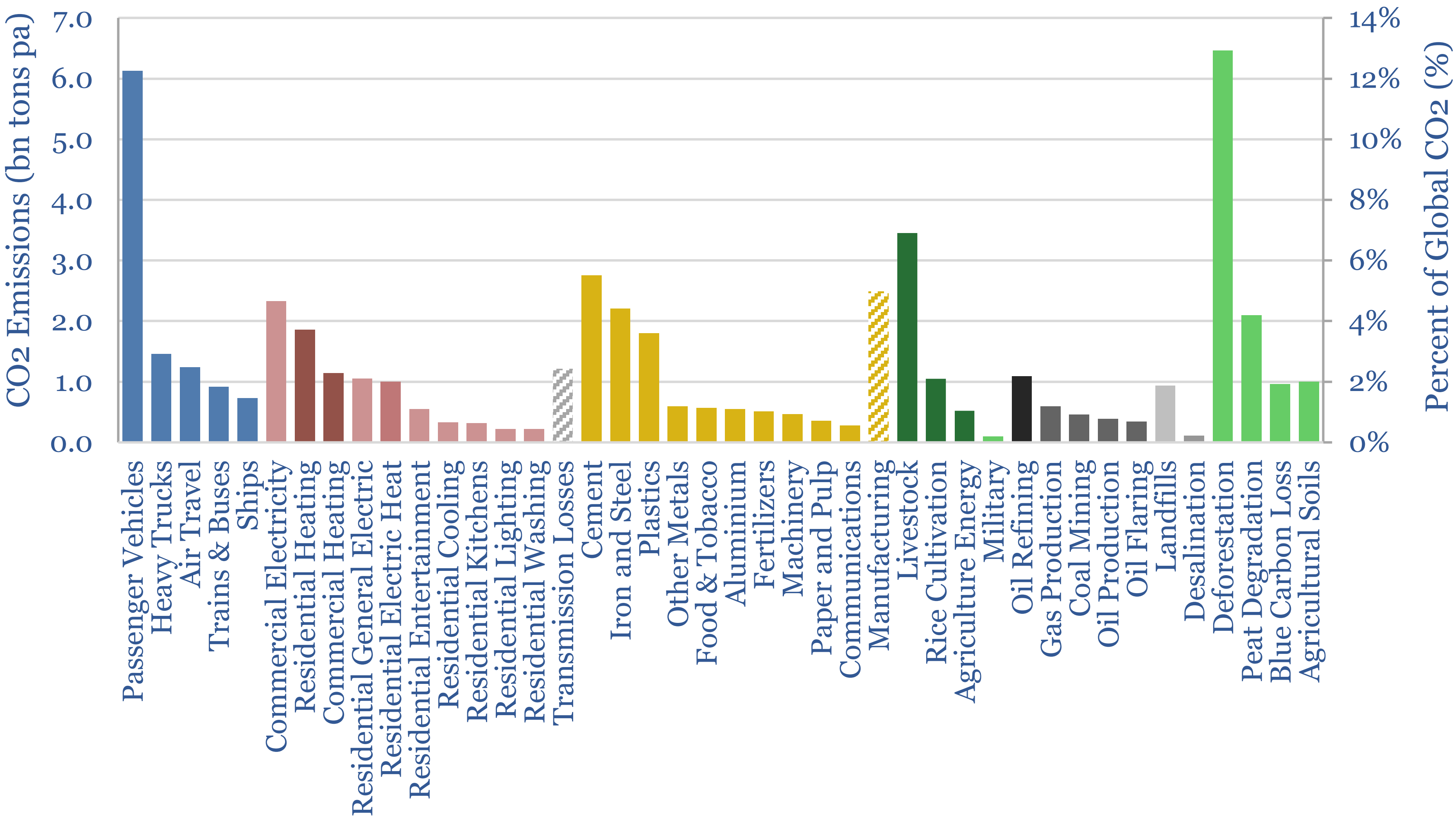
Thunder Said Energy

the research-consultancy for energy technologies

Is the global energy system on the precipice of persistent shortages, and record prices, in the mid-late 2020s? We worry that cumulative under-investment in the global energy system has now surpassed $1trn since 2015, relative to our energy transition roadmap. This opens the door to new capex cycles (including materials, power grids, new technologies, new geographies), energy arbitrage, and re-prioritized resiliency?

www.thundersaidenergy.com

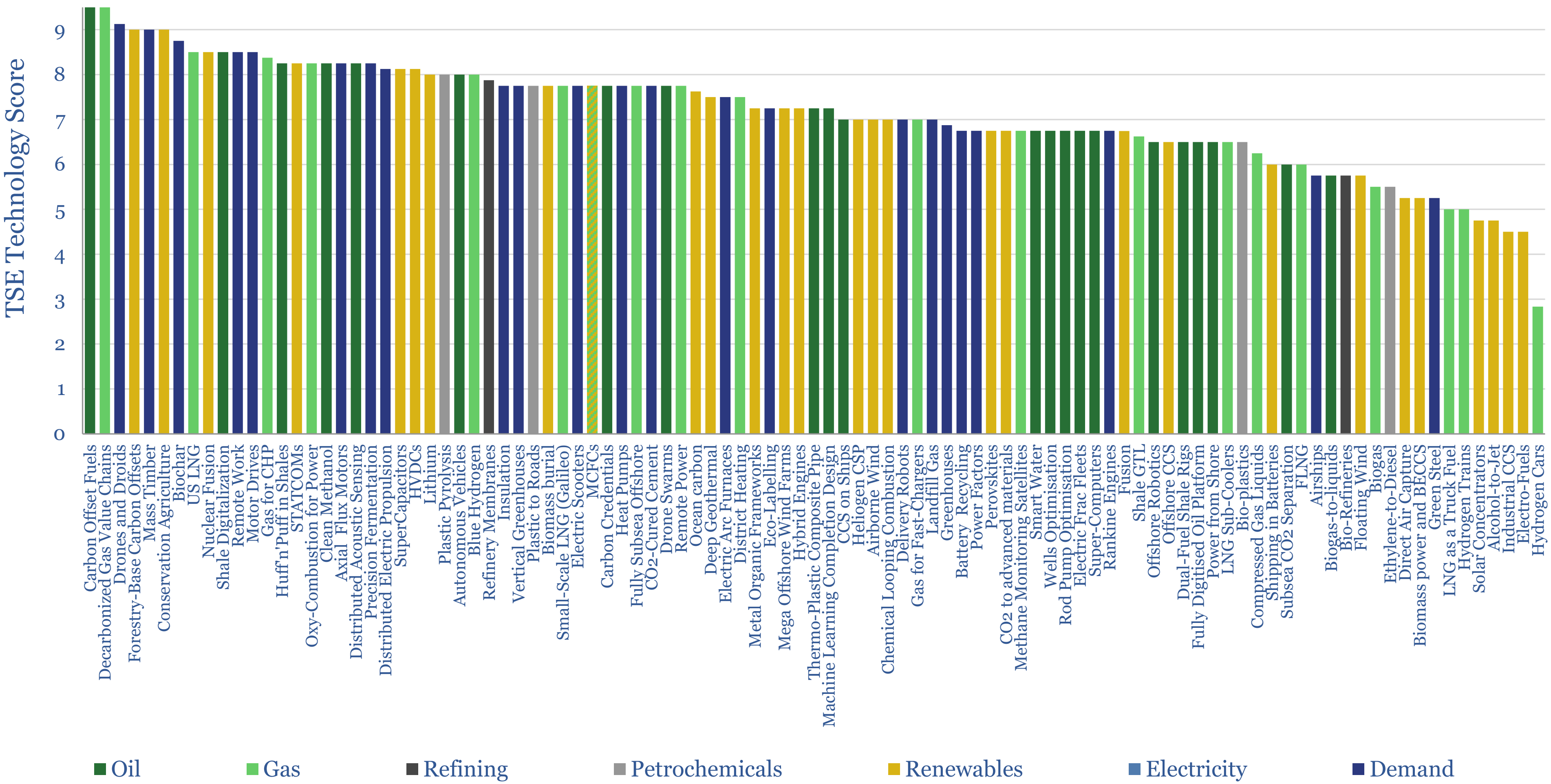
The context for Net Zero. Total global CO2e emissions are 50GTpa. Mitigating CO2 will require new technologies across each of c40 sectors globally. The largest individual CO2 source is just 13% of the total.



