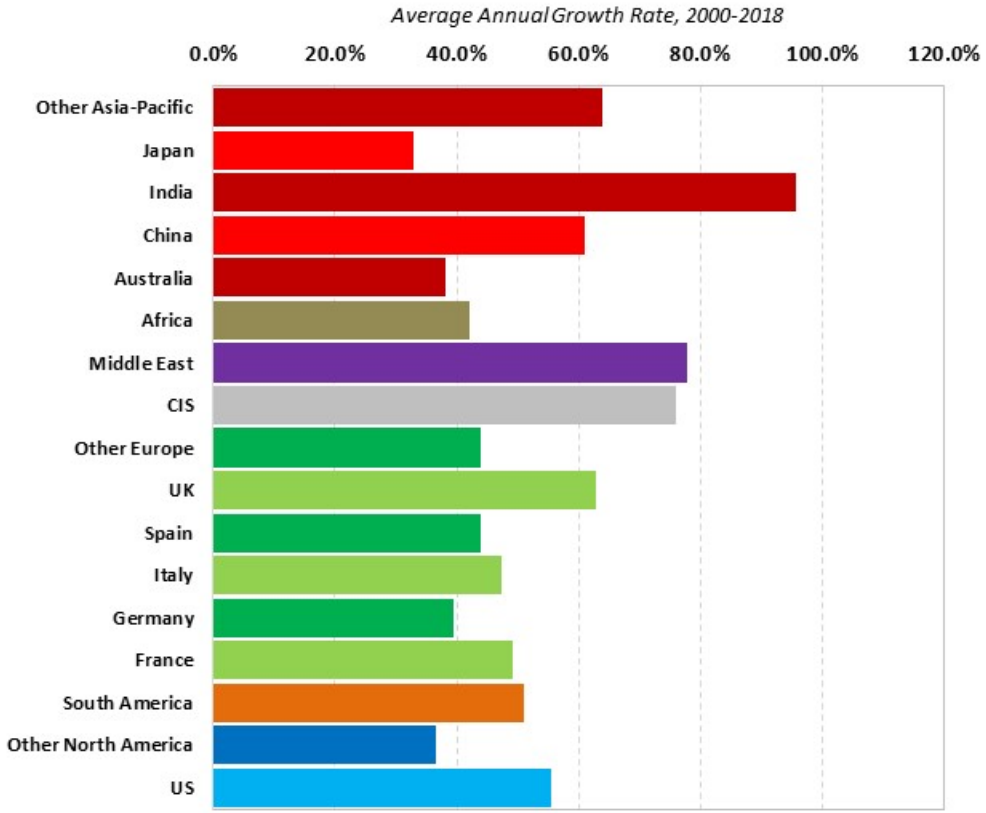


Data Source: BP, 2019

Renewables around the World: Solar Capacity

- Solar PV generation capacity has expanded rapidly since 2000. Regional differences exist, but all are robust, amounting to global capacity expansion of over 489 thousand MW at an average annual growth rate of 44.5%.

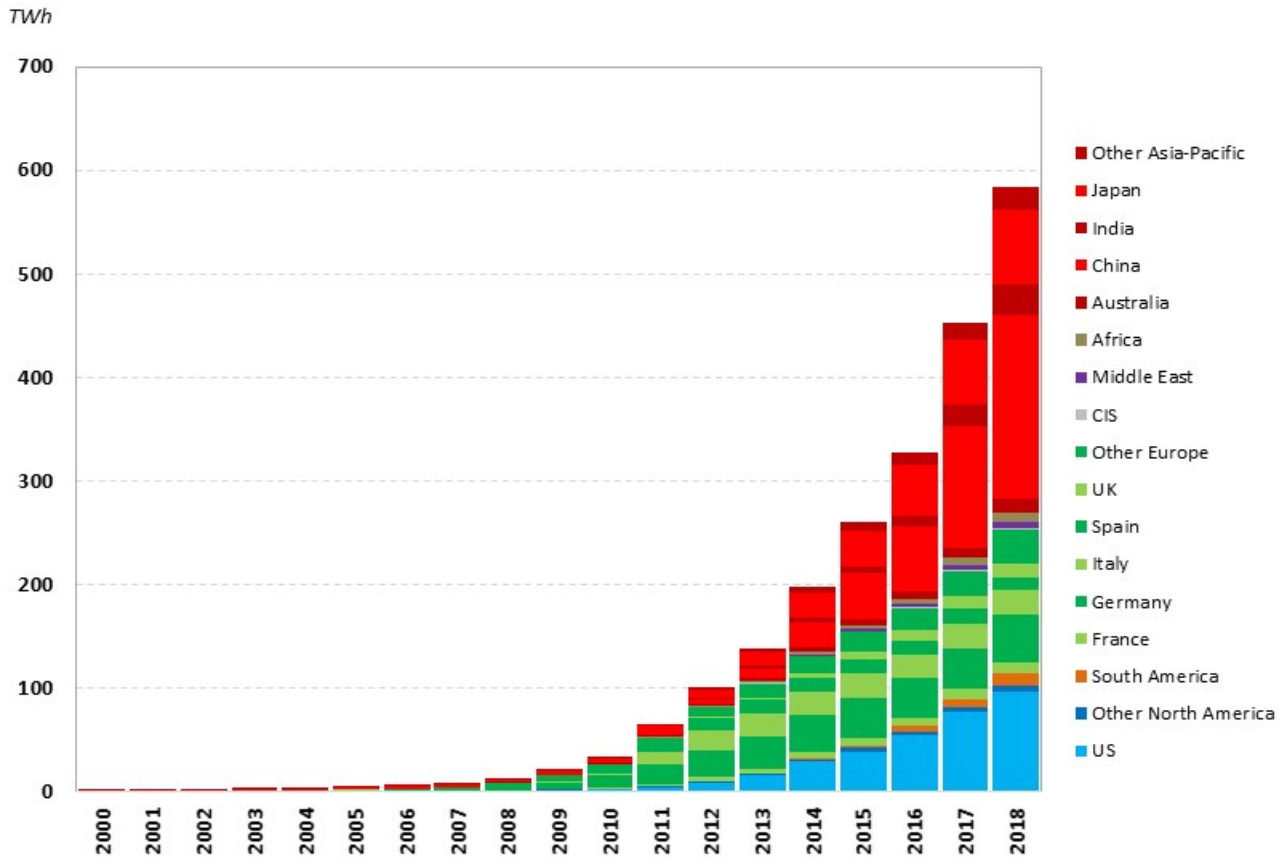


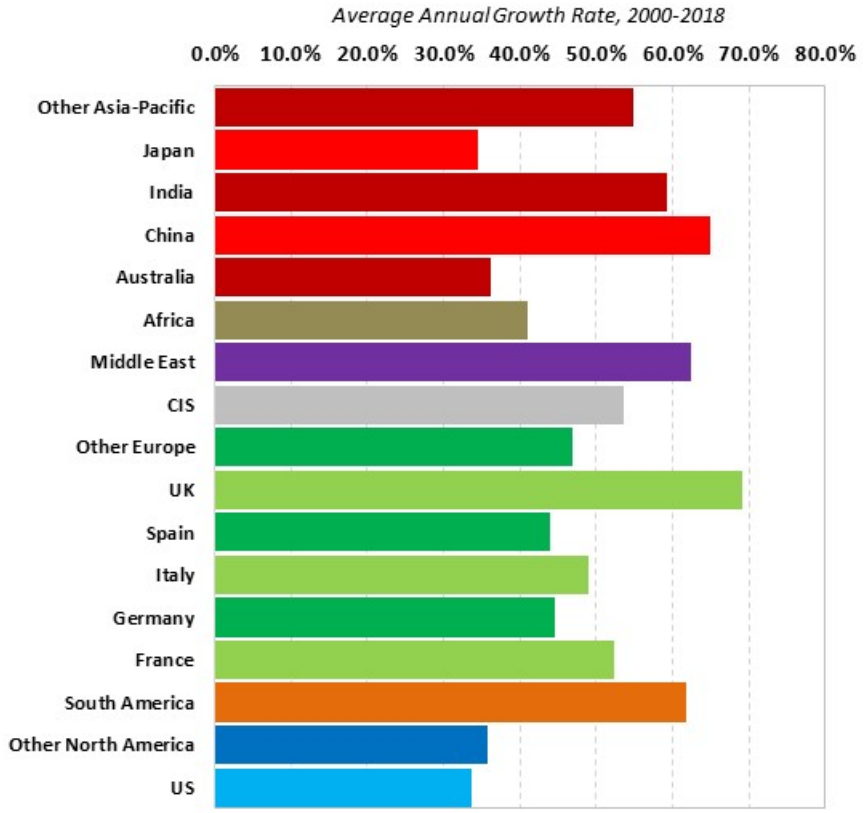


Data Source: BP, 2019

Renewables around the World: Solar Generation

- Solar PV generation has expanded rapidly since 2000. In 2018, solar PV accounted for 585 TWhs of generation equating to average annual growth of 41.5% since 2000. Average load factors: 9% to 22%; with global average at 14%.

