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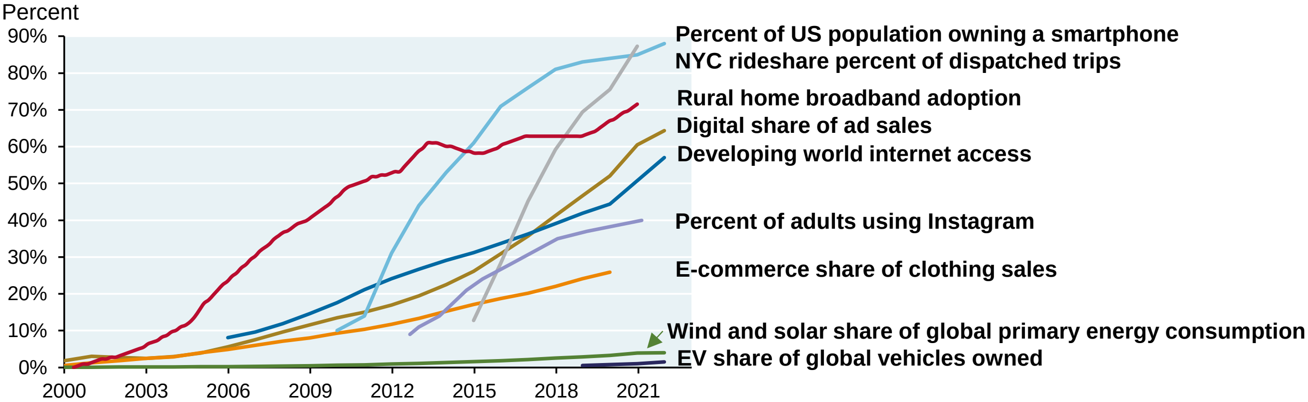
2022 Eye on the Market Energy Paper

The events in Europe underscore the three unifying principles of our annual energy paper since its inception 12 years ago:

- energy transitions differ sharply from transitions in technology, healthcare and other sectors
- decarbonization of electricity is underway but decarbonization of industrial production, transport and heating lag much further behind
- countries that reduce production of fossil fuels under the assumption that renewables can quickly replace them face substantial economic and geopolitical risks

The bottom chart shows performance of fossil fuel companies and their reportedly stranded assets vs renewable energy companies. To quote Mark Twain: “Reports of my death are greatly exaggerated”. We review many of the reasons why in this year’s paper. My recommendation as you think about energy issues: ignore all the hype, hyperbole and hockey stick forecasts and focus on the actual trends in the energy transition.

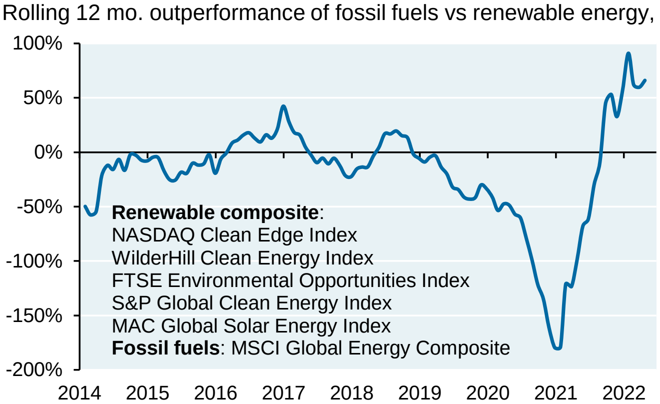
Speed of disruption: some of these things are not like the others



Source: GroupM, Census, BP, IEA, FHV, Pew Research, NYC Taxi & Limousine Commission, JPMAM. 2021.

Reports of my death are greatly exaggerated

Rolling 12 mo. outperformance of fossil fuels vs renewable energy, %



Source: Bloomberg, MSCI, JPMAM. April 29, 2022.

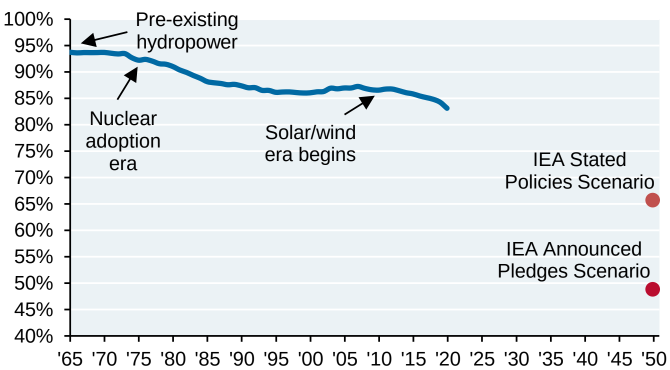
Executive Summary

The fossil fuel share of global primary energy[1] is declining at a slightly more rapid pace now, mostly a result of large investments in wind and solar power used for electricity generation. The market price to procure wind and solar power plummeted over the last decade, a consequence of scale and productivity gains[2]. Even so, fossil fuel reliance across the developed and developing world is still high (70% even in Europe) and the International Energy Agency projects that the world may still be 66% reliant on fossil fuels in 2050. What gives?

First, "levelized costs" comparing wind and solar power to fossil fuels are misleading barometers of the pace of change. Levelized cost estimates rarely include actual costs that high renewable grid penetration requires: (a) investment in transmission to create larger renewable coverage areas, (b) backup thermal power required for times when renewable generation is low, and (c) capital costs and maintenance of utility-scale battery storage. I am amazed at how much time is spent on this frankly questionable levelized cost statistic.

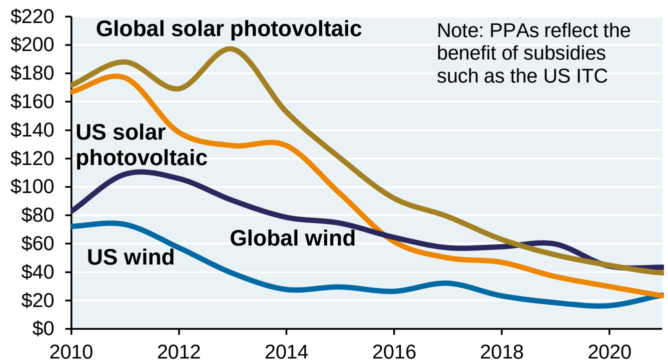
Second, the benefits of grid decarbonization are limited by low electrification of industrial energy use, heating and transportation. While electricity is used for some space/water heating, industrial motors and process heat, electricity is mostly used for space cooling, refrigeration, ventilation, computers and other electronic devices.