Source: https://thundersaidenergy.com/downloads/breakdown-of-global-co2-emissions/

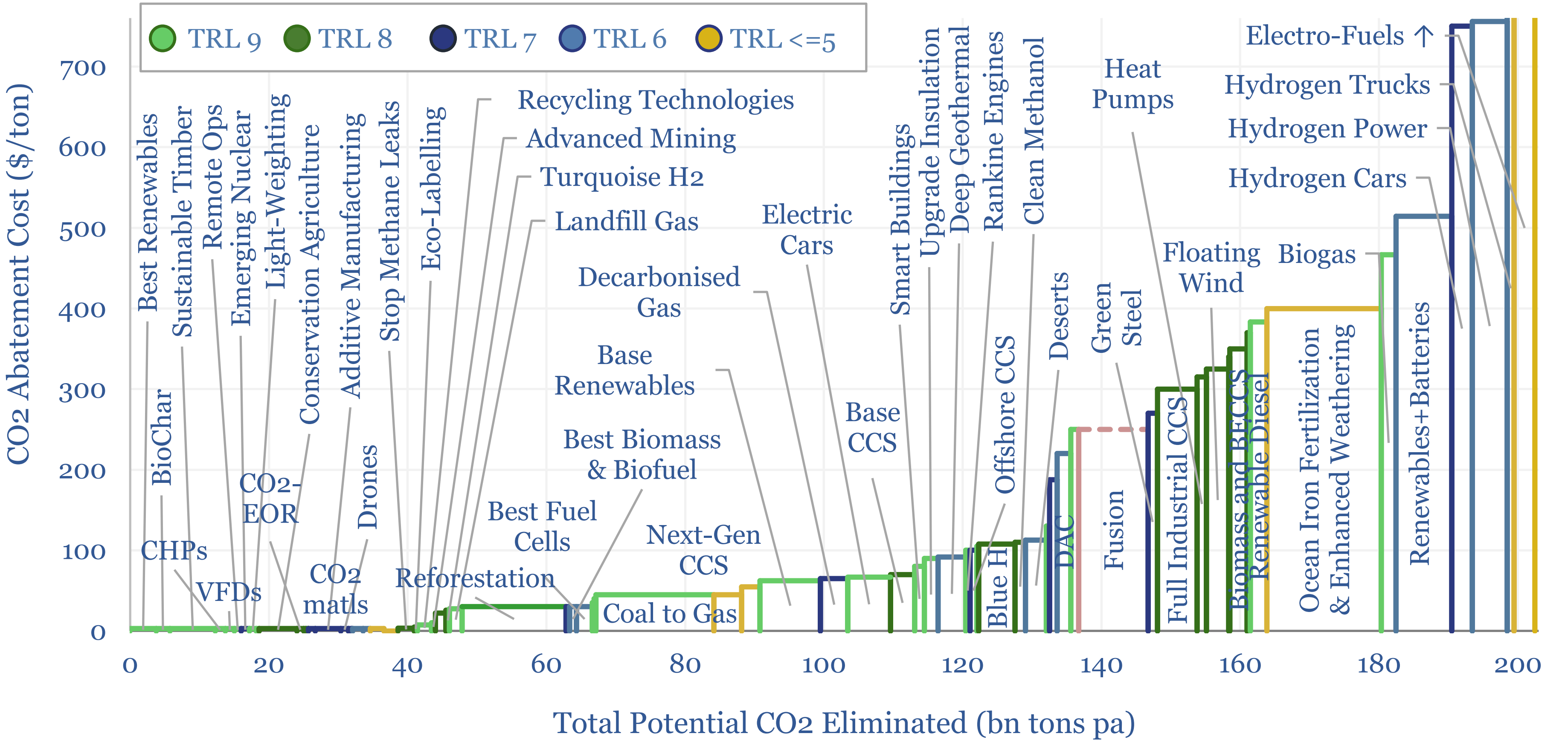
Which energy technologies present the greatest opportunities?

We help decisions-makers identify leading energy technologies to change the world and drive the energy transition. Our top technologies are ranked below, after screening their economic potential and technical readiness; based on patents, technical papers and economic modelling. Key themes are nature-based solutions, integrating renewables, CCUS, bottlenecked value-chains and overlooked efficiency technologies.