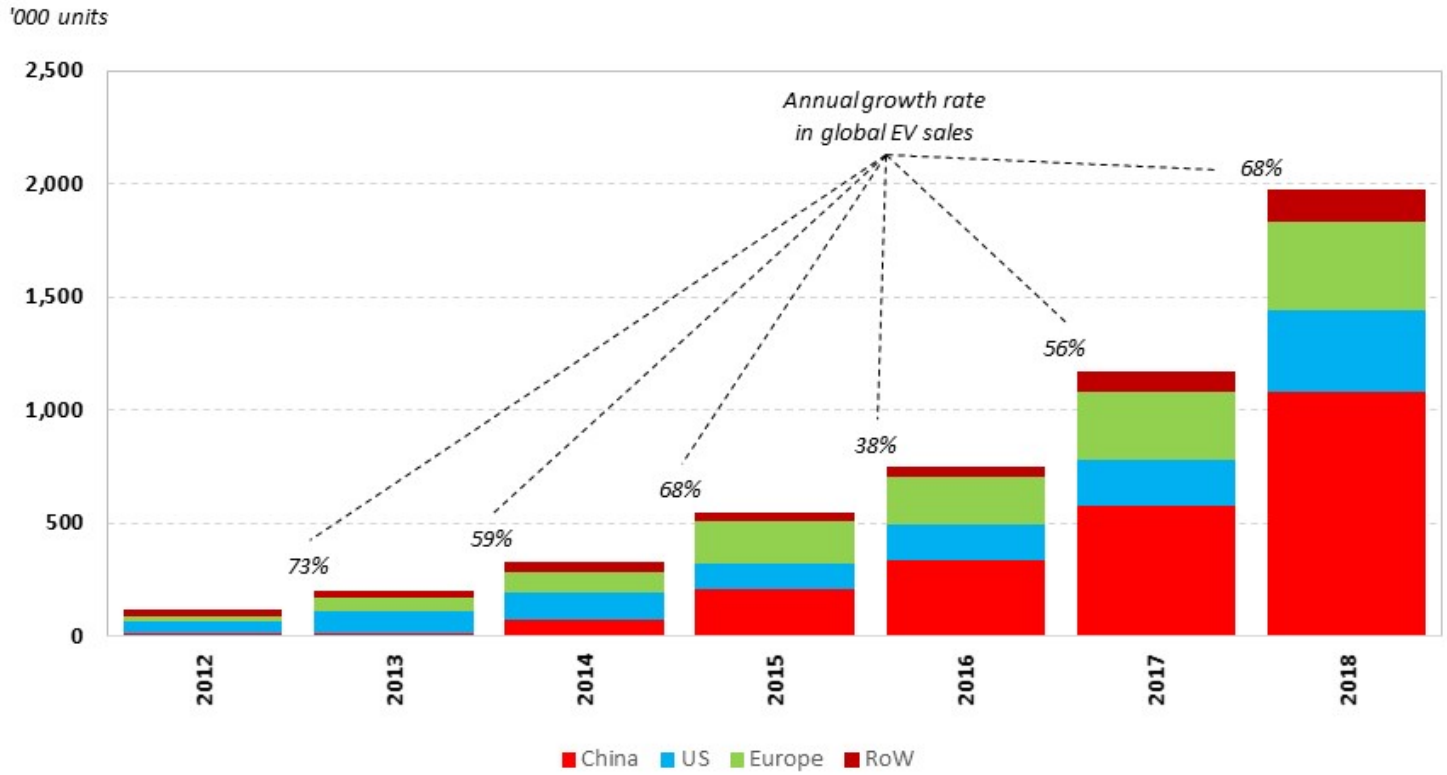




Data Source: BP, 2019

Electric Vehicles

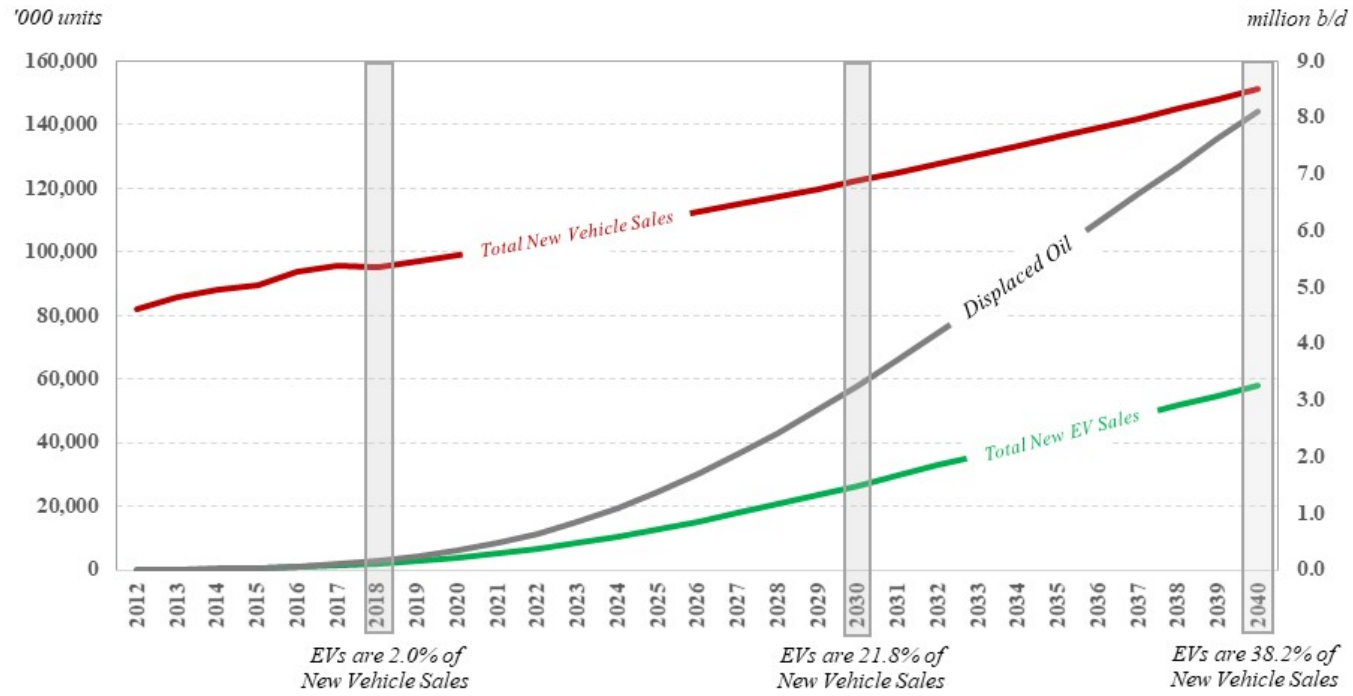
- EV sales have been growing dramatically and are the fastest growing segment of new car sales.
- The market for new EVs is largest in China, followed by Europe and the US.



Data Source: IEA Global EV Outlook, 2019

Electric Vehicles: Impact

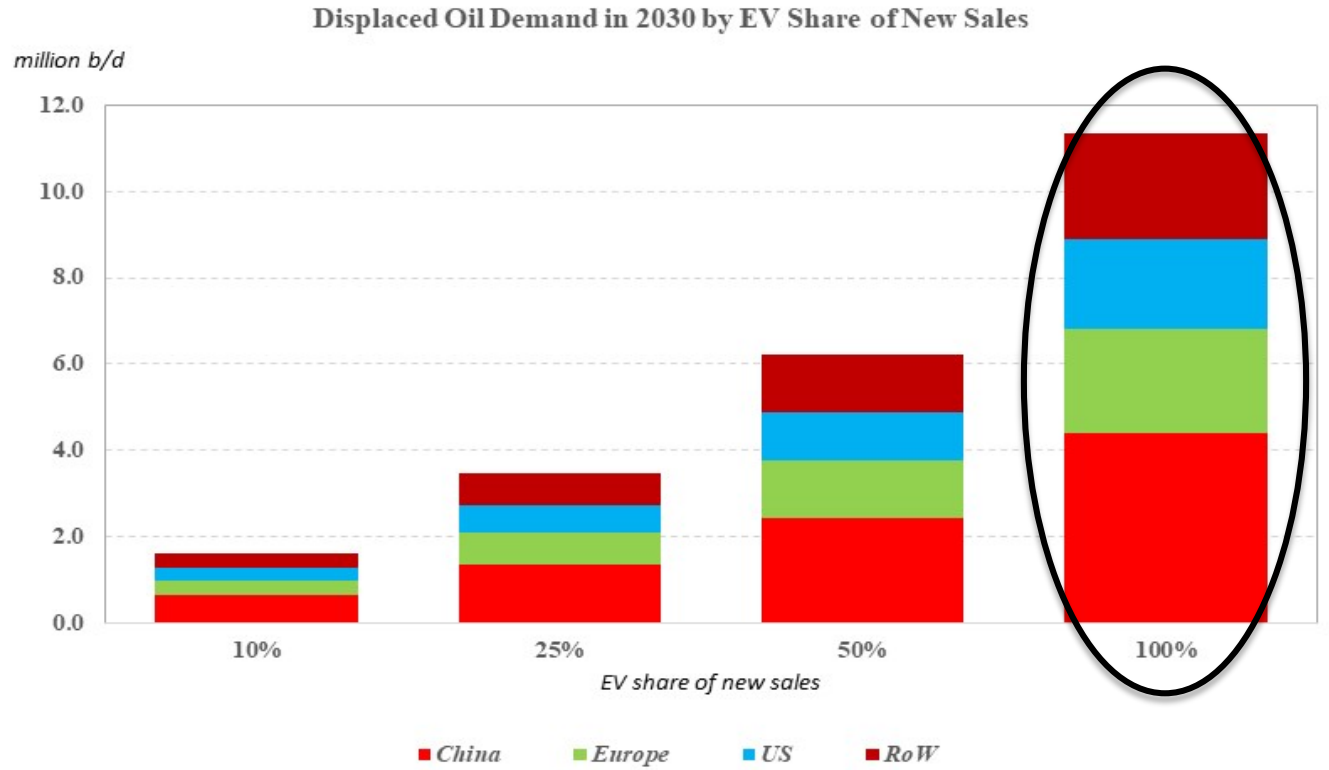
- "After 2020, EVs will start to destroy oil demand." This is a common statement. But, what impact will EVs have on global oil demand?
- The scale of the new vehicle market matters, as does the total vehicle stock.
- The case depicted assumes EV sales expand to 13x current levels by 2030 and 29x current levels by 2040. Through 2040, this reflects an annual growth rate of 16.6%.
- The growth rate of EVs will depend on
  - policy support.
  - battery costs and supply chain rigidities.
  - consumer preferences.
  - EV infrastructure deployment, such as charging and assembly.
  - adoption in emerging markets.



Note: The calculations assume 12,000 mpy and 25 mpg vehicle displacement and Gompertz-type adoption. This puts the calculations on the high side, particularly if early adopters are displacing more efficient vehicles.

Electric Vehicles: Impact (cont.)

- There is tremendous uncertainty in any forecast. With EVs, this is no different.
- What happens if supply chain rigidities emerge? What about fading government support, lack of infrastructure, consumer preference, demographic impacts, etc? All of these ultimately affect adoption rates and hence the oil displacement. But, note that even in the most aggressive case, oil demand remains robust through 2030.



The case shown previously yields 21.8% of new vehicle sales are EVs by 2030 resulting in oil displacement of 3.27 million b/d.

The incremental impact of a 100% EV share of ***new*** vehicle sales in 2030 is about 11.4 million b/d.

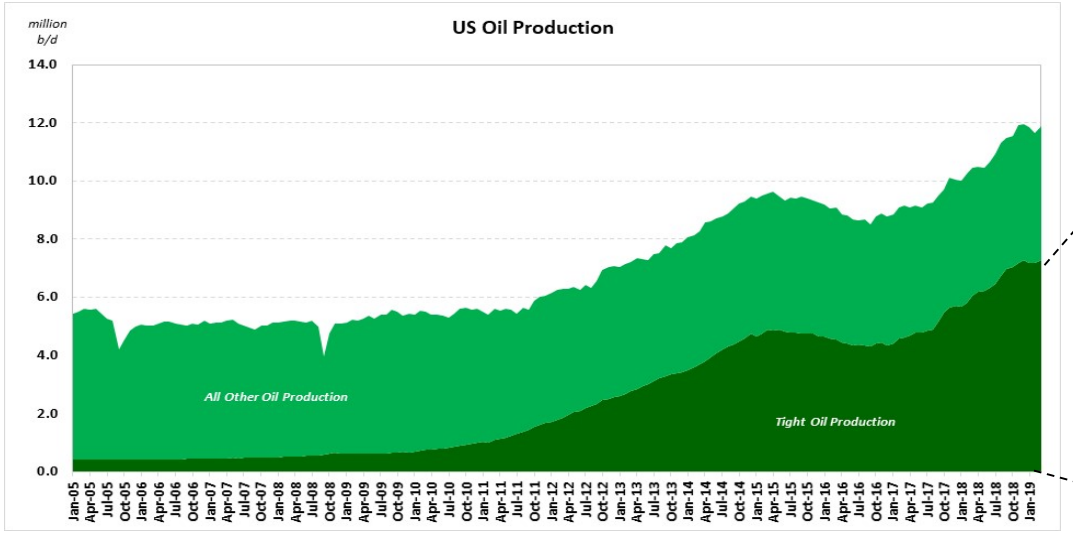
Thus, even the most aggressive scenario does not decimate global demand, and likely does not even result in a peak by 2030.