The world uses fossil fuels for ~83% of its energy
% of global primary energy consumption from coal, oil and nat gas



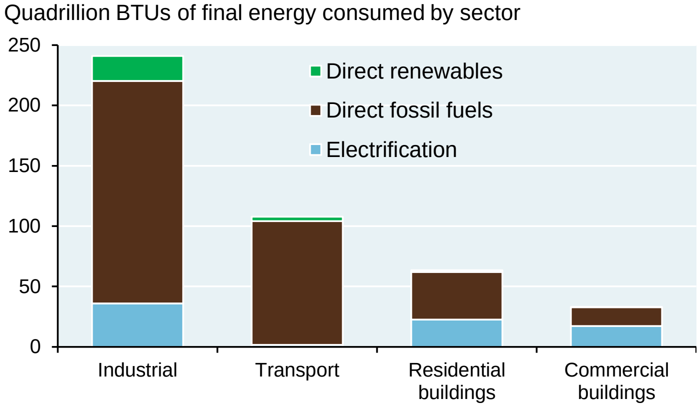
Source: BP Statistical Review of World Energy, IEA, JPMAM. 2021.

Average power purchase agreement by year of operation
Real 2020 $ per megawatt hour



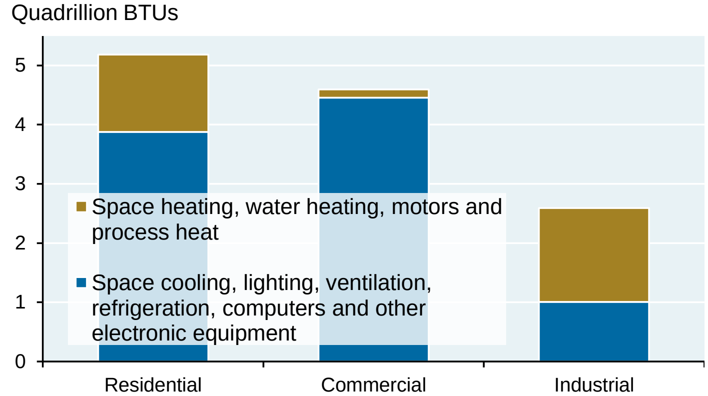
Source: Lawrence Berkeley National Laboratory, IRENA. 2021.

Low levels of electrification in global industry and transport
Quadrillion BTUs of final energy consumed by sector



Source: Energy Information Administration, JPMAM. 2021.

US electricity uses
Quadrillion BTUs



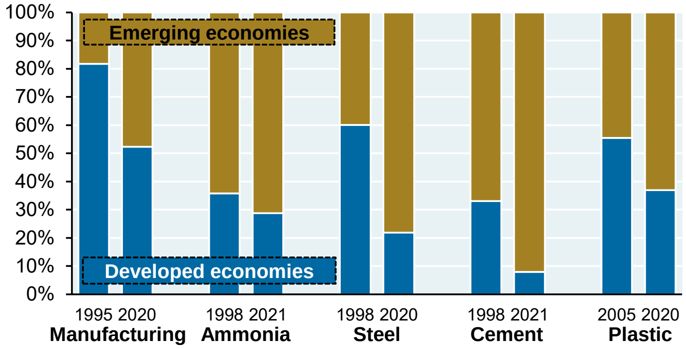
Source: EIA, JPMAM. 2021. Transport too small to plot at 0.04 quads

[1] **Primary energy** refers to thermal energy contained in fossil and biomass fuels, and to thermal equivalents of primary electricity generated from nuclear, wind and solar power. Converting primary electricity to primary energy is generally done by dividing the former by an assumed annual heat rate of fossil fuel plants (40% efficiency, equal to 9 MJ/kWh). **Final energy consumption** is primary energy less (a) energy lost in oil refining and natural gas processing, (b) energy lost in conversion of fossil fuels to electricity, (c) power plant consumption of electricity and (d) grid transmission losses.

[2] In the US and Europe, **wind and solar power purchase agreement levels are rising** due to higher interest rates and inflation in industrial metals and other inputs. There are more PPA increases in the pipeline: wind turbine manufacturers just raised prices to the highest levels since 2015, and some are still unprofitable (GE, Siemens).

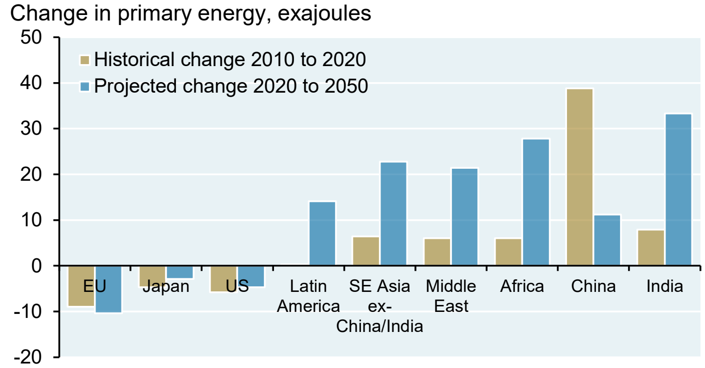
The third critical issue: the energy divide between the developed and developing world. Over the last 25 years, the developed world shifted much of its carbon-intensive manufacturing of steel, cement, ammonia and plastics to the developing world. While the developed world is projected to continue reducing its energy consumption, developing world energy consumption is projected to keep rising (second chart). And as a reminder, coal is still widely relied upon in many developing countries, and also Japan (fourth chart).

A shift in energy intensive manufacturing to the emerging world, % of global production



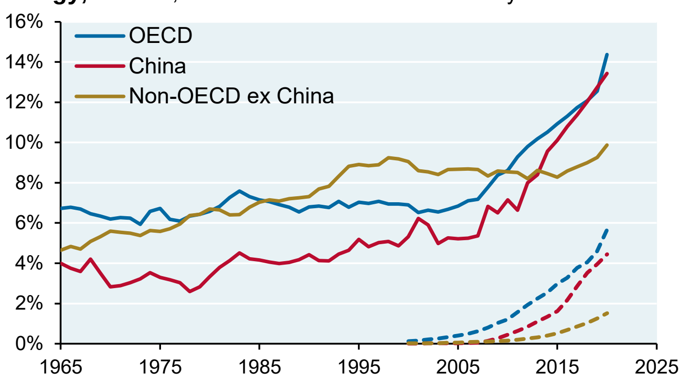
Source: UN Dept. of Social and Economic Affairs, Worldsteel, Plastics*Europe*, USGS. 2021.