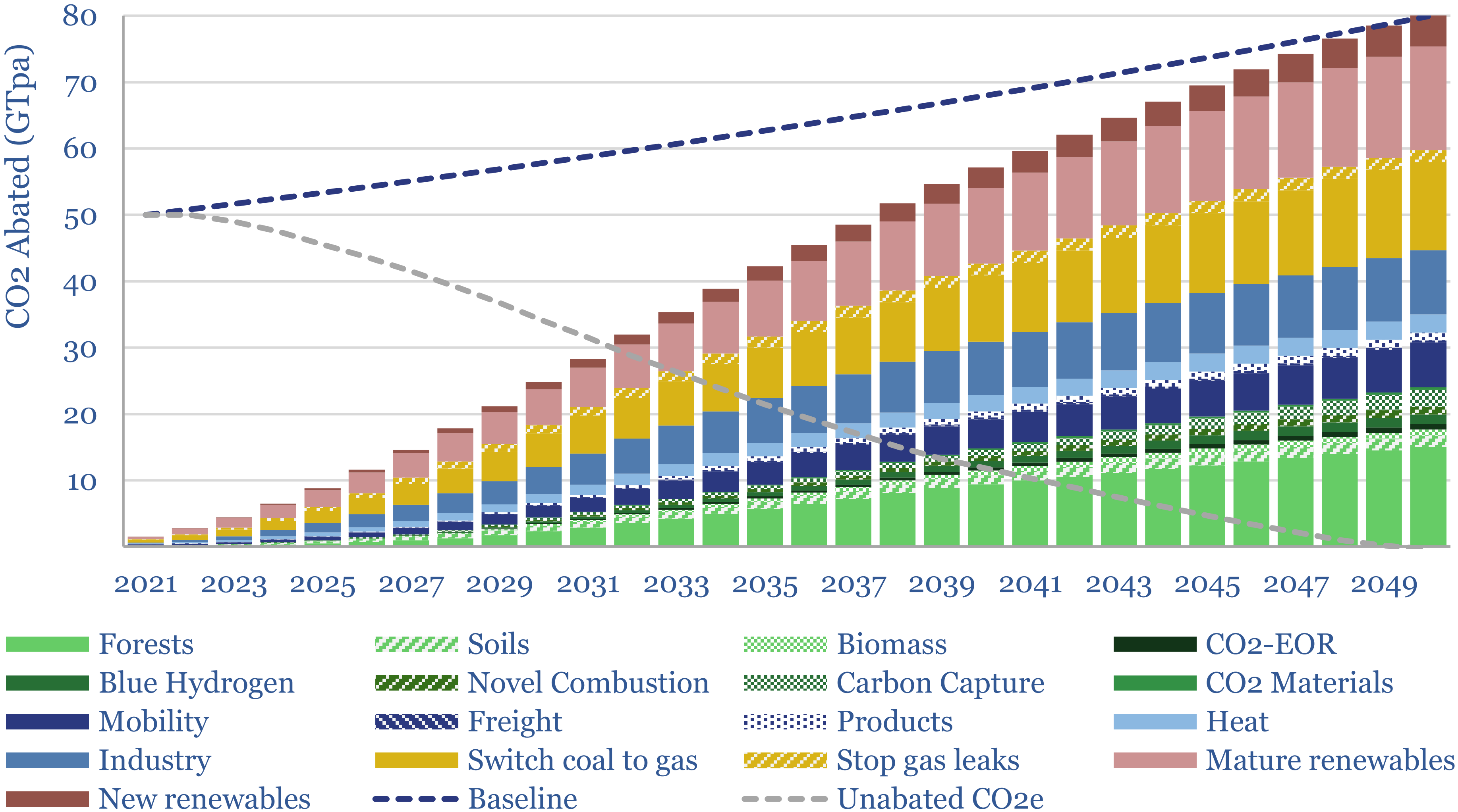


How can these technologies decarbonise the world?

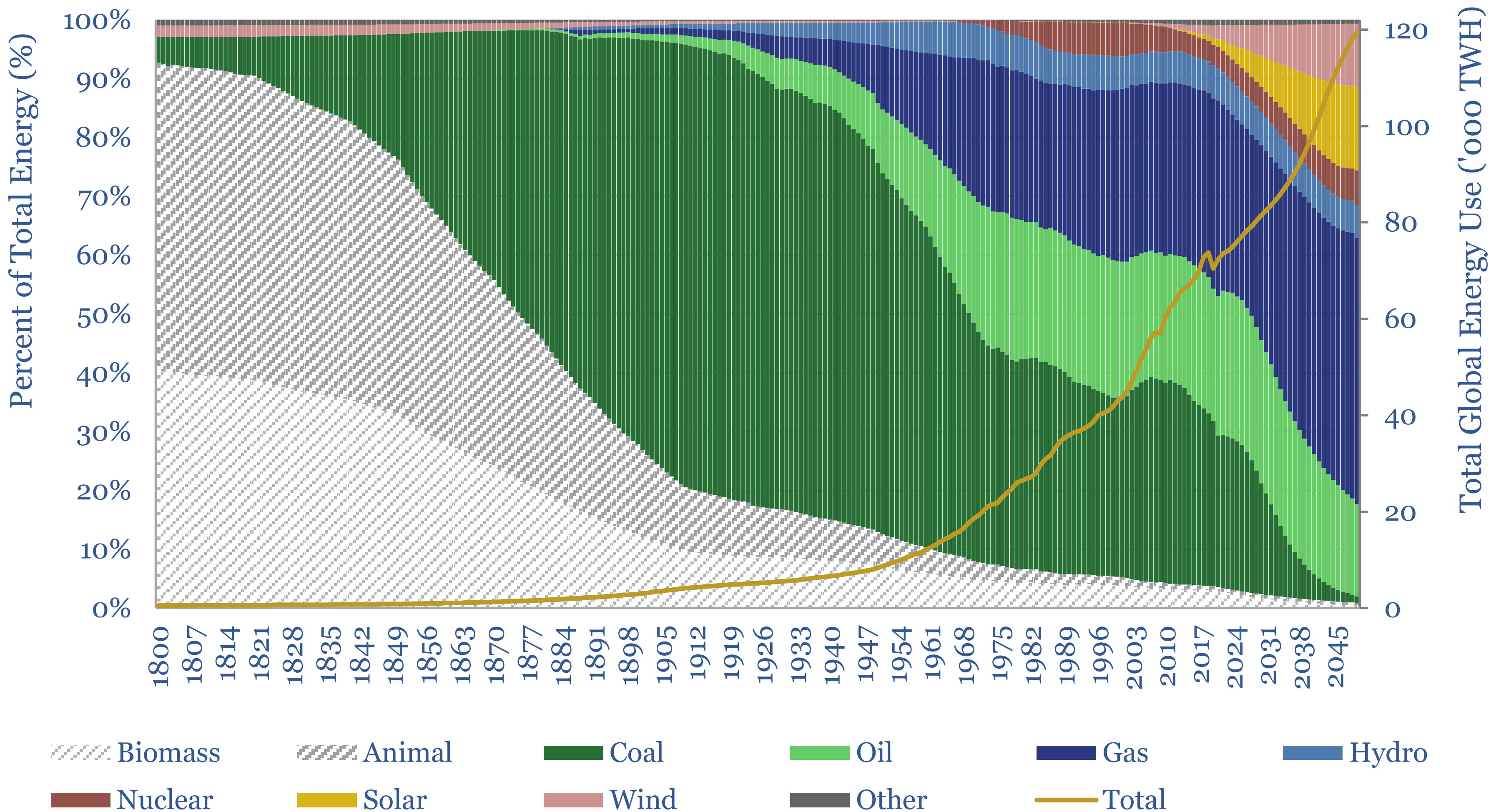
The opportunities in our work can decarbonise the global energy system almost 3x over by 2050. The most economical roadmap has an average abatement cost of $40/ton. Fossil fuel demand is c25% higher than today on this scenario. But these must be the cleanest, most efficient fossil fuels possible, offset by carbon capture and well-trusted nature-based offset technologies. We find leading industrial companies are already beginning to shift their portfolios, with potential re-ratings for the leaders, and likely de-ratings for laggards.



Our Roadmap to Net Zero is a fully modelled framework, which meets the 120,000 TWH of total useful energy demand in 2050 industry by industry, region by region, with no net CO2 emissions, in the “most plausible” overall way. 50 different commodities and sub-industries are captured, the average CO2 abatement cost is $40/ton (upper bound is $100/ton) and 88% of the technologies are technically ready (TRL 8+).