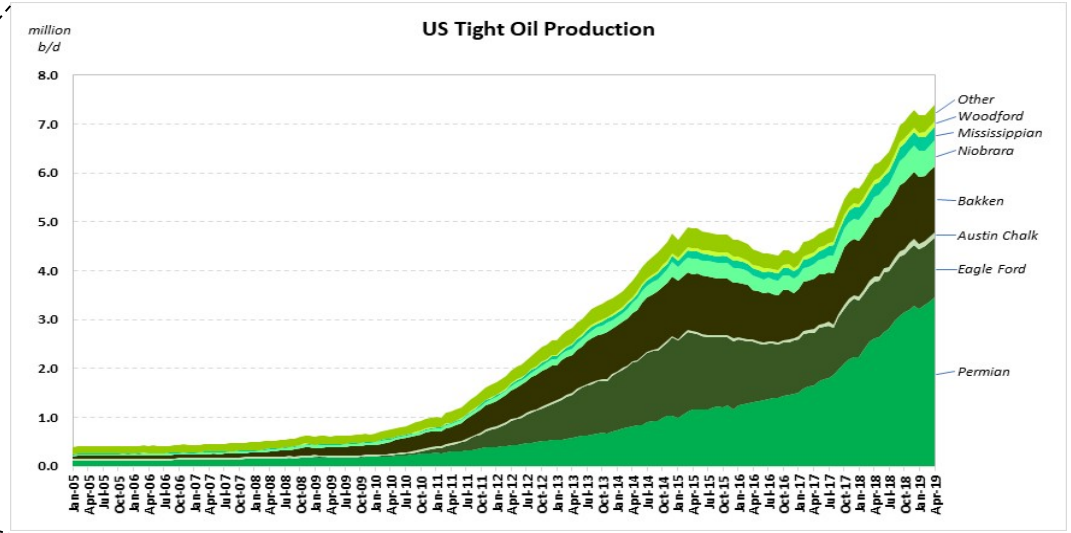
Two major drivers in global energy

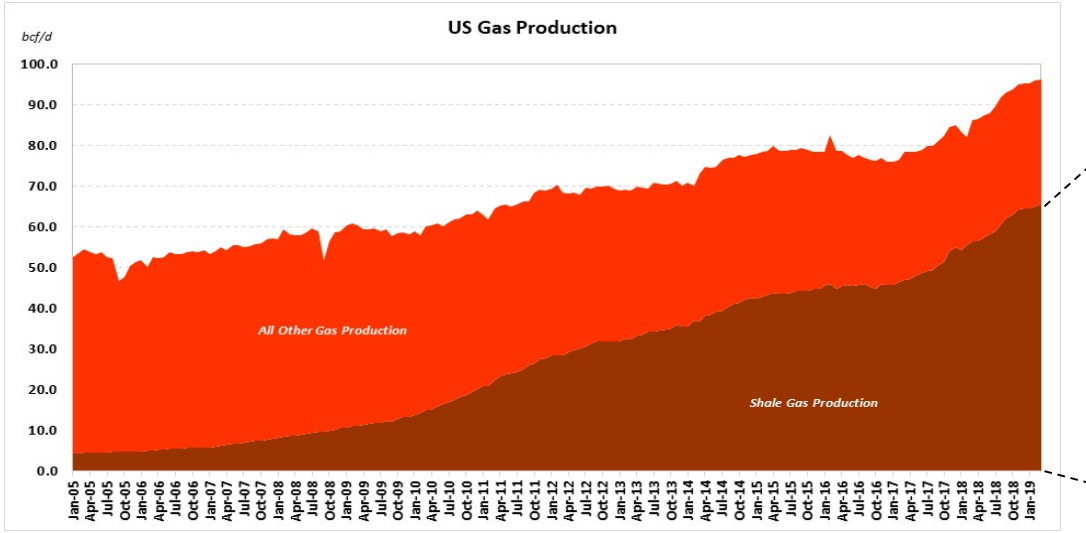
The two biggest sources of change in the global energy landscape (yet often unmentioned in the energy transitions context) over the last 15 years:

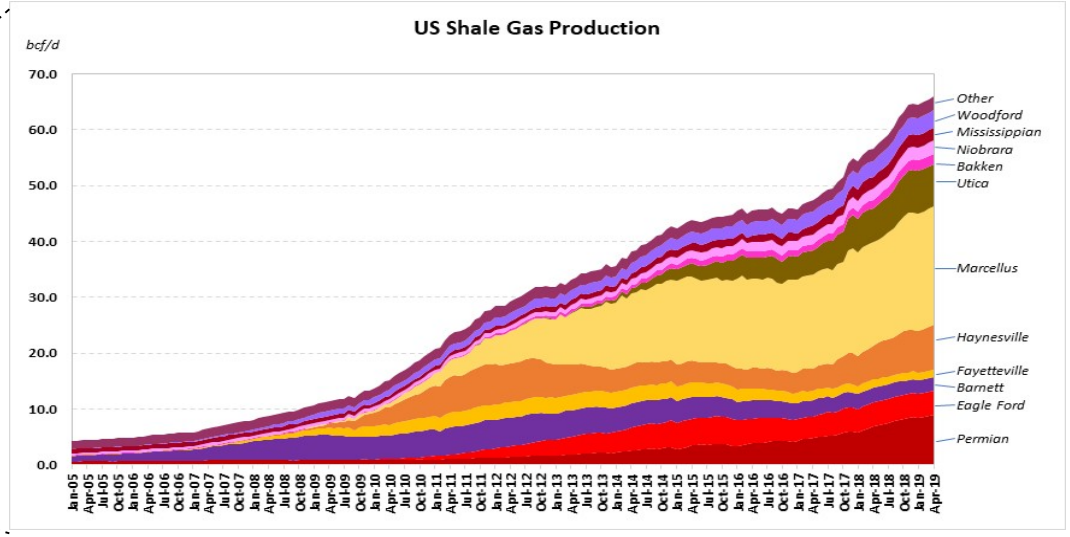
(1) US Shale and (2) Demand growth in Asia

Shale has driven an increase in US oil and gas production…





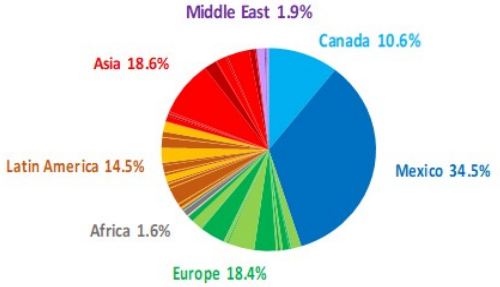




Source: Data from US EIA

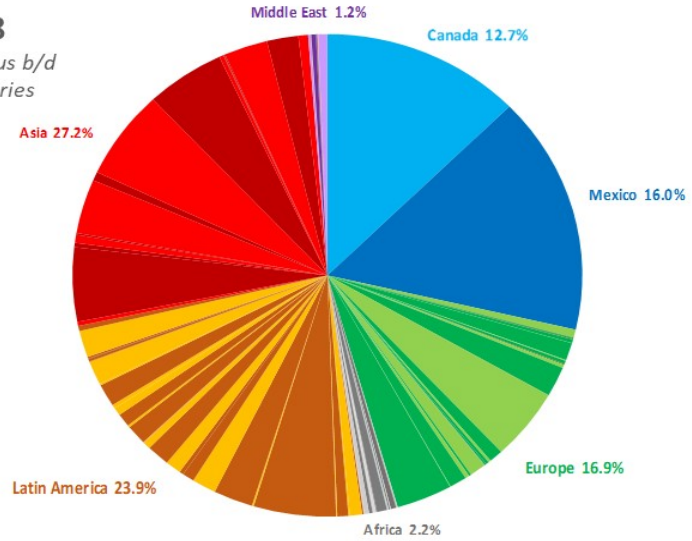
… pushing growth in US exports with expanding geographic reach.

2000
1,037.6 thous b/d
75 countries



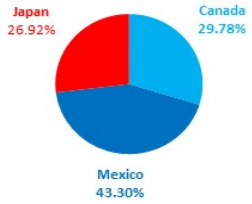
Crude Oil and Petroleum Products Exports

2018
7,583.7 thous b/d
109 countries



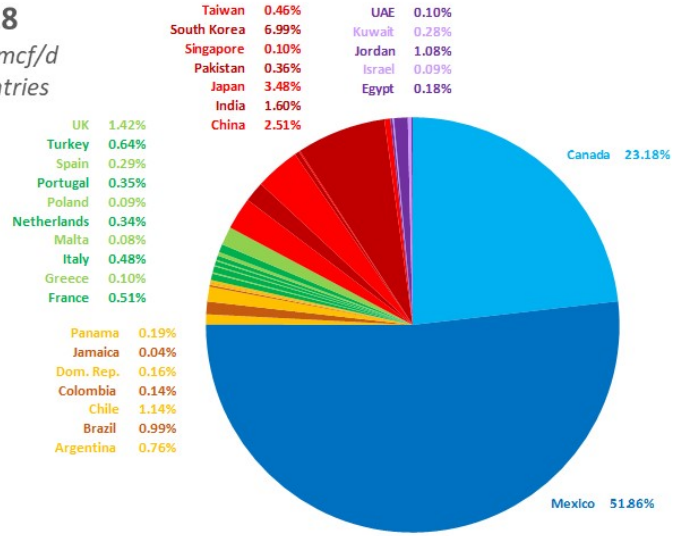
Note, in 2008, crude oil and petroleum product exports totaled 1,802.5 thous b/d to 87 different countries.