China is the only EM country projected to slow primary energy consumption growth over the next three decades
Change in primary energy, exajoules



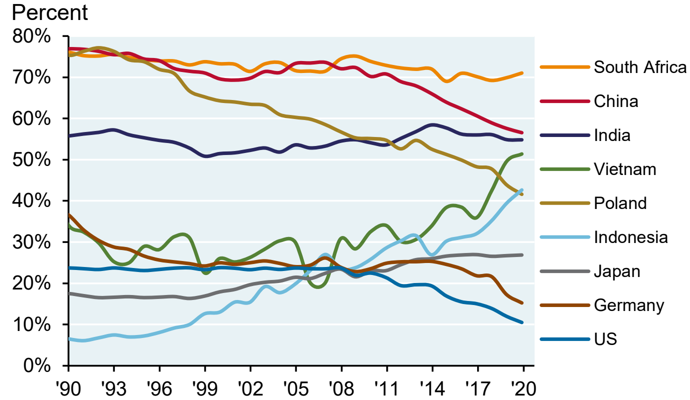
Source: International Energy Agency Stated Policies Scenario. 2021.

Wind, solar, hydro and other renewables share of primary energy, Percent, with dotted line for wind/solar only



Source: BP Statistical Review of World Energy, JPMAM. 2021.

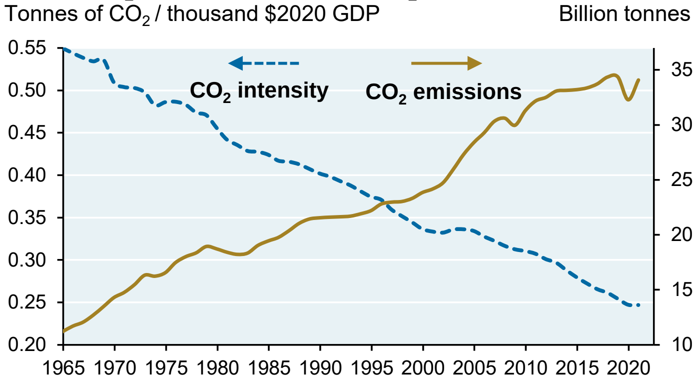
Coal share of primary energy consumption
Percent



Source: BP Statistical Review of World Energy, JPMAM. 2021.

The world gets more energy *efficient* every year, but emissions *levels* keep rising. That's why most deep decarbonization ideas rely on replacement of fossil fuels rather than on reducing fossil fuel consumption per capita or per unit of performance.

Global CO_2 intensity declining, CO_2 emissions rising
Tonnes of CO_2 / thousand $2020 GDP — Billion tonnes



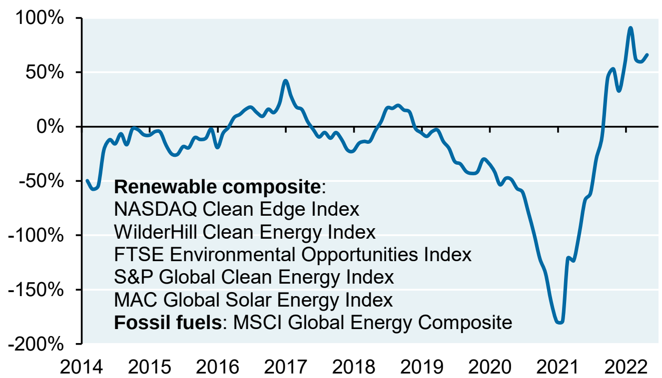
Source: BP Statistical Review of World Energy, Conference Board, IHS Markit, JPMAM. 2021.

"Reports of my death are greatly exaggerated"

Some of the most ill-advised things I've ever heard about energy were said during the spike in renewable energy stocks in 2020. The short version: "fossil fuel stocks are dead money since the renewable transition is irreversible, ready to power large economies and rapidly displacing the former." Irreversible, yes; the rest of it, not so much. In our 2020 and 2021 energy papers, we argued that stars were aligning for a substantial rebound in oil and gas profitability. The reason: poor oil & gas stock price performance was the result of management decisions to focus on market share and revenue rather than profits, and *not* because of imminent displacement by renewable energy. As shown below, oil & gas industry cash flow and oil demand rebounded sharply in 2021.

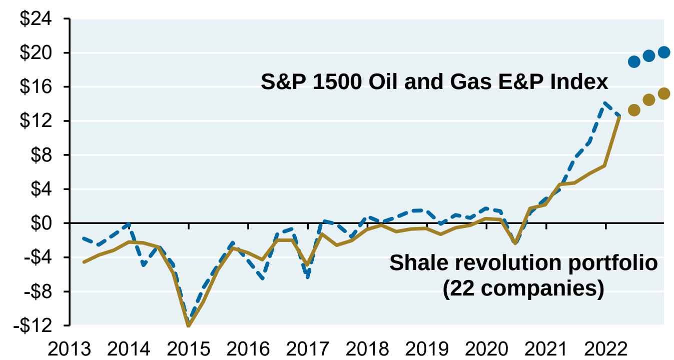
The big picture: global gas and coal consumption in 2021 were already above pre-COVID levels, and global oil consumption should surpass pre-COVID levels sometime next year. Looking further out, some forecasts of oil demand in 2030 and 2040 are not that different from today. We also estimate that the US might need almost as much natural gas in the year 2035 as it consumes today, based on assumptions we made on wind and solar growth, EV and heat pump adoption and the decommissioning of coal and nuclear plants[3]. With energy demand still in excess of supply, I believe the MSCI Global Energy Composite will outperform both renewable energy stocks[4] and the broad equity market again over the next year.

Reports of my death are greatly exaggerated
Rolling 12 mo. outperformance of fossil fuels vs renewable energy, %



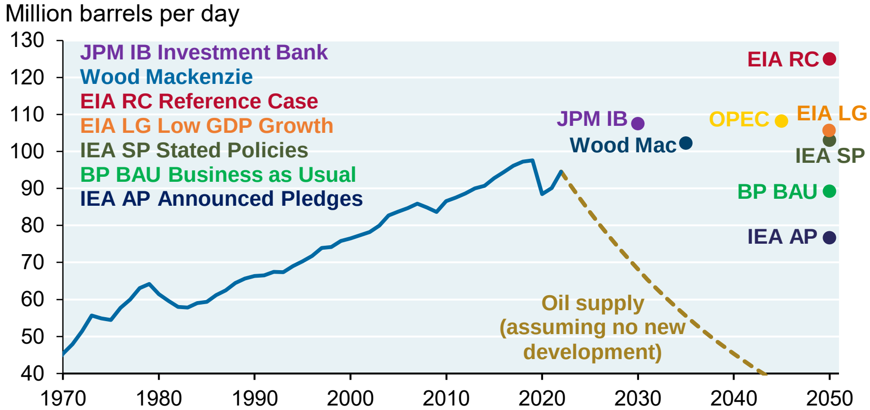
Source: Bloomberg, MSCI, JPMAM. April 29, 2022.