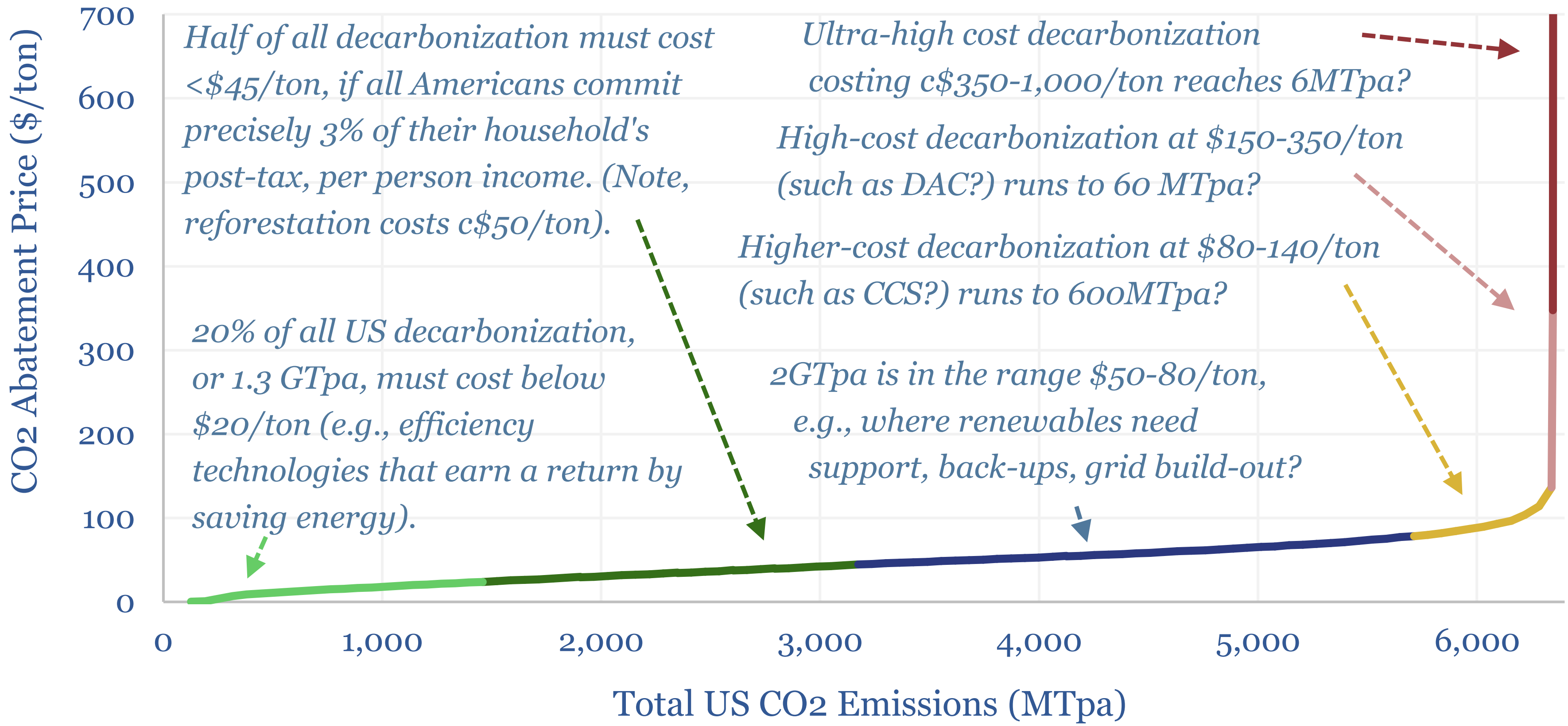


Total Global Energy Consumption runs at 80,000 TWH (equivalent to a kitchen toaster running constantly for every man, woman and child on the planet). Of this useful energy, c30% is from gas, c30% is from coal, c25% is from oil and the remainder is from 'clean' sources. Wind and solar are currently c3,000TWH (5% of useful energy). By 2050, total global useful energy demand will be 120,000 TWH.

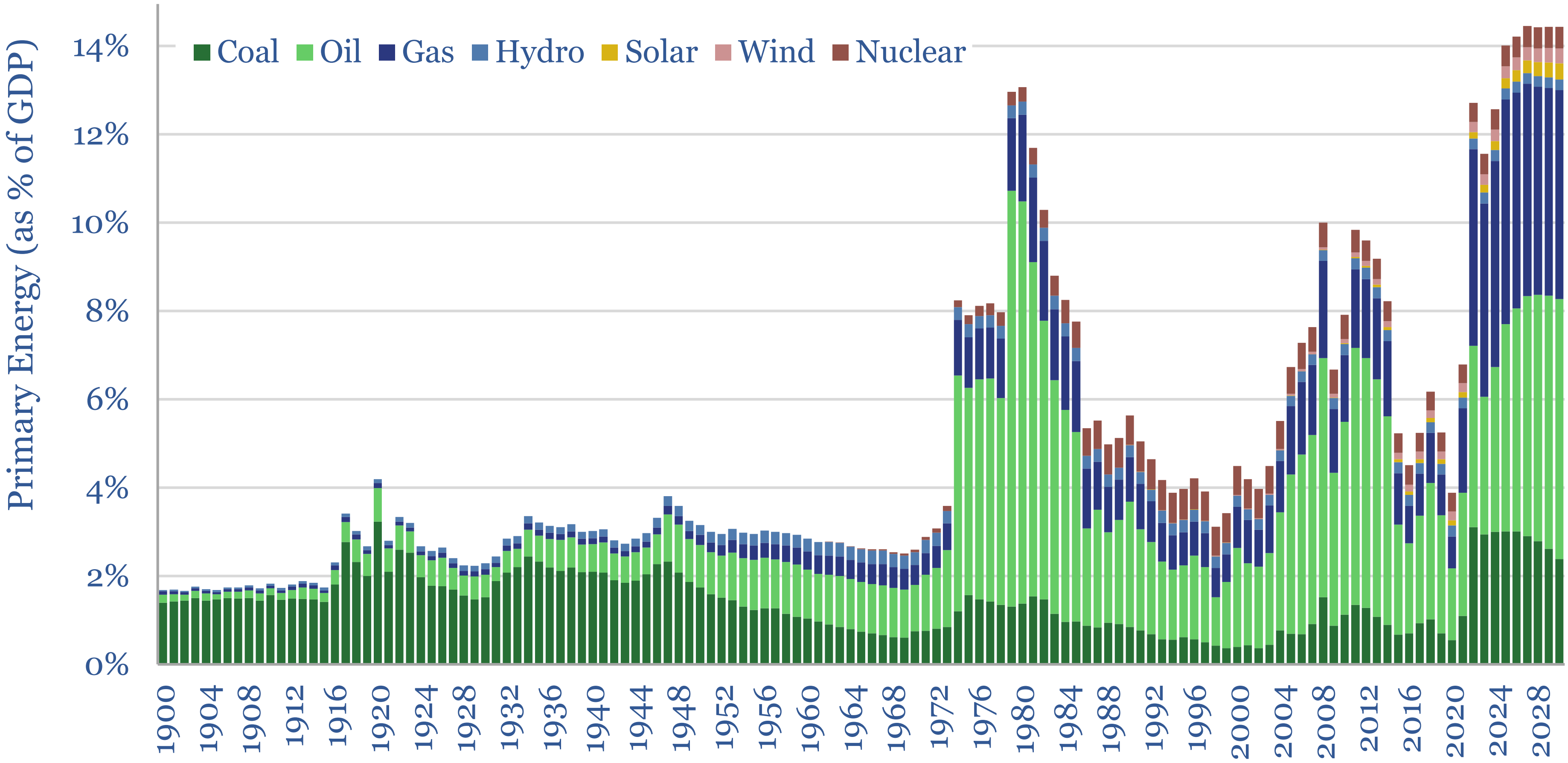


Source: https://thundersaidenergy.com/downloads/the-2050-energy-mix-a-simple-model/

The biggest challenge we are seeing in the energy transition is a lack of pragmatism and a focus on implausibly expensive technologies. ***90% of decarbonization*** needs to cost <$80/ton, in a strange thought experiment where every American surrenders precisely 3% of their post-tax household income to decarbonize the nation. ***Another 600MTpa*** could cost $80-140/ton around the upper decile. ***60MTpa*** could cost $150-350/ton, at the upper percentile. ***6MTpa*** could cost $350-1,000+/ton, at the upper 0.1% of the cost distribution.