2000
667 mmcf/d
3 countries



Natural Gas Exports

2018
9,883 mmcf/d
33 countries

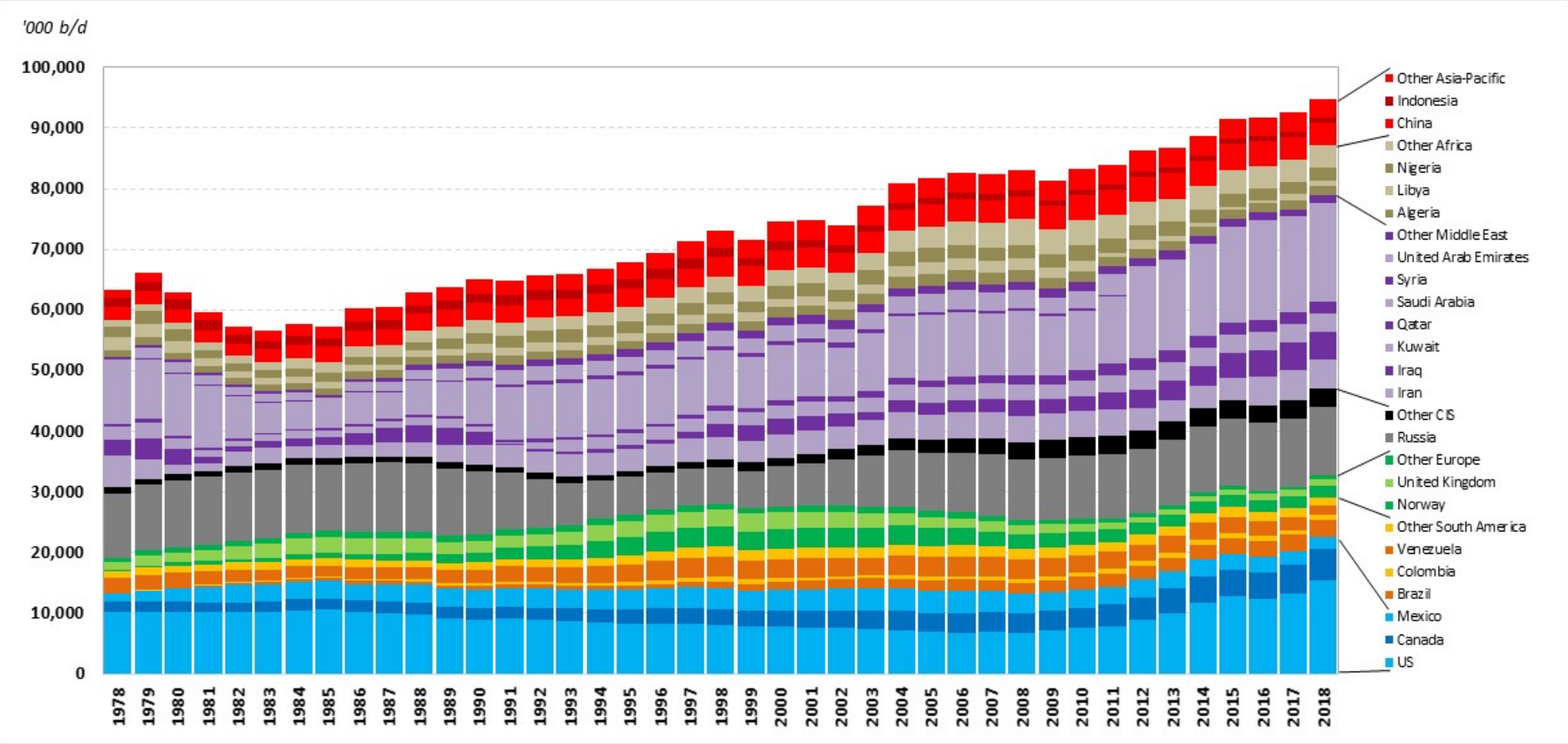


Note, in 2008, natural gas exports totaled 2.639 bcf/d to 3 different countries.

Source: Data from EIA

Global oil supply growth has been consistent since the mid-1980s, …

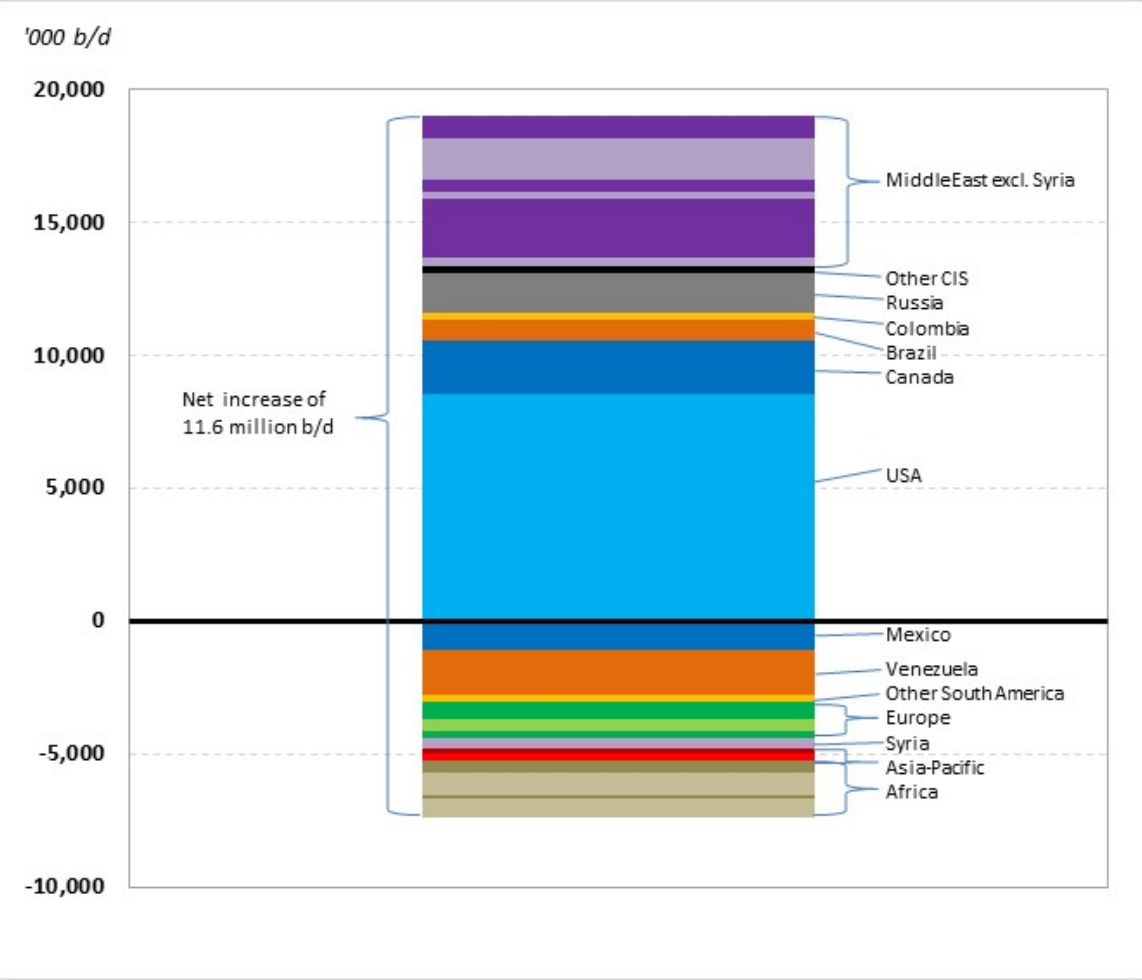
Global Oil Supply, 1978-2018



Data Source: BP, 2019

… but shale has balanced negative "above-ground" issues, having the largest impact since 2008, …