Oil and gas industry finally turns a profit
Free cash flow, $ billions



Source: Bloomberg. Q1 2022. Dots represent consensus estimates.

Oil demand, supply from existing fields and demand projections
Million barrels per day



Source: BP, EIA, IEA, OPEC, Wood Mackenzie, JP Morgan Investment Bank, JPMAM. 2021.

Energy sector highlights

- Earnings estimates still do not reflect higher energy prices, rising domestic production and operating leverage
- Energy sector still trades at 9.5x fwd earnings vs 16.5x avg since 1990
- Energy sector trades at 1x book value and is an inflation hedge; also capital intensive and less sensitive to wages
- Energy sector only 4% of S&P market cap vs 20 year avg of 8%
- Some asset manager ESG filters may be relaxed after recent performance

Source: JP Morgan Global Equity Strategy

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[3] See 2021 *Eye on the Market* energy paper, pages 32-33.

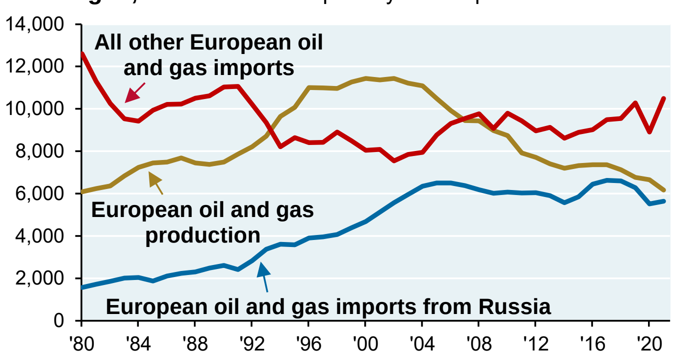
[4] **Renewable energy profitability, or lack thereof**. From 40%-60% of the companies in the Renewable Energy indices shown above are not expected to have positive free cash flow in 2023. Furthermore, most indices include large industrial companies with subsidiary renewable energy businesses (Con Ed, ON semiconductors, the Indian conglomerate Adani, Quanta Services infrastructure, Linde and Air Liquide industrial gases, Wolfspeed semiconductors, etc). In other words, "pure play" renewable companies have an even higher rate of negative free cash flow if we strip out the big industrial companies.

Europe is paying a steep price for its reliance on Russian energy

Europe miscalculated by reducing its *production* of fossil fuels much faster than it reduced its own *consumption* of fossil fuels, and is caught in the vice of Russian energy reliance. **Ramifications for Europe include**: a likely recession; energy consumption displacing non-energy goods and services; a lower rate of growth and a decline in competitiveness of exported energy intensive goods; risks that "cold turkey" withdrawal from Russian energy will require curtailment of industrial production (steel, fertilizer, cement etc) and related employment; higher food prices; and domestic political tensions as anti-establishment candidates take advantage of distress. **Latest news**: Russia cut off Poland and Bulgaria from natural gas shipments since they refused to pay in Rubles.

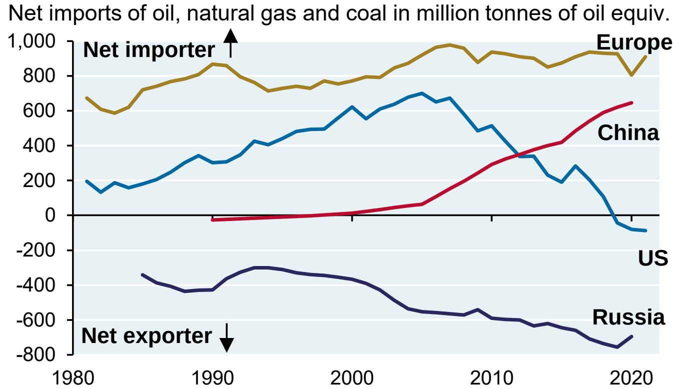
For the record: Mitt Romney warned everyone about Russia during the 2012 Presidential election. He was mocked by Democrats for doing so in 2012, and then ignored by Republicans in 2016.

Europe curtails oil & gas production while keeping imports unchanged, Thousand barrels per day of oil equivalent



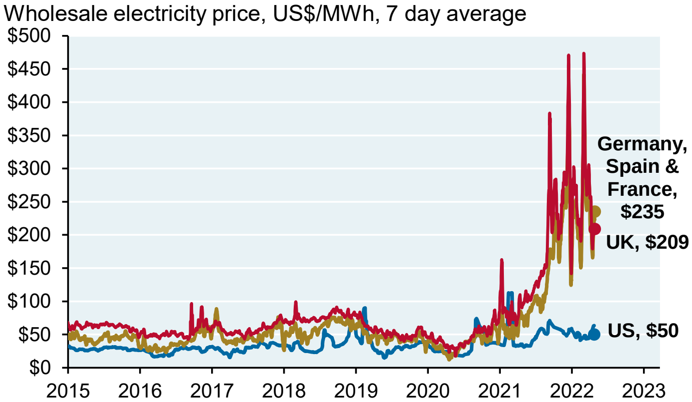
Source: BP, Gazprom, Eurostat, Perovic et al, Russia Federal Customs Service, JPMAM calculations. 2021.

Energy dependence and independence
Net imports of oil, natural gas and coal in million tonnes of oil equiv.



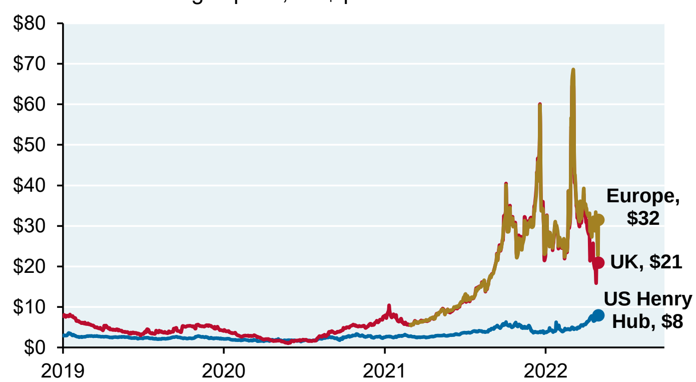
Source: BP Statistical Review, NBS China, JPMAM. 2021.