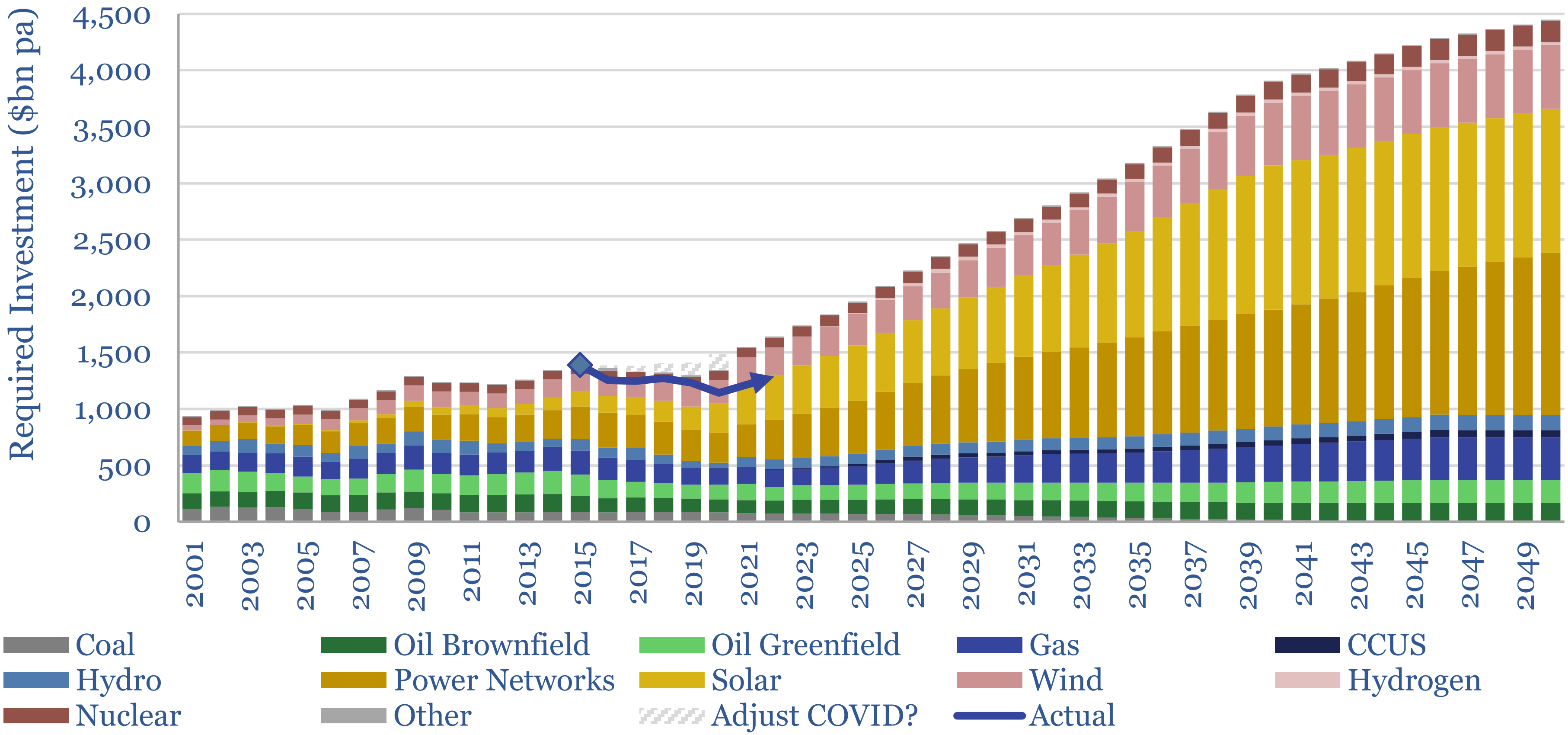
Energy Macro. 2022 saw the joint highest energy prices on record, matching the peaks of the 1979-80 oil shock ($100/bbl Brent, $6.5/mcf Henry Hub, $40/mcf European gas, $18/mcf LNG, $385/ton Australian coal). Our best guess is that 2023 will bring weak macro conditions, as high inflation and rising interest rates ripple through the financial system. This will temporarily mute energy demand and prices. In turn, this will result in even further under-investment. Thus as demand recovers in the mid-late 2020s, will the recent trends result in energy shortages and record energy prices in order to destroy unsatisfiable demand? The purpose of this ten-page presentation is to weigh up evidence around these energy-related anxieties.



Further Reading: https://thundersaidenergy.com/2023/01/01/global-energy-ten-themes-for-2023/

Data Source: https://thundersaidenergy.com/downloads/the-2050-energy-mix-a-simple-model/

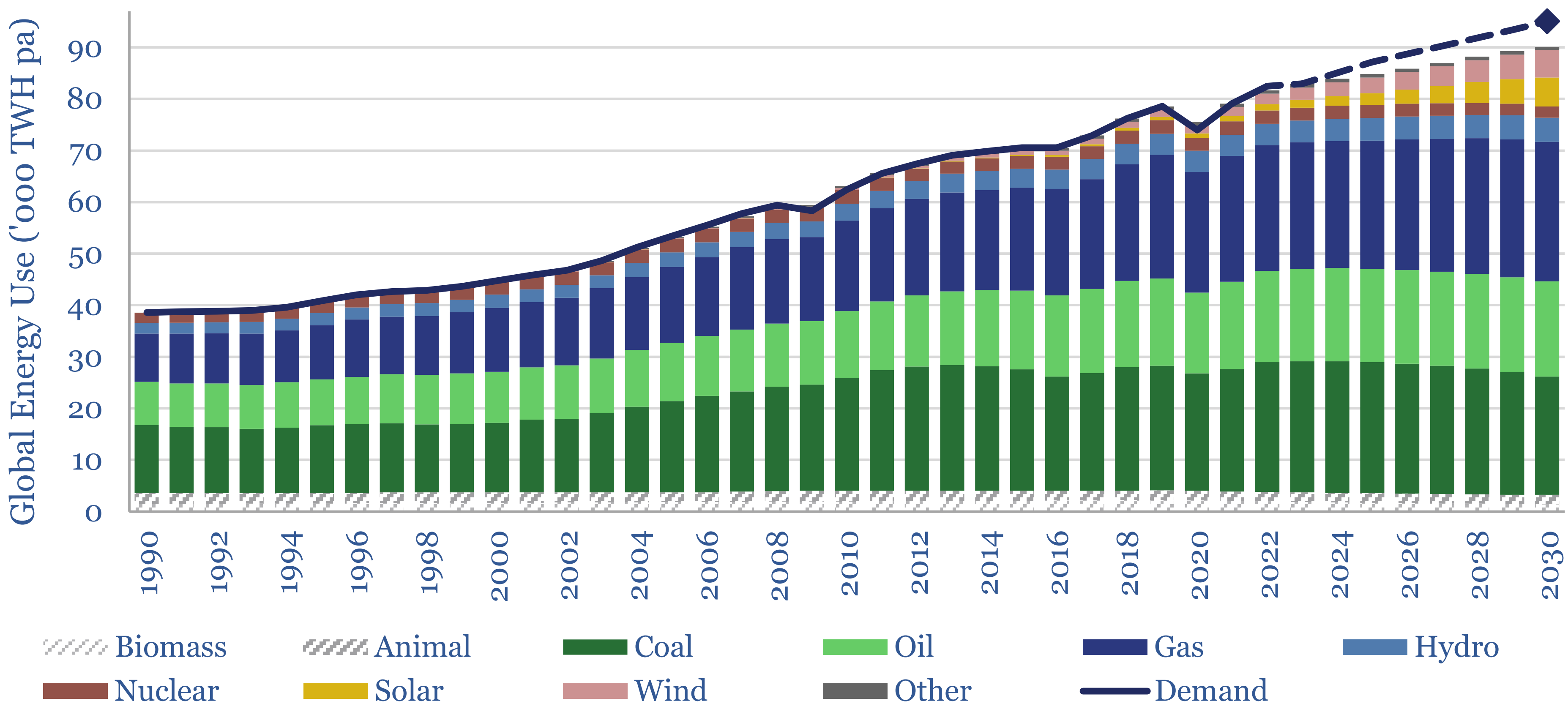
$1trn of under-investment? If we try to add up all of the primary energy investment needed in our roadmap to net zero, we think the 2015-20 average was $1.4trn pa across the categories below, rising to $2.5trn by 2030, $4trn by 2040 and $4.5trn pa by 2050. On a comparable basis, we think the world was spending $1.4 trn in 2015 (in line with requirements), declined to $1.1trn at trough in 2020 (COVID crisis), and recovered close to $1.3trn in 2022. Upstream investment in combustion fuels declined from $775bn in 2015 to $530bn in 2022; while generally, each $1bn invested in combustion fuels yields 10x more useful energy per $1bn than renewables.