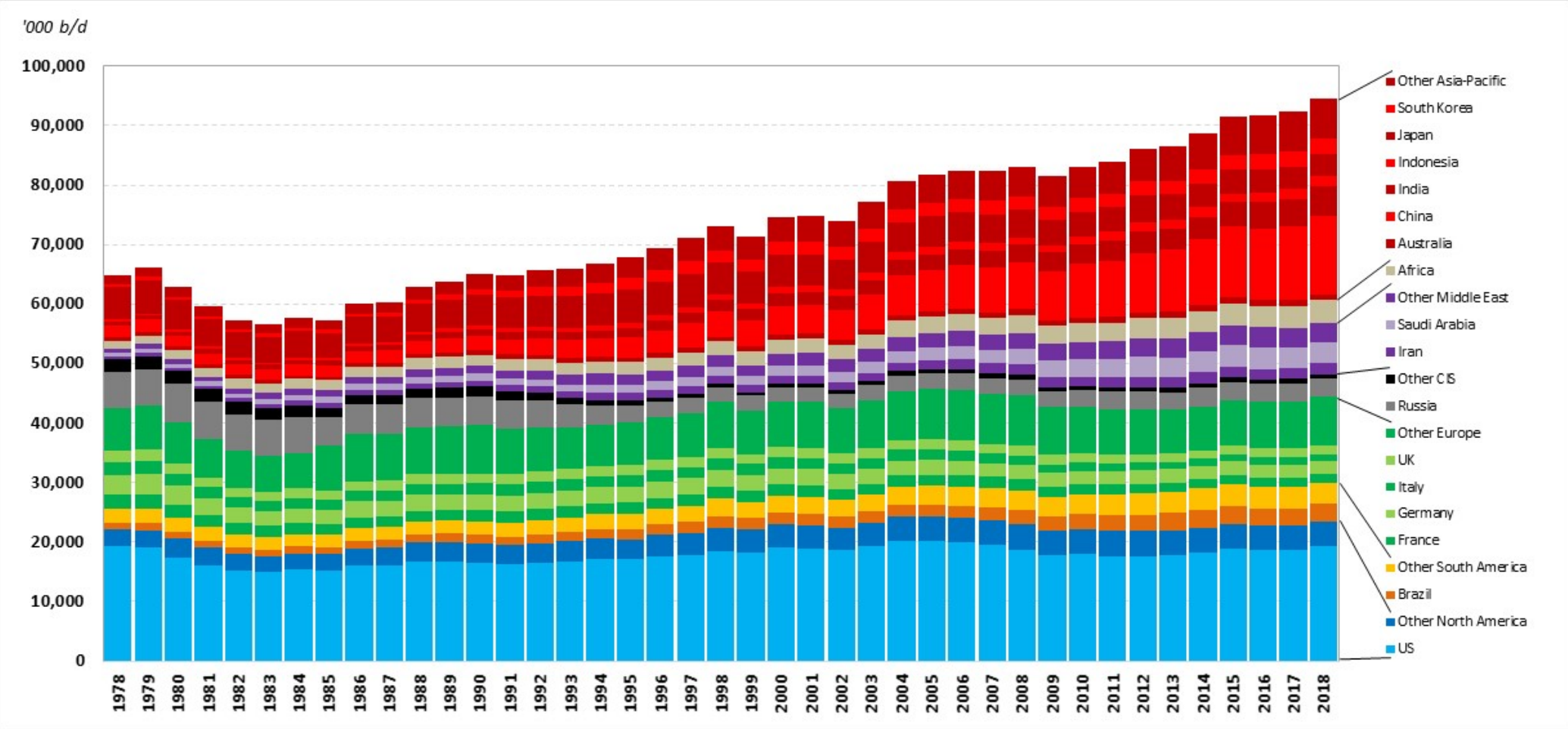
Change in Global Oil Supply, 2008-2018



Data Source: BP, 2019

… and is much needed to balance new demands…

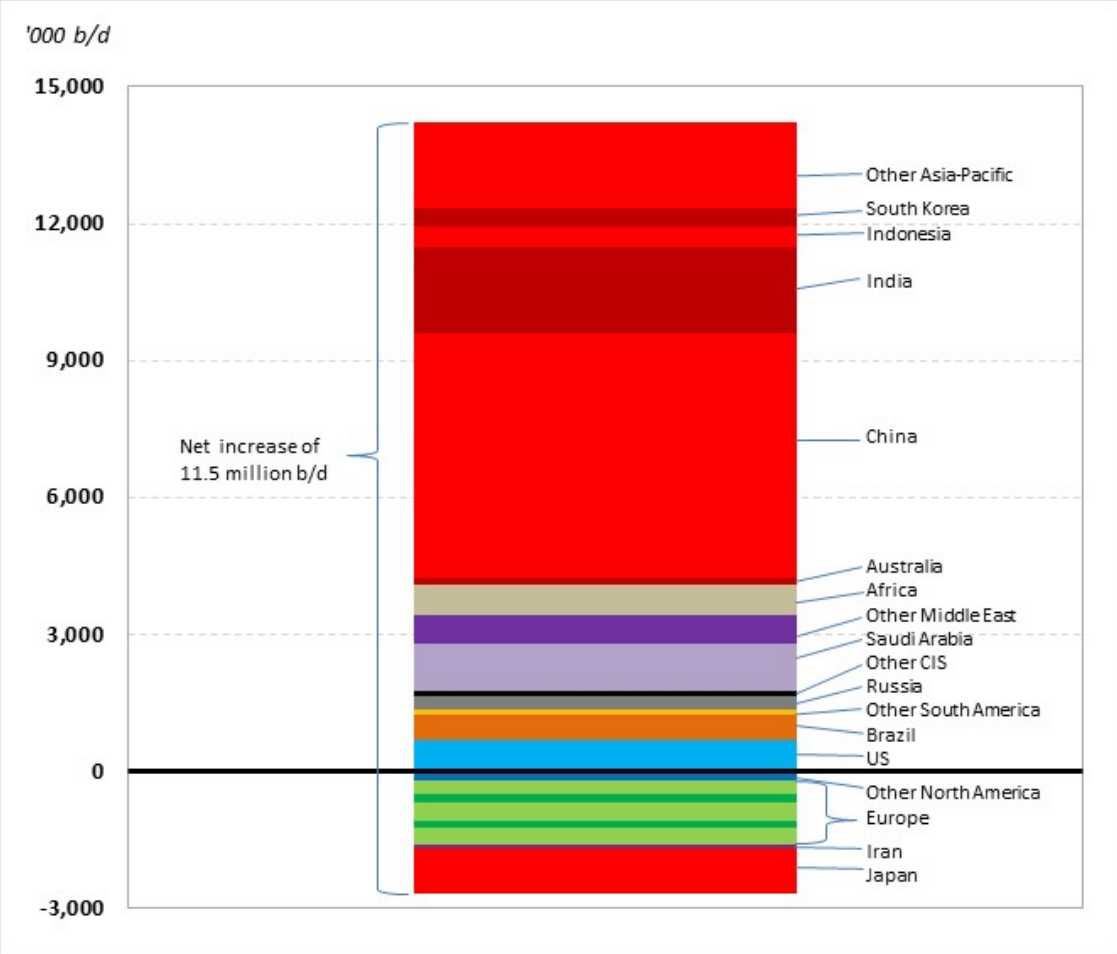
Global Oil Demand, 1978-2018



Data Source: BP, 2019

… especially from developing regions over the last decade.