The US-Europe electricity gap
Wholesale electricity price, US$/MWh, 7 day average



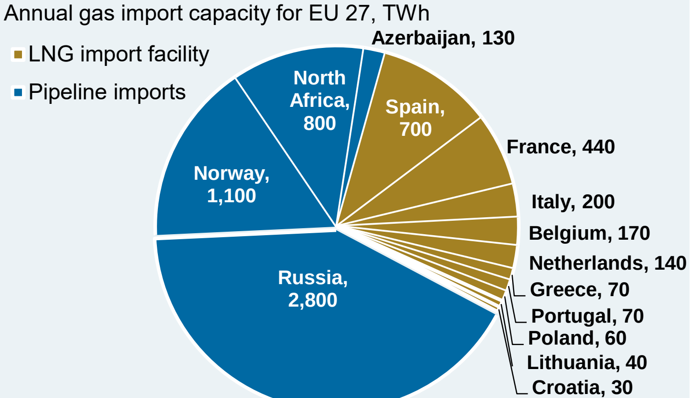
Source: Bloomberg. May 3, 2022. Dots represent latest daily price.

The US-Europe natural gas gap
Wholesale natural gas price, US$ per MMBTU



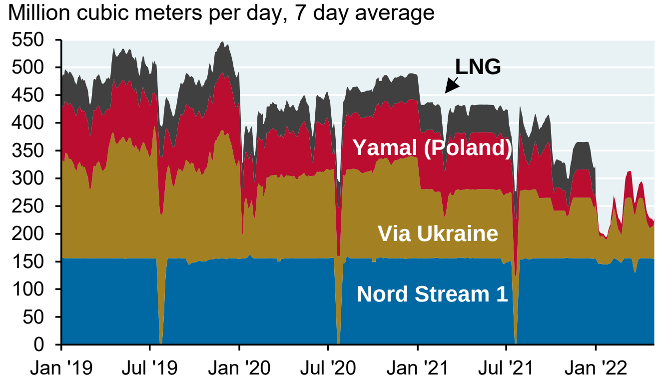
Source: Bloomberg. May 3, 2022.

Russia dominates European gas import capacity
Annual gas import capacity for EU 27, TWh



Source: Bruegel, JPMAM. 2022.

Russian natural gas exports to Europe
Million cubic meters per day, 7 day average



Source: Bloomberg, EIA, JPMAM. May 1, 2022. Excludes pipelines to and through Turkey. Annual LNG data amortized daily; no LNG data for 2022.

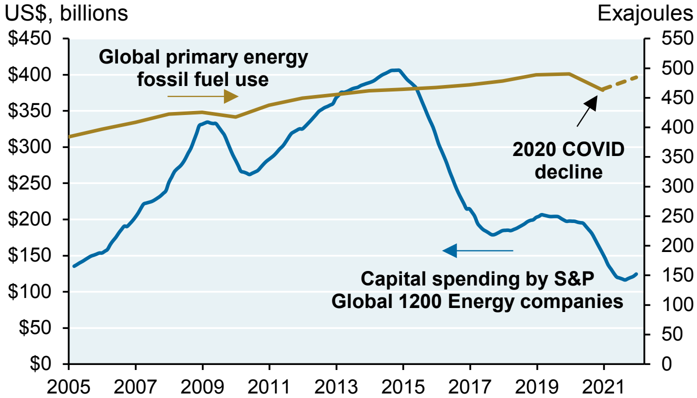
Can Europe quickly change course? They will try to. One plan we have seen entails replacing 2.6 mm bpd of Russian crude oil imports via the US (0.8 mm) and increased production from Canada, Norway, UK and Denmark (0.8 mm). Anything else could require a deal with Iran which still exports 1.3 mm bpd less than in 2018. Gas substitution is a lot harder: Europe imports 174 bcm per year from Russia, and our understanding is that there is not a lot of spare LNG regasification capacity. Spanish LNG regasification utilization rates were only 45% in January but it has limited pipeline connections with the rest of Europe. My guess is that Europe gets part of the way this year through diversification and then has to rely on longer term adjustments. Faster wind and solar? Installations are often constrained by transmission delays and local factors. Electrification of residential heating? So far, mostly confined to Scandinavia (see Section 3). More LNG regasification capacity? Expensive and time consuming. Greater use of nuclear power? The region has been abandoning it other than in France.

Europe is not the only region at risk: on a global basis, capital spending on oil and gas production is declining while oil and gas consumption is not. Many countries are now faced with three broad choices: ramp up their domestic production of fossil fuels to avoid a geopolitical and economic trap; rely on the countries in the table below for imported energy; or confront the obstacles to a faster renewable transition head-on.

The last option is not something that can be accomplished by increasing the cost of capital for fossil fuel companies or by university divestment. A faster transition requires a lot more than that: policymakers would have to curtail community delays and cancellation of renewable energy/transmission projects, and build consensus for some kind of price on carbon. Without these efforts, decarbonization will remain stuck in the slow lane despite all the corporate disclosure rules, shareholder resolutions, ESG policies, etc. A revival of the US "Build Back Better" bill could speed up the US transition a little[5], but there is no news to report yet.

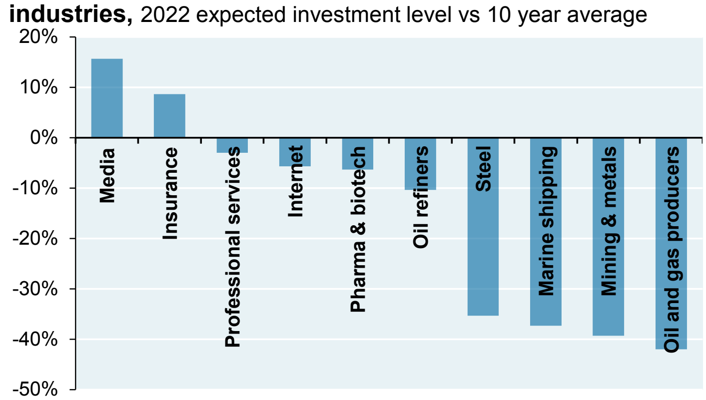
By the way, which country benefits most from renewable energy adoption from a production standpoint? China, of course (see table).

Fossil fuel capex falling despite no change in consumption



Source: BP, Bloomberg, IEA, JPMAM. Dec 2021. Dotted lines = estimates.

Collapse in global investment in energy-intensive industries, 2022 expected investment level vs 10 year average



Source: GS, JPMAM. November 10, 2021.

Largest proven reserves of oil and natural gas

	Natural gas (tr cu ft)			Oil (billion barrels)	
1	Russia	1,320	1	Venezuela	304
2	Iran	1,134	2	Saudi Arabia	298
3	Qatar	871	3	Canada	168
4	Turkmenistan	480	4	Iran	158
5	US	446	5	Iraq	145
6	China	297	6	Russia	108
7	Venezuela	221	7	Kuwait	102
8	Saudi Arabia	213	8	UAE	98
9	UAE	210	9	US	69
10	Nigeria	193	10	Libya	48
11	Iraq	125	11	Nigeria	37
12	Azerbaijan	88	12	Kazakhstan	30

Source: BP Statistical Review of World Energy. 2020.