Model: https://thundersaidenergy.com/downloads/the-2050-energy-mix-a-simple-model/

Investment: https://thundersaidenergy.com/2021/11/25/is-the-world-investing-enough-in-energy-2/

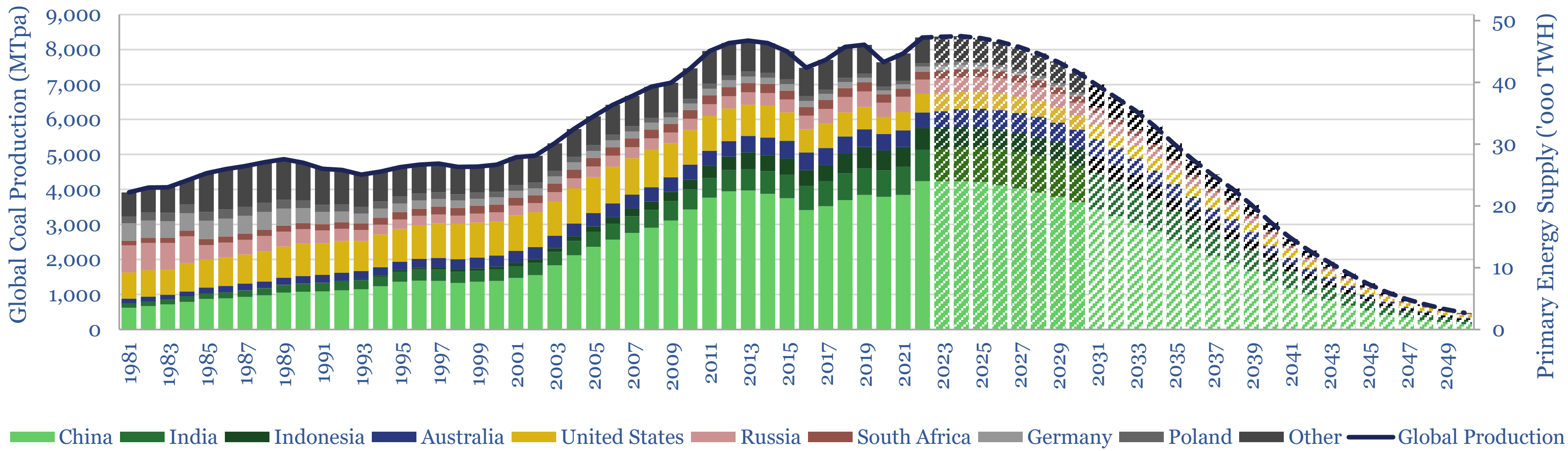
Global energy markets are likely to be 2.5 - 5% under-supplied in aggregate in 2025-30 (2,500-5,000 TWH). This assumes 1% pa growth in global population, 0.75% pa growth in energy demand per capita (1990-2019 CAGR is +1.2%), wind adds rise 2.5x to 250GW pa by 2030, solar additions treble to over 600GW pa, new oil projects add 3.5Mbpd/year to offset declines, 10% of all coal is phased out by 2030, global gas production grows c10% by 2030 (+5bcfd/year, net). No material supply disruptions are factored in. But this model is clearly wrong as energy demand cannot exceed supply. The likely resolution is higher prices to destroy demand?