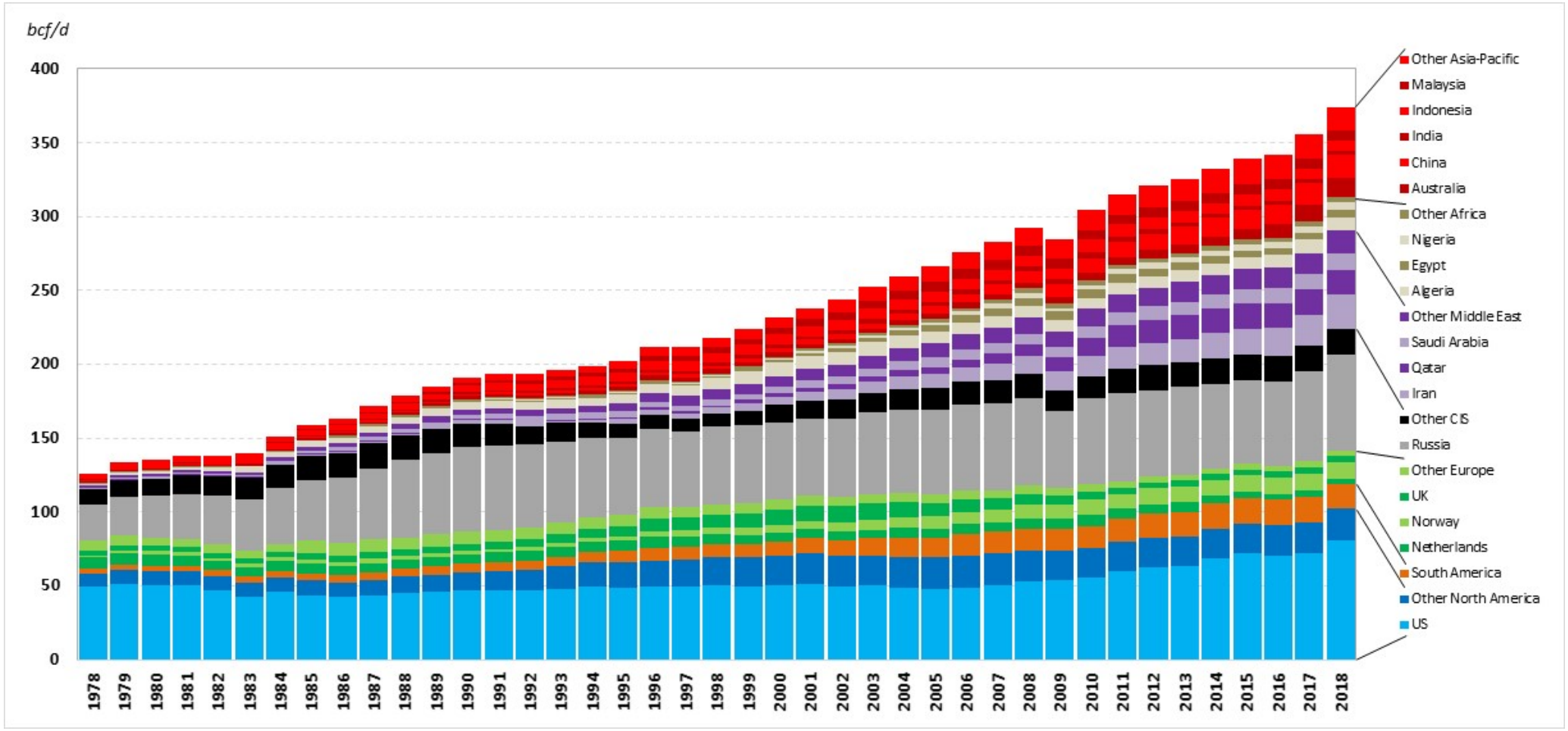
Change in Global Oil Demand, 2008-2018



Data Source: BP, 2019

Global gas supply growth has also been strong, and…

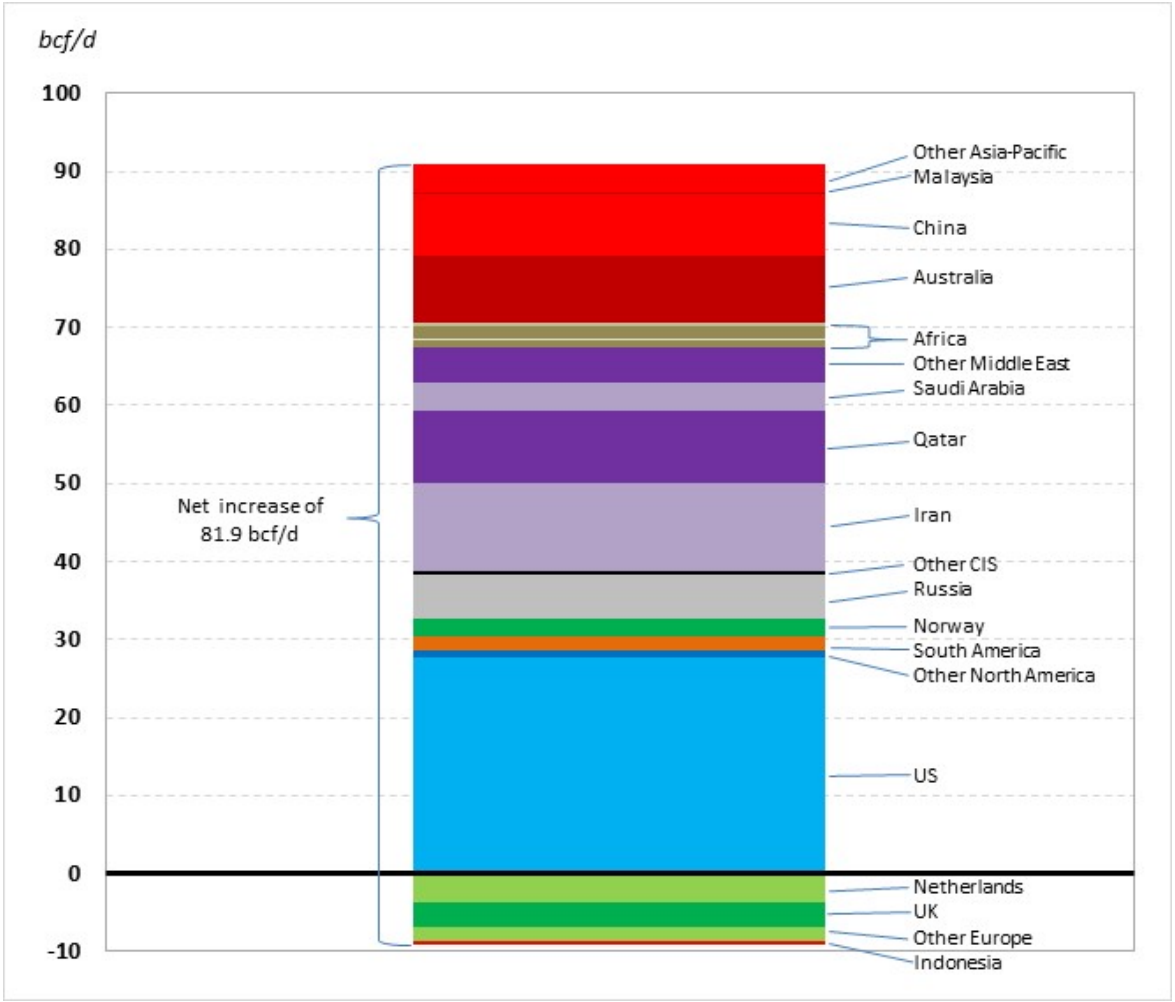
Global Gas Supply, 1978-2018



Data Source: BP, 2019

… similar to oil, shale has had the largest impact since 2008,…

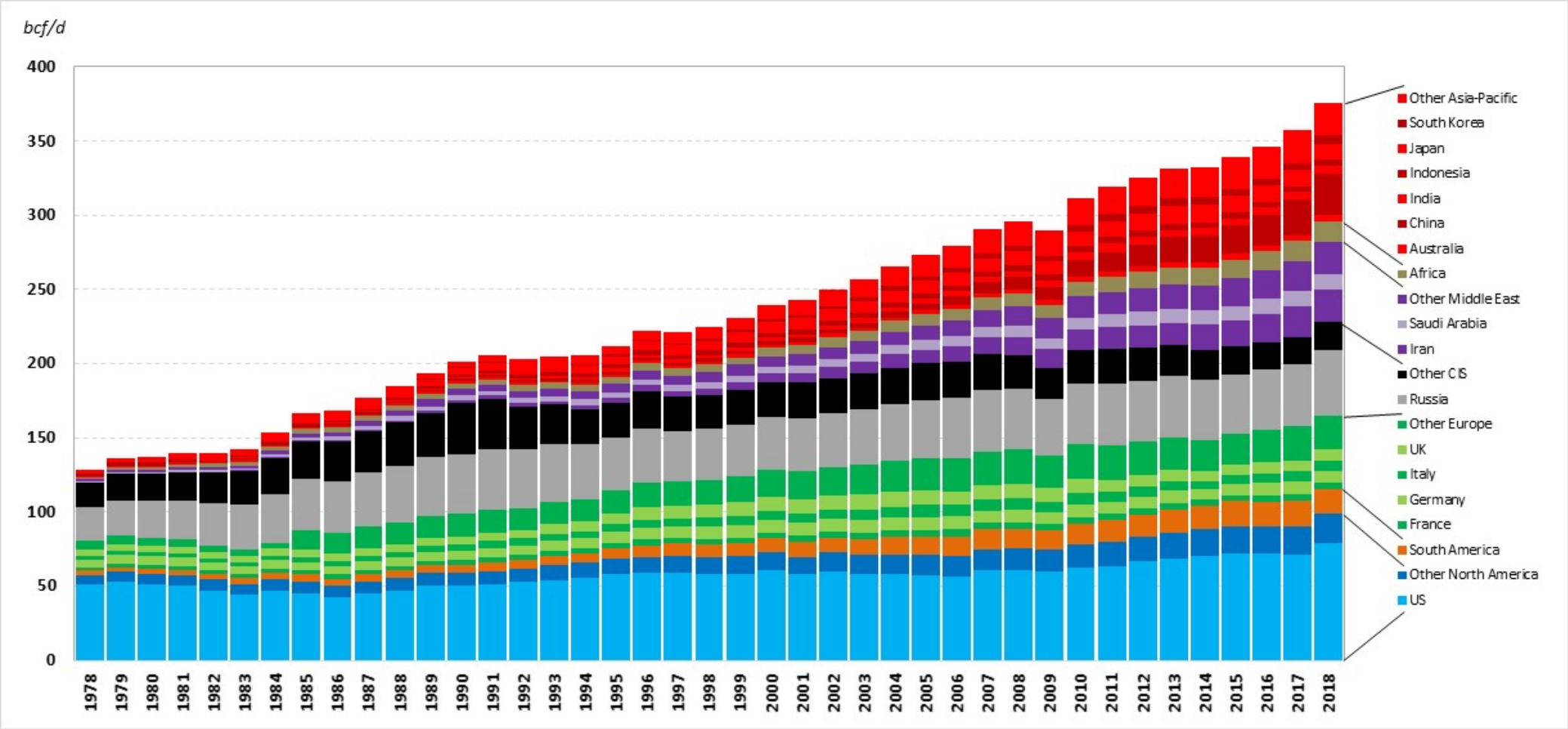
Change in Global Gas Supply, 2008-2018



Data Source: BP, 2019

… and it is much needed to balance new demands…

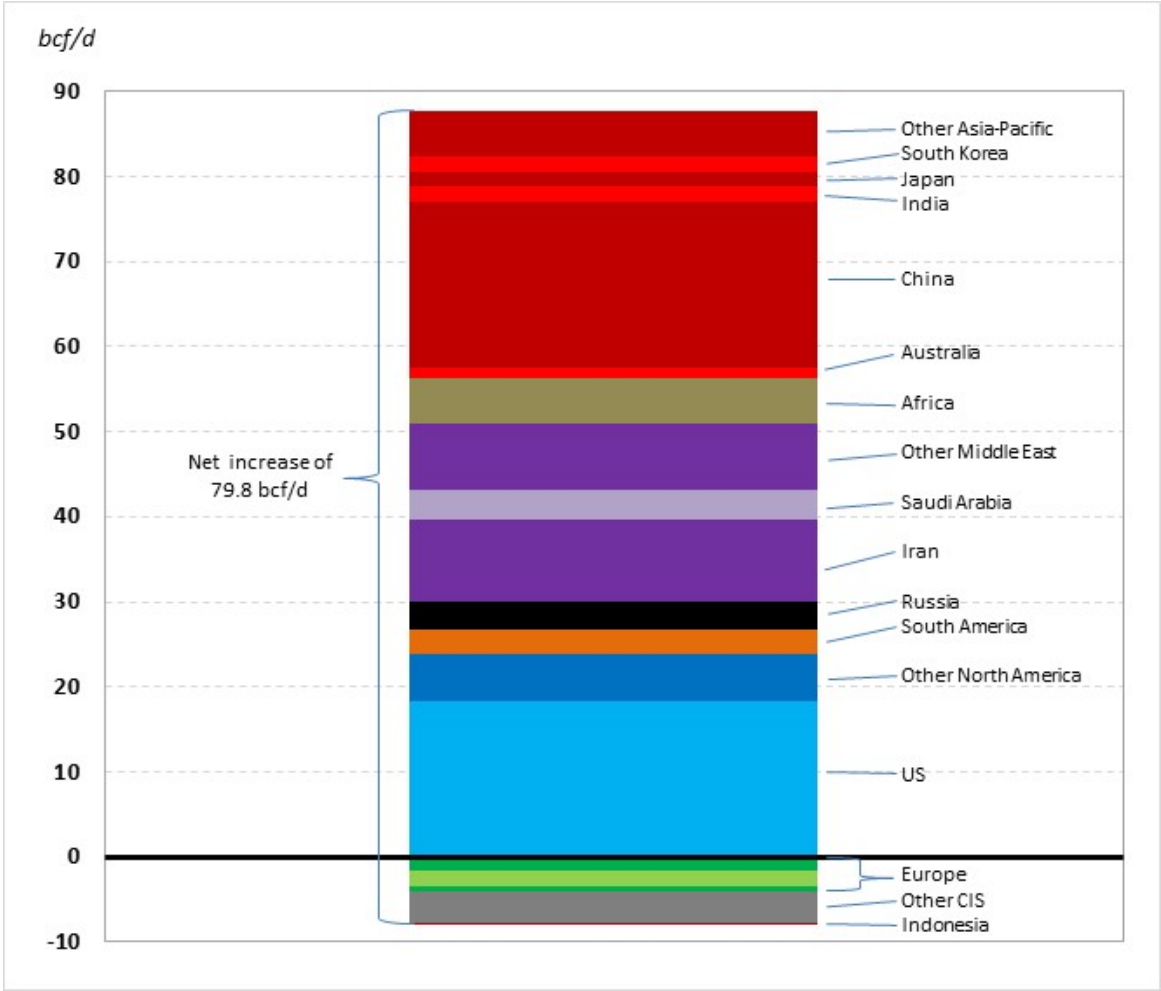
Global Gas Demand, 1978-2018



Data Source: BP, 2019

… almost everywhere (except Europe) over the last decade.