Renewable production global market share

	China	US	EU
Solar PV module shipments, 2019	63%	<5%	<5%
Wind capacity order book, 2019	46%	14%	40%
Lithium ion battery manuf. capacity, 2021	79%	6%	9%
EV mineral processing/refining (Nickel, Cobalt, Graphite, Lithium, Manganese avg)	79%	1%	6%
EV cathode/anode production	85%	1%	1%

Sources: IEA, BNEF, S&P, Benchmark Mineral Intelligence, 2021.

[5] Most of the bill's proposed spending is reportedly focused on energy efficiency in buildings, tax credits for wind/solar, raising EV tax credits from $7k to $12k, EV infrastructure, air pollution mitigation and reforestation. Proposed spending on hydrogen, CCS, nuclear power, transmission and renewable fuels is smaller.

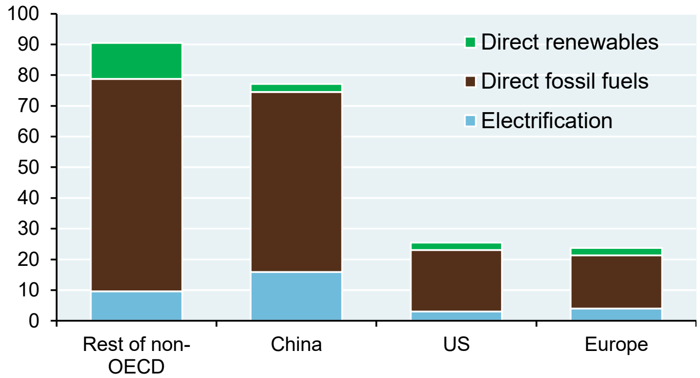
Before getting started: beware of industrial decarbonization and carbon capture fairy tales

We covered two topics last year that are critical parts of the decarbonization challenge: the real-world difficulty in electrifying industrial energy use, and the massive cost/scope required for geologic carbon sequestration to make a material impact. Beware of hockey stock forecasts on these topics; progress has been and will likely remain very slow. You can read more about them via the links below to last year's sections.

Challenges of industrial electrification and decarbonization

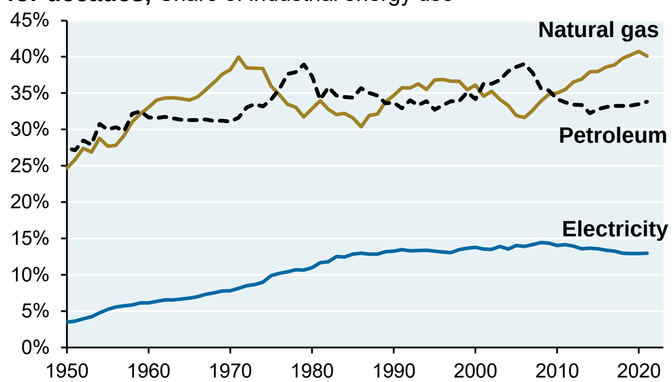
Plastics, cement, steel, ammonia and other industrial materials form the building blocks of the modern world. Electricity is a small share of the energy used to create them; in the US, the electrification share has been unchanged for decades, a testament to the difficulty in increasing it. The primary challenges: (a) industrial production often relies on waste-to-heat energy which is lost during electrification, and (b) many industrial products are non-metallic which makes electrification harder. Natural gas and petroleum remain the dominant energy sources for industrial products. You can learn more at the link above.

Electricity a small share of industrial energy use
Quadrillion BTUs of industrial energy consumed



Source: Energy Information Administration, JPMAM. 2021.

Electricity share of US industrial energy use unchanged for decades, Share of industrial energy use



Source: EIA. October 2021.

The challenging energy math of geologic carbon sequestration and direct air carbon capture

One of the highest ratios in the world of energy science: the number of academic papers *written* on carbon sequestration divided by the actual *amount* of carbon sequestration (~0.1% of global emissions at last count). The infrastructure required for meaningful geologic carbon sequestration would be enormous. In addition, the energy and materials requirements for direct air carbon capture are essentially unworkable. Here's a quick summary of our conclusions on the topic from last year.

- To sequester just 15%-20% of US CO_2 emissions via traditional carbon capture and storage, the volume of US carbon sequestration (1.2 billion cubic meters) would need to exceed the volume of all US oil production in 2019 (858 billion cubic meters). That's a LOT of infrastructure that does not exist
- Gathering and storing 25% of global CO_2 through direct air carbon capture could require 40% or more of global electricity generation, even when assuming the presence of waste heat to power the carbon capture, requiring ~1,200 TWh per Gt of CO_2. This is clearly an absurd proposition. To quote one of the researchers we worked with, "direct air carbon capture is unfortunately an energetically and financially costly distraction in effective mitigation of climate changes at a meaningful scale"

Other efforts are based on "letting nature do the carbon capture work". One involves conversion of agricultural waste into low-energy, high-carbon oil using pyrolysis, after which the oil is injected underground. Another involves fast growing ocean kelp absorbing carbon, after which it sinks to low temperature depths which may limit the kelp's decomposition. Some profitable tech companies are reportedly paying $600 to $2,000 per ton of carbon to such start-ups. While these ideas might help individual companies hit their carbon footprint targets at a very high price, they are highly unlikely to move the sequestration needle on any meaningful scale.

This year's energy paper: the Elephants in the Room

The phrase "elephants in the room" refers to glaringly obvious issues that need to be resolved. This year's paper covers some of the elephants in the room regarding the energy transition.

We start with three topics on electrification, which is the foundation of many deep decarbonization plans. First, the morass of the US **transmission grid**, clogged interconnection queues and the growing number of renewable transmission projects rejected by landowners and environmental groups. After all, without a robust grid, electrification will be more difficult. Then, the latest on **electric vehicle** adoption, what policies might be needed to get **US gasoline "super-users"** to switch and how rising metals prices affect battery costs. We conclude the electrification section with a look at home heating. Replacing on-site combustion of natural gas, propane and fuel oil with **electric heat pumps** has been mentioned by the IEA as a critical step for the OECD to reduce its GHG footprint. But so far, residential heat pump adoption is mostly a Scandinavian phenomenon.

Next, a deep dive into the so-called **hydrogen economy**, which is still in its infancy. Ultimate hydrogen use cases may be narrower than advertised once costs, round-trip efficiency, materials handling and competition from direct electrification are factored in. The final section is on **China,** whose carbon intensity of energy consumption and emissions are the highest in the world. The IEA sees a path for deep decarbonization in China, but this path is highly reliant on a lot of very aggressive assumptions. We take a closer look.