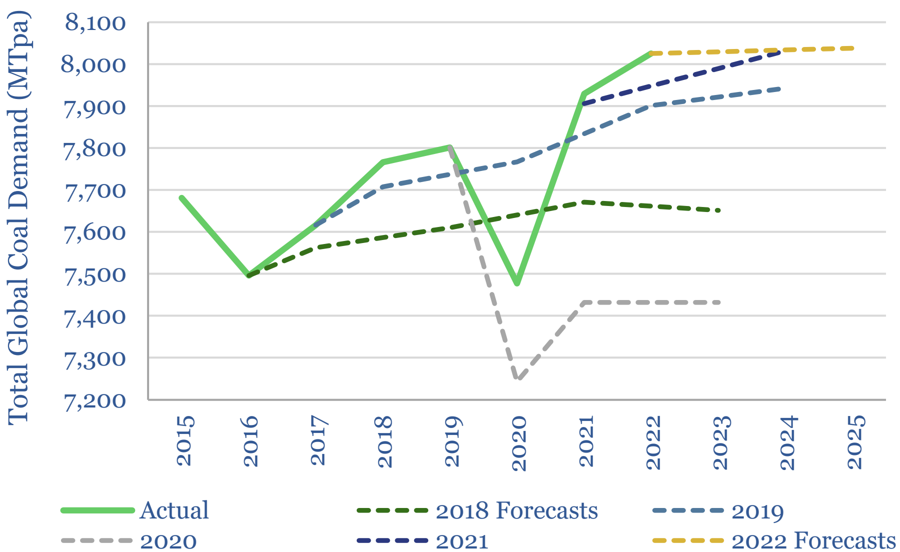


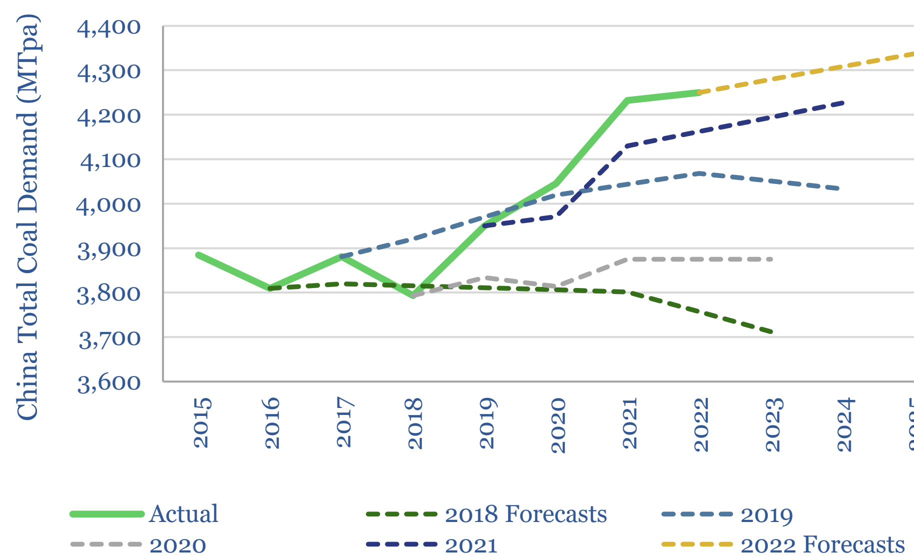
Model: https://thundersaidenergy.com/downloads/global-energy-supply-demand-balance/

Renewables Bottlenecks: https://thundersaidenergy.com/2022/01/06/renewables-can-they-ramp-up-faster/

Record coal? 2022 saw a new record in global coal consumption, above 8GTpa (top). Forecasts for 2023-25 global coal use, and China's, have now been revised up by >5% since 2018 (bottom). This strongly suggests new energies are still not ramping up fast enough to displace even the highest-carbon energy sources (note here).



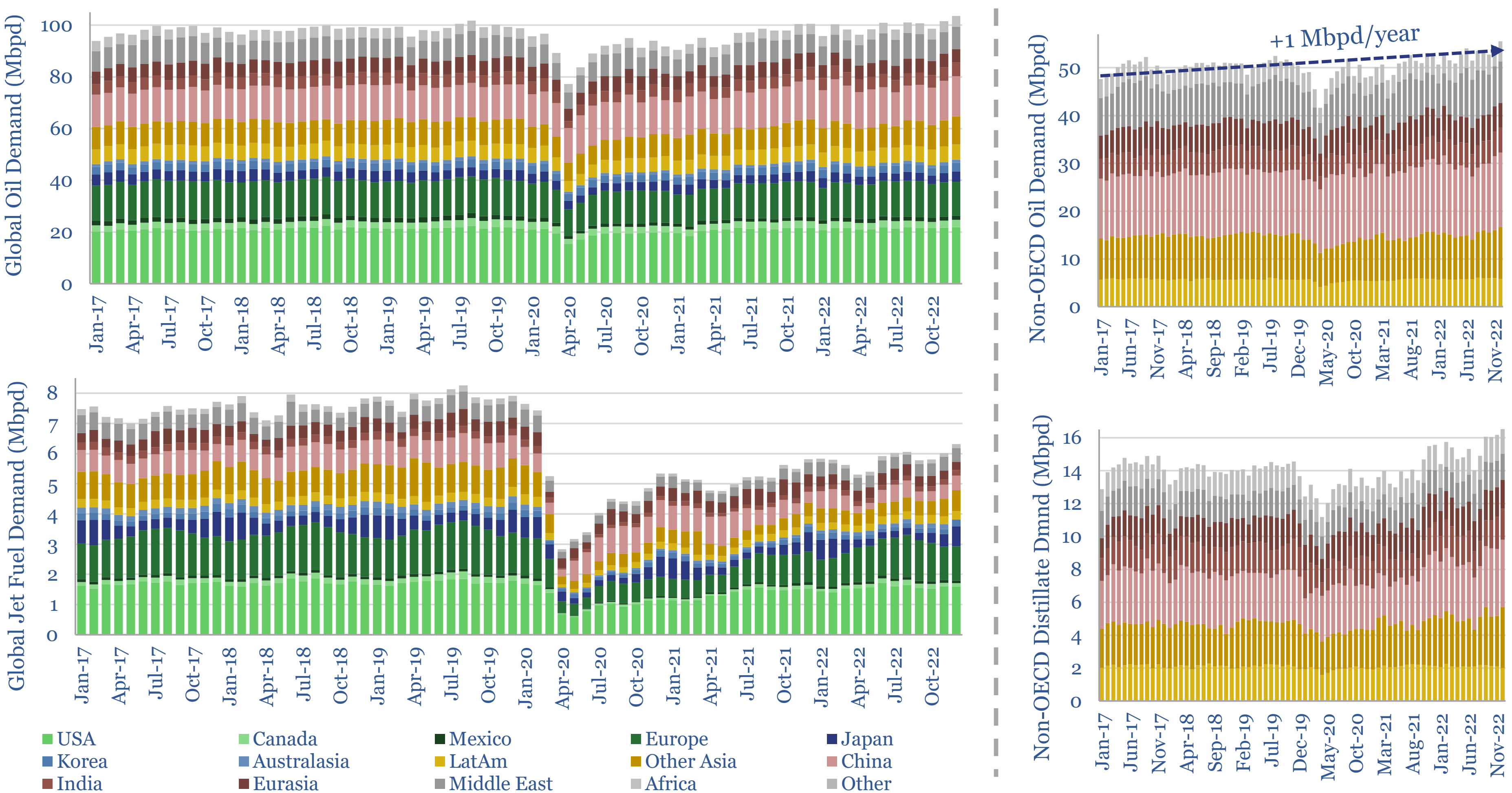




Research Note: https://thundersaidenergy.com/2023/02/16/energy-transition-the-fantasy-of-the-perfect/