Change in Global Gas Demand, 2008-2018

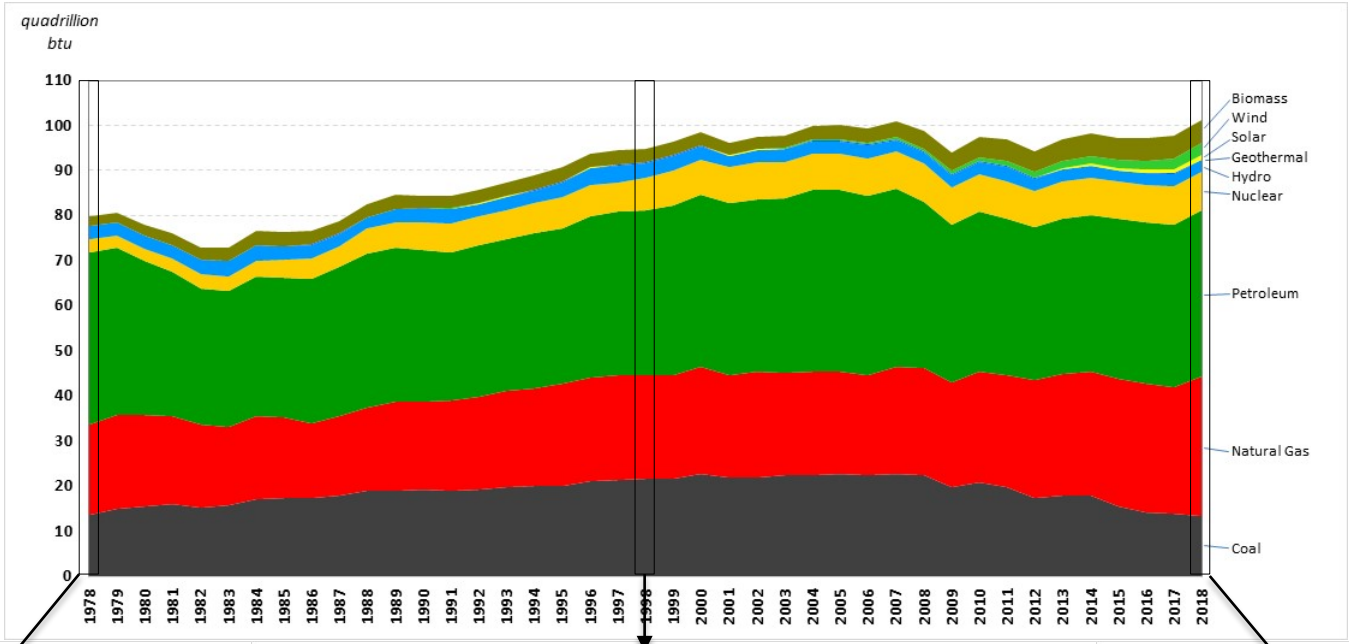


Data Source: BP, 2019

The US Energy Landscape as a Microcosm of the Pace of Transitions

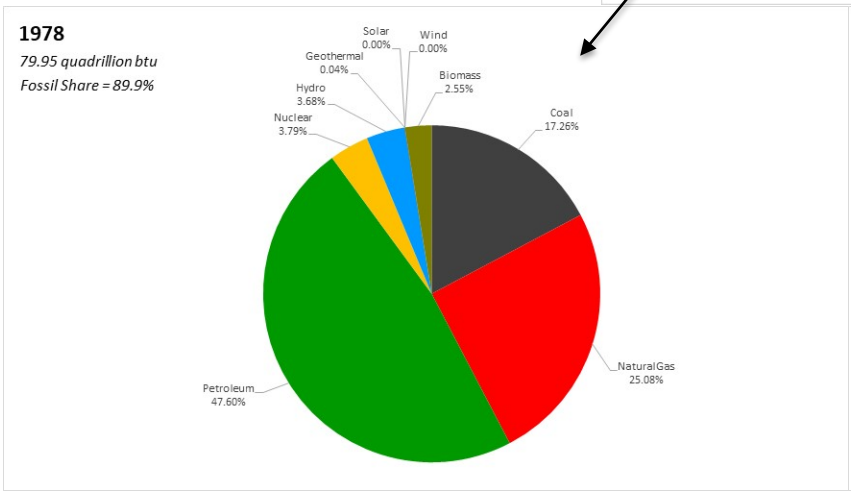
US energy mix: Change comes slowly, even with policy support

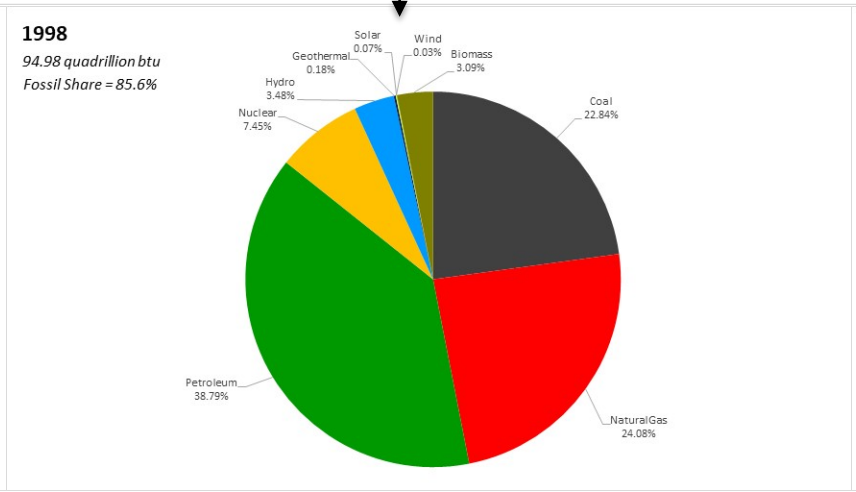
Oil and natural gas remain staples of the US energy mix, accounting for 67.1% of total primary energy use in 2018, up from 62.8% in 1998, which was down from 72.5% in 1978.

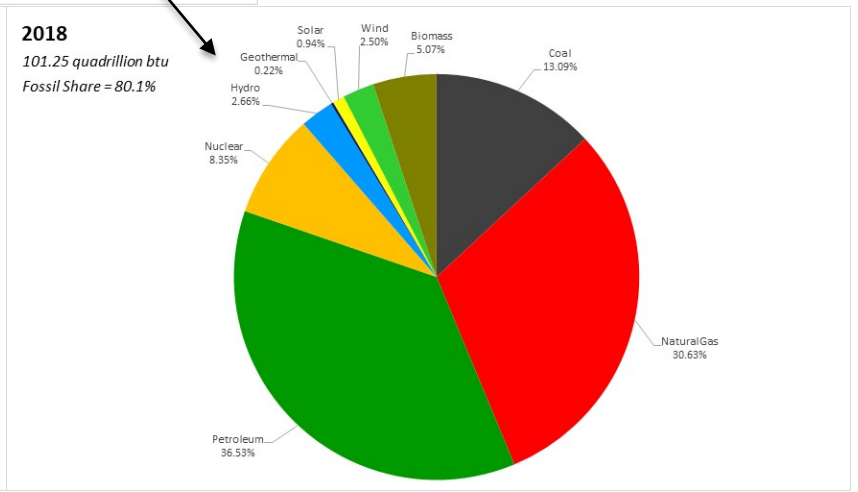


The recent decline of coal and the growth of renewables and natural gas is a story of the US power sector.

Data Source: US Energy Information Administration

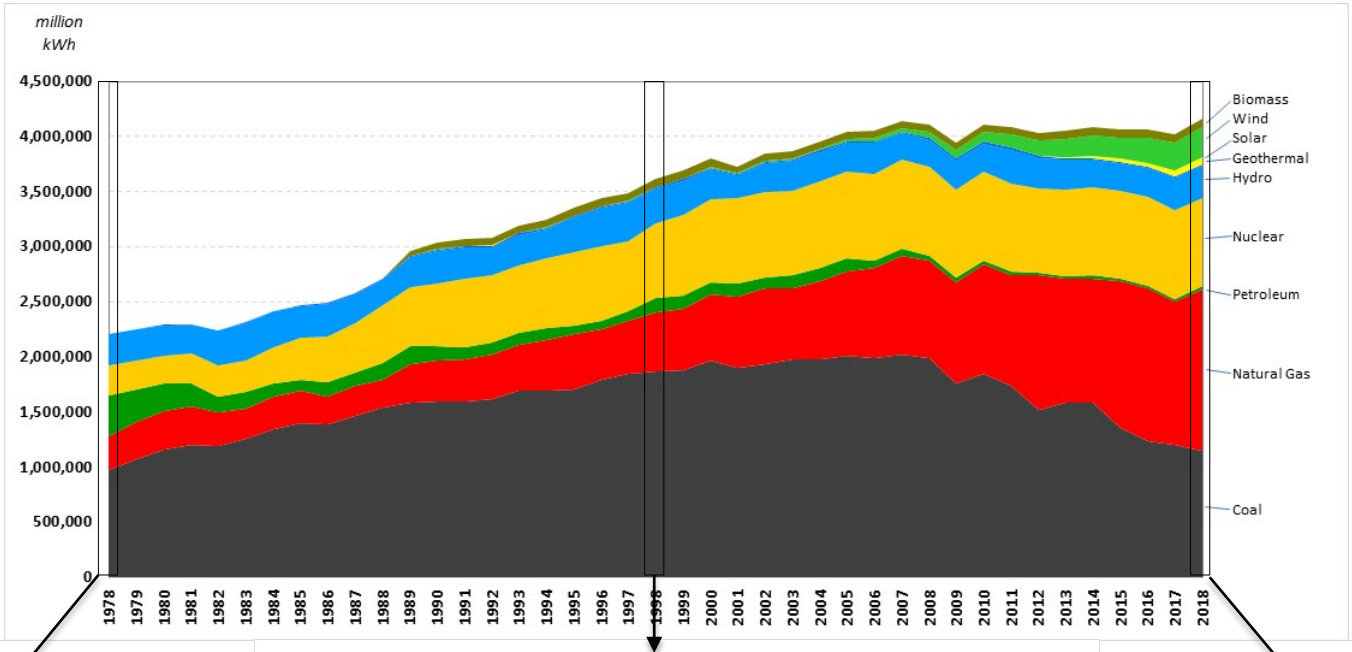






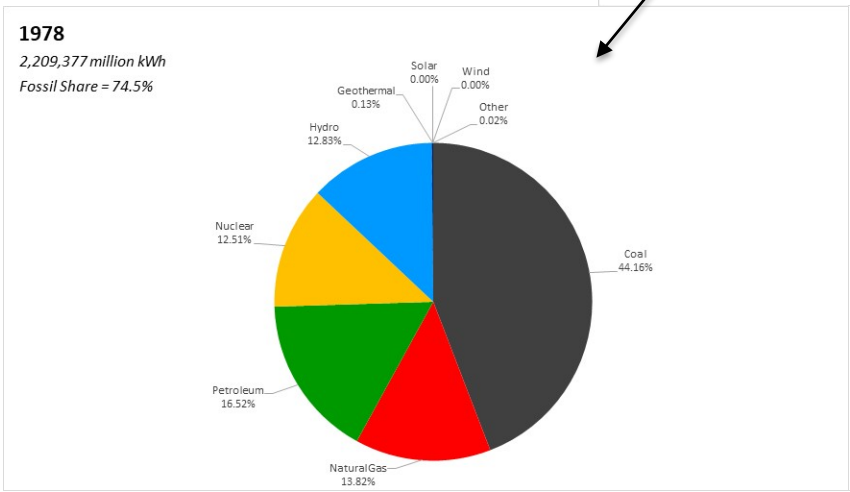
US power generation: The roles of legacy, scale and technology

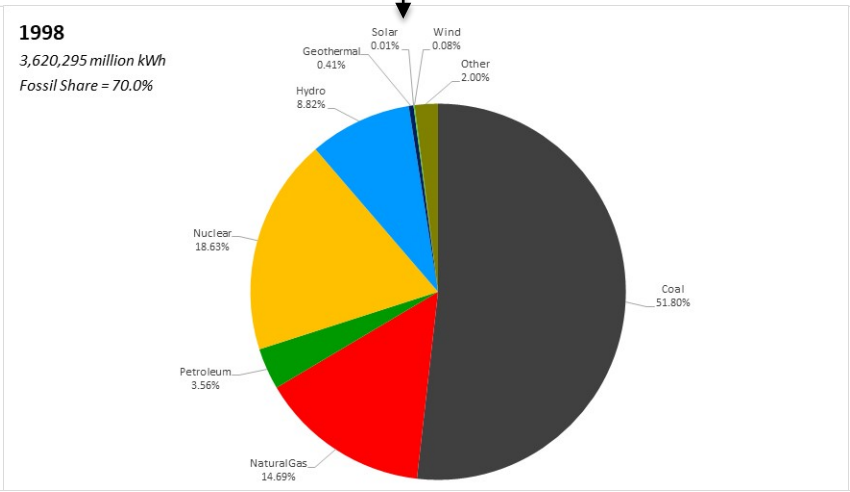
Coal's precipitous decline: A function of fleet age, and the scale at which new technology – renewables and the extraction and combustion of natural gas – is altering the competitive landscape.