Closing remarks: for some people who write about wind and dead birds, I made you a new name badge.

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What am I *not* writing about? The GHG benefits of natural gas vs coal, since it's not totally clear what they are

If you accept EPA data at face value, methane "leakage" rates from natural gas have fallen to ~1%, down from 2% in 1990. These rates include leakage from exploration, production, gathering, processing, transmission, storage and distribution. However, EPA emissions data is usually provided by the oil & gas industry and may not reflect variations in utilization or operating performance. As a result, climate scientists conduct their own measurements. Based on aerial, satellite and other surveillance methods, some believe that the EPA underestimates methane leakage rates by 50%-100% (some estimates are even higher). This would offset part of the very large GHG benefits normally associated with coal to gas switching; on a pure CO_2 basis, gas has a 60% lower emissions rate than coal per MWh.

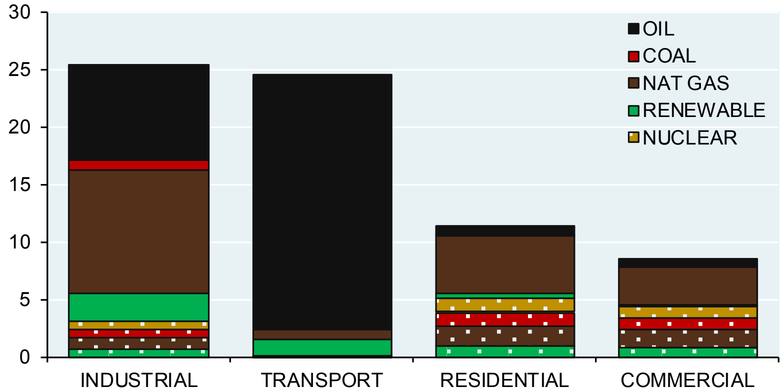
To be clear, coal mining has other highly negative environmental impacts: sulfur dioxide and nitrogen oxide emissions (though they have fallen sharply since the 2005 Clean Air Interstate Rule), mercury emissions and the aftermath from sludge, slurry and fly ash ponds that contain a variety of toxins. In any case, the real-world GHG impact of coal to gas switching may be quite different than the optimal version often assumed.

Sources include Robert Howarth (Cornell), the Harvard School of Public Health and the following studies:
"*Analysis of Oil and Gas Ethane and Methane Emissions in the Southcentral and Eastern US Using Four Seasons of Continuous Aircraft Ethane Measurements*", Barkley et al, JGR Atmospheres, May 2021
"*Assessment of methane emissions from the U.S. oil and gas supply chain*", Alvarez et al, Science, June 2018
"Quantifying methane emissions from the largest oil-producing basin from space", Zhang et al, Science Advances, April 2020

Executive summary exhibits 1-3: Energy use by country, sector and fuel, and energy acronyms

US energy consumed by end-use sector and fuel type

Quadrillion BTUs of final energy consumed; dotted segments = electricity consumed



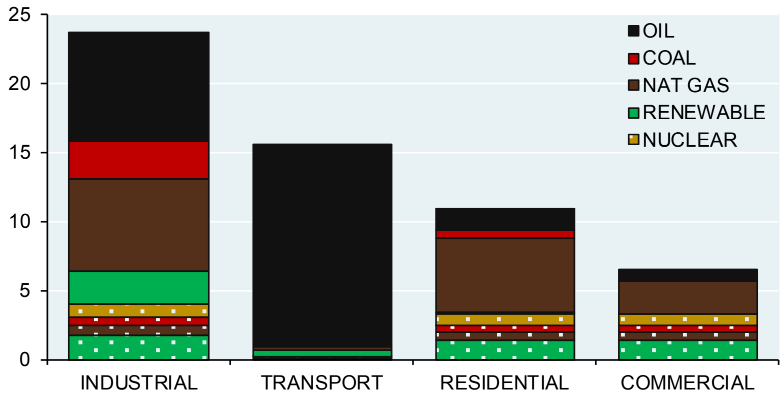
Key stats

Quads of primary energy consumption	93.3
Quads of final energy consumption	70.1
Electricity % of energy consumed	18%
Electricity % of industrial energy consumed	12%
Electricity % of transport energy consumed	0%
Electricity % of residential energy consumed	44%
Fossil fuels % of primary energy	79%
Passenger car energy % of transport energy	60%
Industrial fossil fuels % of primary energy	27%
Renewable % of electricity generation	20%
Renewable energy % of primary energy	13%
Low carbon % of electricity generation	43%
Low carbon energy % of primary energy	21%
Coal % of primary energy	10%
Coal to natural gas ratio in primary energy	0.3
Hydropower share of renewable electricity	37%

Source: Energy Information Administration, JP Morgan Asset Management. 2021. Electricity generation segments are net of thermal conversion, power plant consumption and transmission losses. "Low carbon" refers to renewable generation plus nuclear generation.

OECD Europe energy consumed by end-use sector and fuel type

Quadrillion BTUs of final energy consumed; dotted segments = electricity consumed



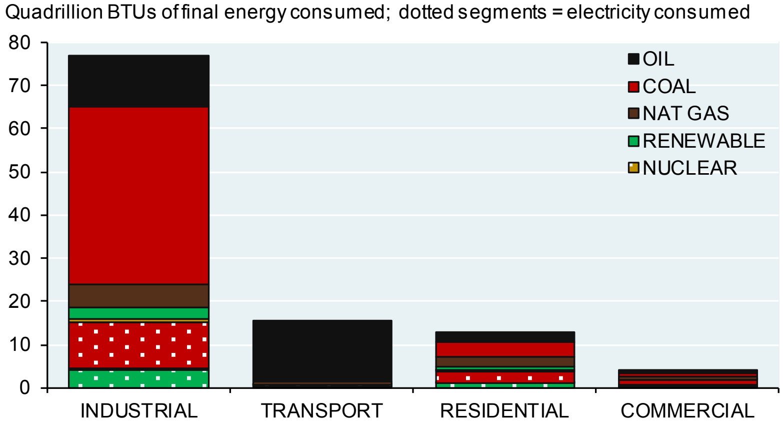
Key stats

Quads of primary energy consumption	76.8
Quads of final energy consumption	56.7
Electricity % of energy consumed	19%
Electricity % of industrial energy consumed	17%
Electricity % of transport energy consumed	2%
Electricity % of residential energy consumed	30%
Fossil fuels % of primary energy	69%
Passenger car energy % of transport energy	50%
Industrial fossil fuels % of primary energy	27%
Renewable % of electricity generation	44%
Renewable energy % of primary energy	22%
Low carbon % of electricity generation	69%
Low carbon energy % of primary energy	31%
Coal % of primary energy	10%
Coal to natural gas ratio in primary energy	0.4
Hydropower share of renewable electricity	43%

Source: Energy Information Administration, JP Morgan Asset Management. 2021. Electricity generation segments are net of thermal conversion, power plant consumption and transmission losses. "Low carbon" refers to renewable generation plus nuclear generation.