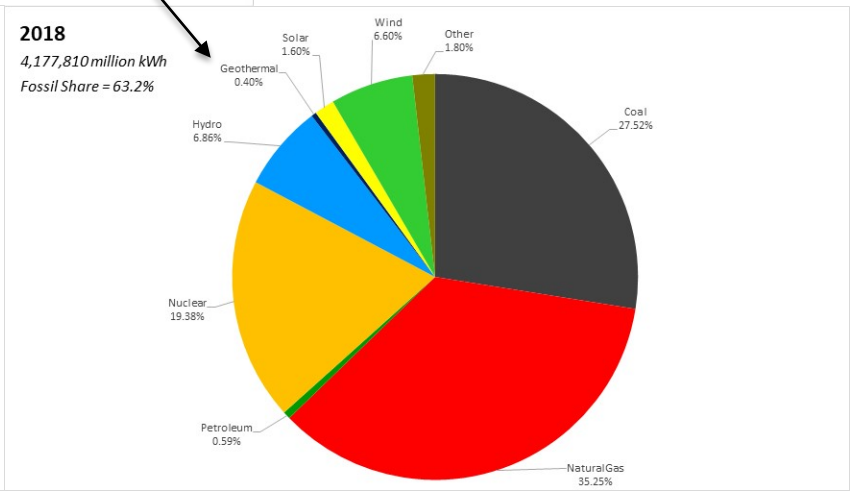


Renewables growth began in earnest after 2000 and has been dominated by wind. Solar is beginning the trek that wind has been on. Future growth will demand storage technology and/or greater transmission integration.

Data Source: US Energy Information Administration







Food for thought…

Does history repeat itself?

- The early 1980s was a period of robust interest in renewable energy and distributed generation. Why?
  - High oil prices and energy security.
  - Natural gas supply concerns.
- What happened?
  - Fuel costs fell and efficiency increased.
  - Fixed costs of adoption matter.
  - Coal expanded.
- How is the present different?
  - Renewables costs are lower, and coal is encumbered. Each is affected by policy.
    - Caution: LCOE is misleading!
  - Energy *and* environmental security.
  - Natural gas supply is robust.
- Are recent developments lasting?
  - Yes. Drivers today are different!

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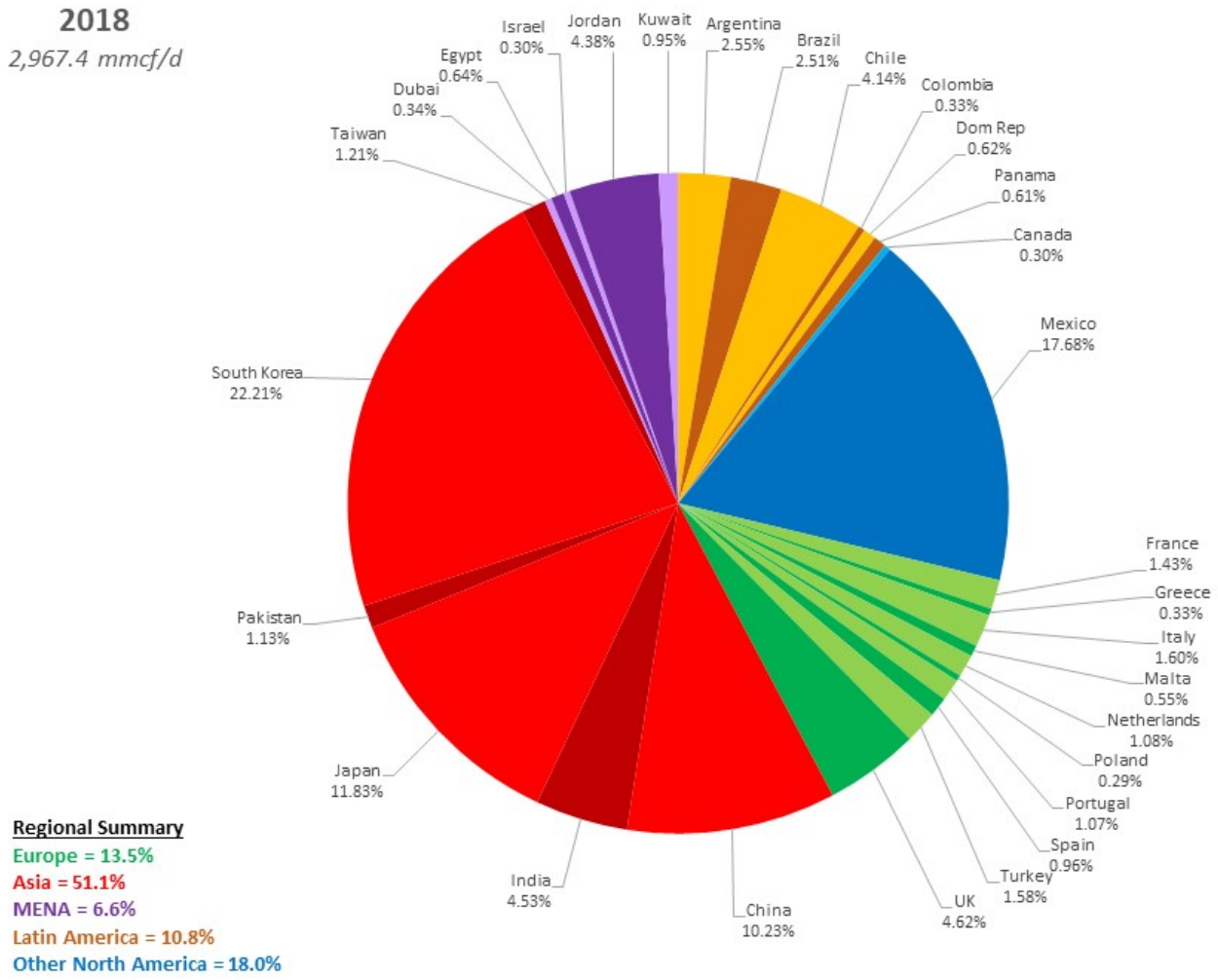
LNG Market Developments

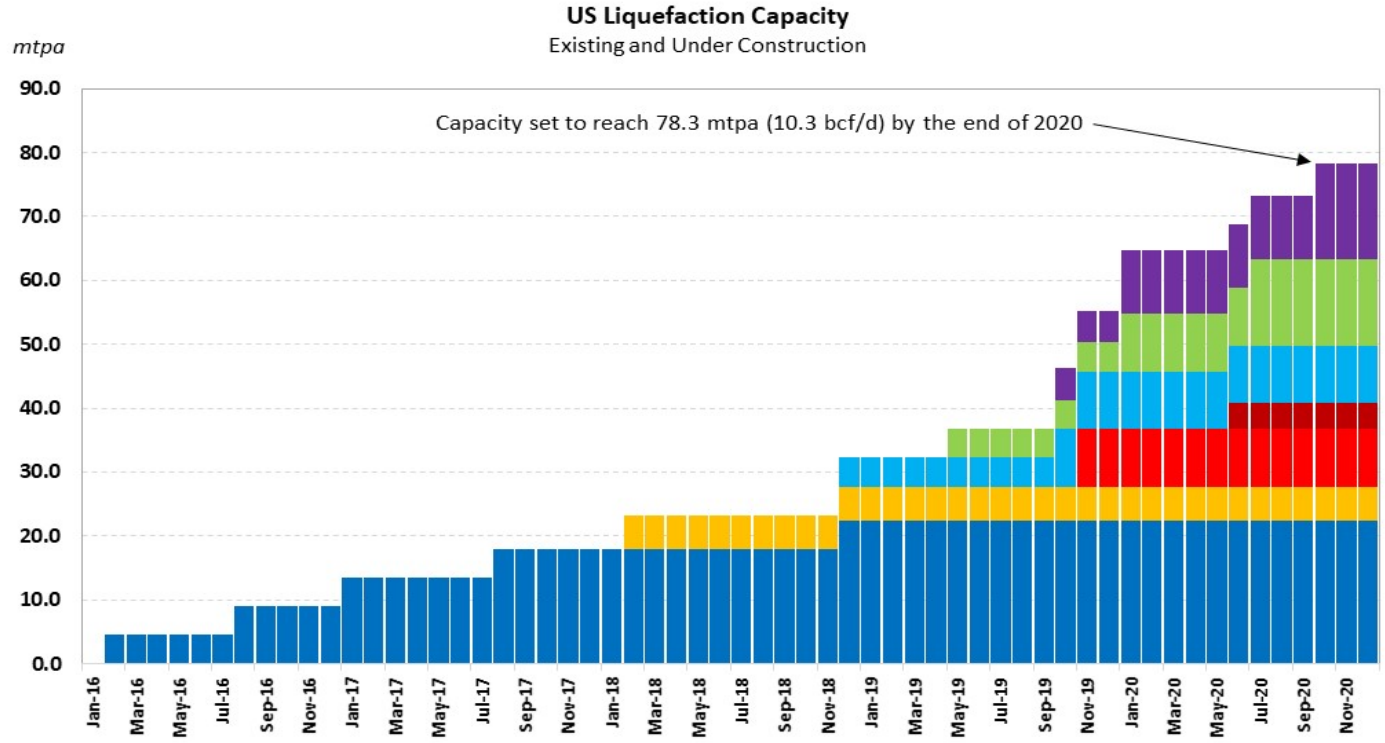
US LNG is at the center of a larger "transition" in gas markets…



Source: Data from CEDIGAZ and US DOE

… and they are poised to grow even more…

- There is 4.8 bcf/d of LNG export capacity between Sabine Pass, Cove Point, Corpus Christi and Cameron.
- There is another 5.5 bcf/d of capacity under construction that is scheduled to open by year-end 2020, setting the stage for a potential surge of exports, the vast majority of which will come from the US Gulf Coast.
- Given other facilities both under construction and approved, this could climb to over 20 bcf/d by 2025.



Source: Data from US FERC and US EIA; Start dates for new capacity are speculative.

- Of course, capacity does not guarantee volume. However, the reality being forged in the Permian Basin has huge implications. Oil-directed activity is bringing large associated gas volumes and could open new opportunities. Take-away infrastructure is paramount.

… with long term market altering implications.

- Physical connectedness with the global market will have implications for market liquidity, pricing and investment paradigms.
- Long-term contracts will remain important because they are "bankable", especially when debt-financing is considered.
- However, take-or-pay clauses will be eroded by the "real option" value associated with capacity rights that are tradable.
- Hence, the chicken-and-egg paradigm…
  - Real option value is greater initially, but as parties begin to capture this value it erodes because trading frequency increases.
  - However, an increase in trading frequency drives greater price discovery, which establishes more market transparency and liquidity.
  - This, in turn, alters the risk associated with market entry, or new investment, because a liquid market mitigates uptake and offtake risk.
  - Liquidity also provides elements of energy security to both producers and consumers because market access is not easily compromised.

Source: Ongoing Baker Institute CES research