China energy consumed by end-use sector and fuel type

Quadrillion BTUs of final energy consumed; dotted segments = electricity consumed



Key stats

Quads of primary energy consumption	160.2
Quads of final energy consumption	109.6
Electricity % of energy consumed	20%
Electricity % of industrial energy consumed	21%
Electricity % of transport energy consumed	4%
Electricity % of residential energy consumed	32%
Fossil fuels % of primary energy	84%
Passenger car energy % of transport energy	25%
Industrial fossil fuels % of primary energy	59%
Renewable % of electricity generation	25%
Renewable energy % of primary energy	14%
Low carbon % of electricity generation	30%
Low carbon energy % of primary energy	16%
Coal % of primary energy	59%
Coal to natural gas ratio in primary energy	7.9
Hydropower share of renewable electricity	57%

Source: Energy Information Administration, JP Morgan Asset Management. 2021. Electricity generation segments are net of thermal conversion, power plant consumption and transmission losses. "Low carbon" refers to renewable generation plus nuclear generation.

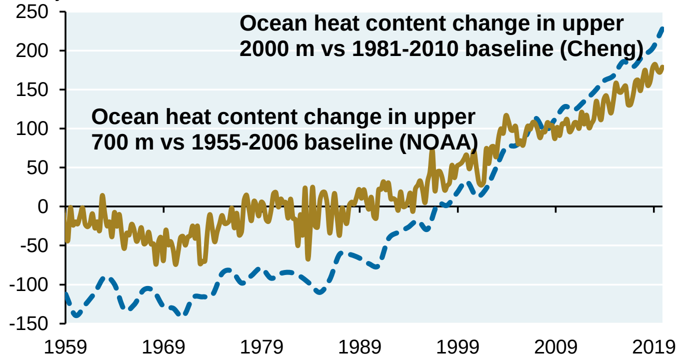
Bcm billion cubic meters; **Bpd** barrels per day; **BTU** British thermal unit; **CCS** carbon capture and storage; **EIA** US Energy Information Agency; **EJ** exajoule; **EOR** enhanced oil recovery; **EPA** Environmental Protection Agency; **GHG** greenhouse gases; **GW** gigawatt; **H_2** hydrogen; **IEA** International Energy Agency; **ISO** independent system operator; **kWh** kilowatt hour; **LNG** liquefied natural gas; **m^3** cubic meter; **MJ** megajoule; **MMT** million metric tons; **MT** metric ton; **Mtoe** million tonnes of oil equivalent; **MWh** megawatt hour; **PPA** power purchase agreement; **Quad** quadrillion BTUs; **TWh** terawatt hour

Executive summary exhibits 4-7: select climate charts

I asked my colleague Sarah Kapnick for exhibits to illustrate the latest climate research she has been following. Sarah is the Senior Climate Scientist and Sustainability Strategist for JP Morgan Asset and Wealth Management. Sarah was previously a climate scientist and Deputy Division Leader at the National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory. Sarah is also a member of the American Geophysical Union, the American Meteorological Society and the American Association for the Advancement of Science.

Warming oceans

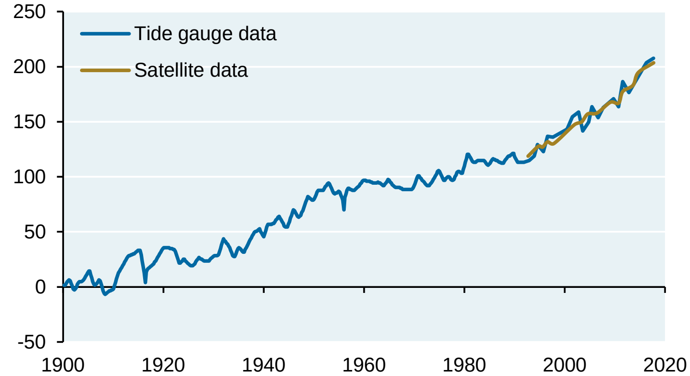
Zettajoules



Source: Cheng, L. *et al.*, Advances in Atmospheric Sciences; Dahlman and Lindsey, National Oceanic and Atmospheric Administration. February 2020.

Sea level change (1900-2018)

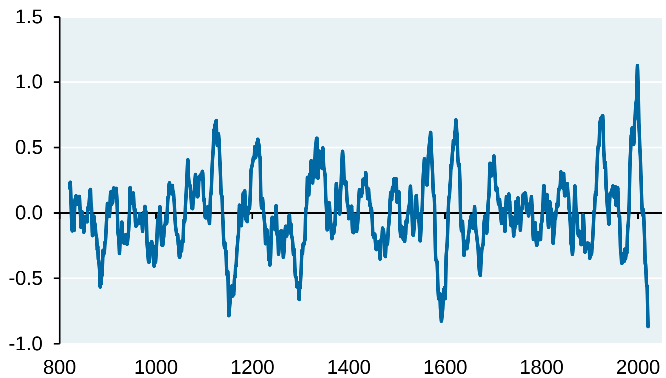
Millimeters



Source: NASA's Goddard Space Flight Center. 2018.

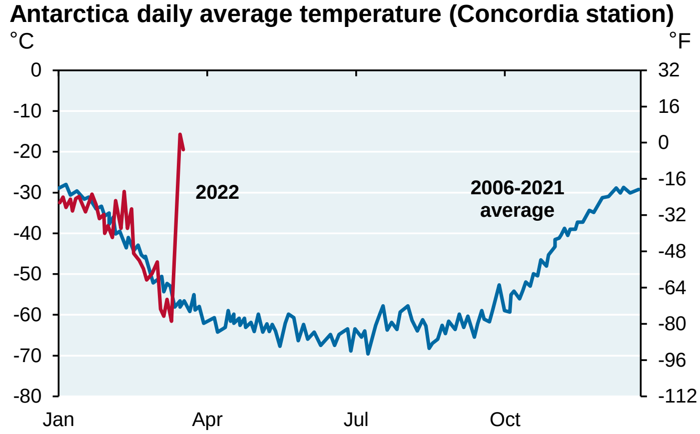
Western drought conditions since 800 AD

Soil moisture relative to 800-2021 average, standard deviations



Source: Nature Climate Change. March 2022.

Antarctica daily average temperature (Concordia station)



Source: National Oceanic and Atmospheric Administration. March 24, 2022.

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