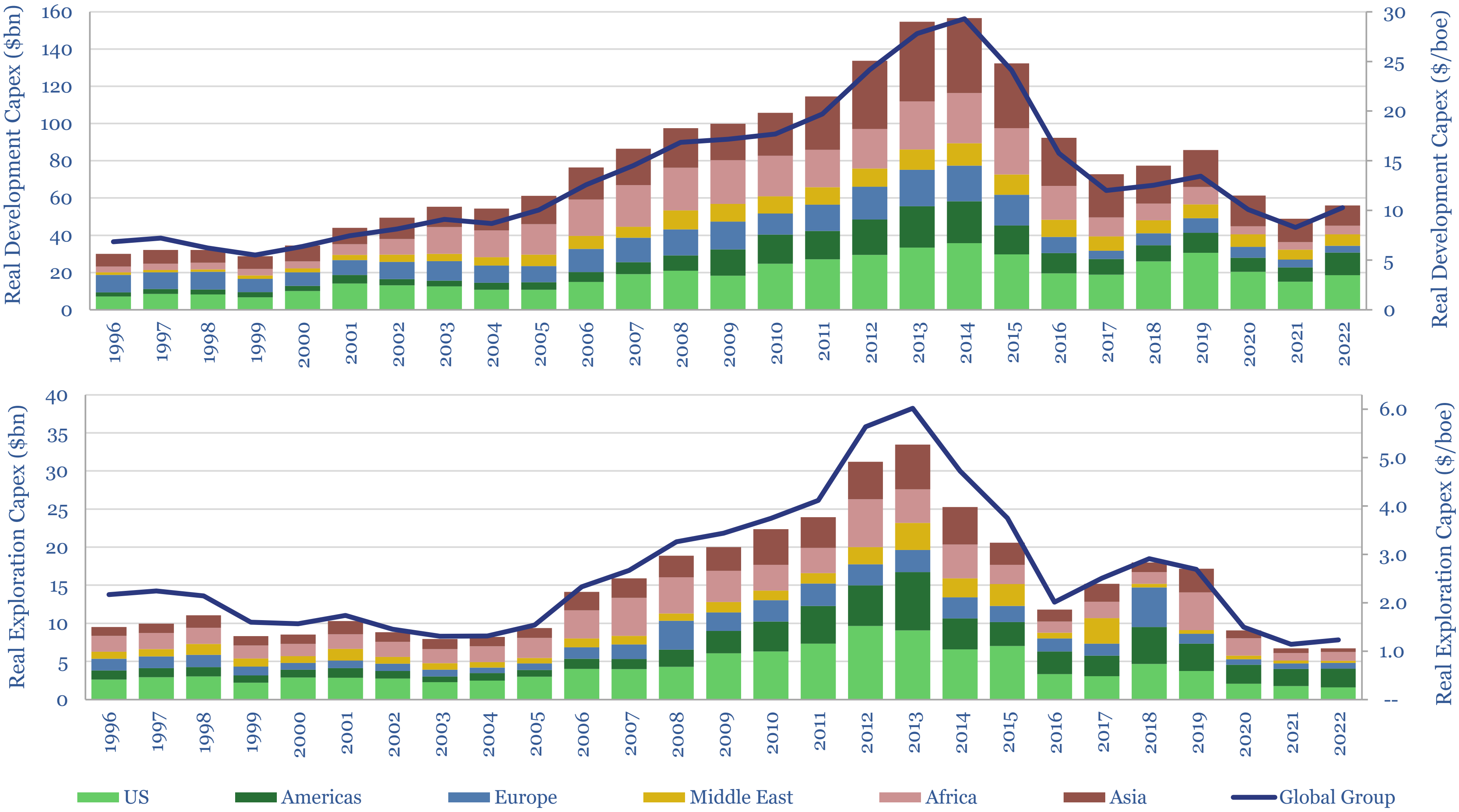
Source 2: https://thundersaidenergy.com/downloads/global-coal-production-a-supply-outlook/

Record oil? Global oil demand made new all-time highs in 2022, above 100Mbpd, including a record 104Mbpd reading in December-2022 (top left). But even by Dec-22, jet fuel demand remained -1.3Mbpd below 2019 (bottom left). Every other oil product (ex-gasoline) is now back at new highs, driven by the emerging world, which is growing at +1Mbpd/year (examples on the right), which is faster than the developed world is declining. Again, these charts strongly suggest new energies have not been ramping fast enough to *reduce* combustion demand.



Source: https://thundersaidenergy.com/downloads/global-oil-demand-breakdown-by-product-by-country/

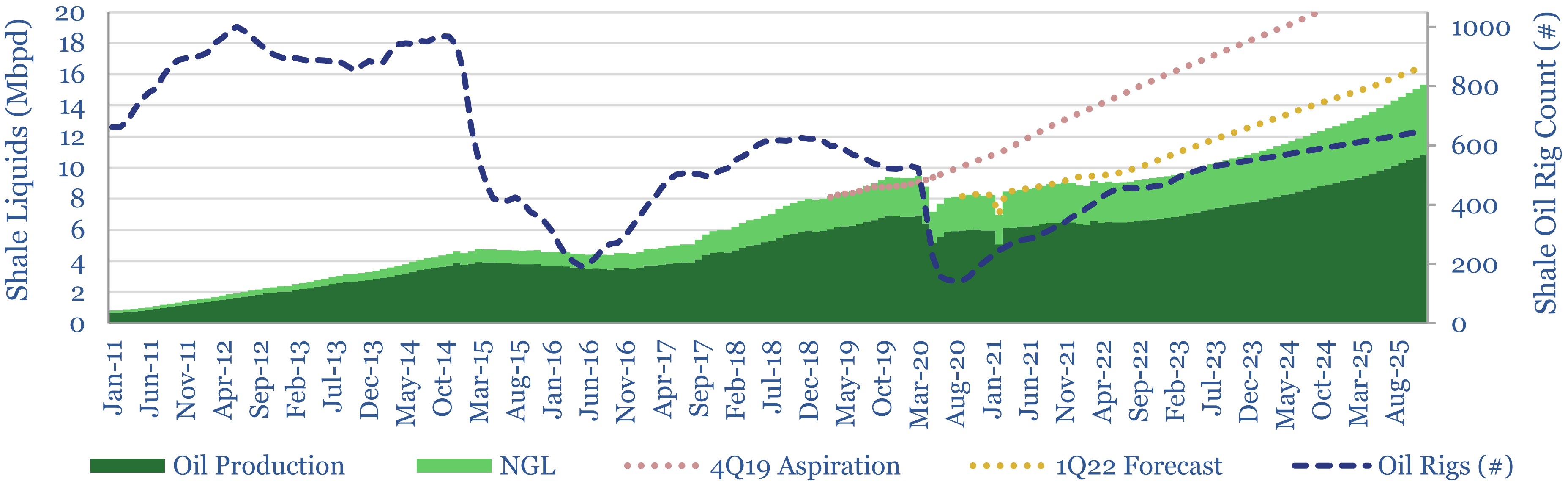
Oil investment? The 'big five' SuperMajors, which comprise 11% of global oil and gas production, spent $10/boe ($2022 real terms) on organic development capex in 2022; versus an average of $18/boe in the decade from 2004-2014, over which timeframe their aggregate production nevertheless declined by 1.5% per year (i.e., they were not investing enough). Exploration capex, at $1/boe, is also at all time lows in real terms.

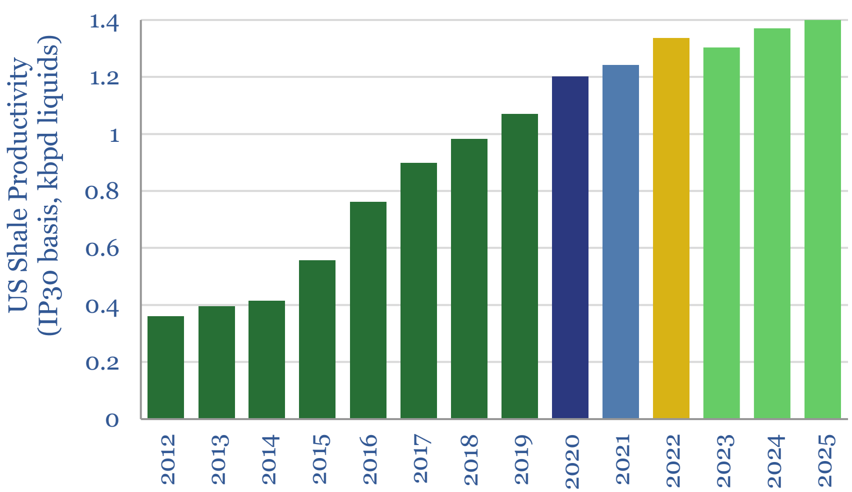


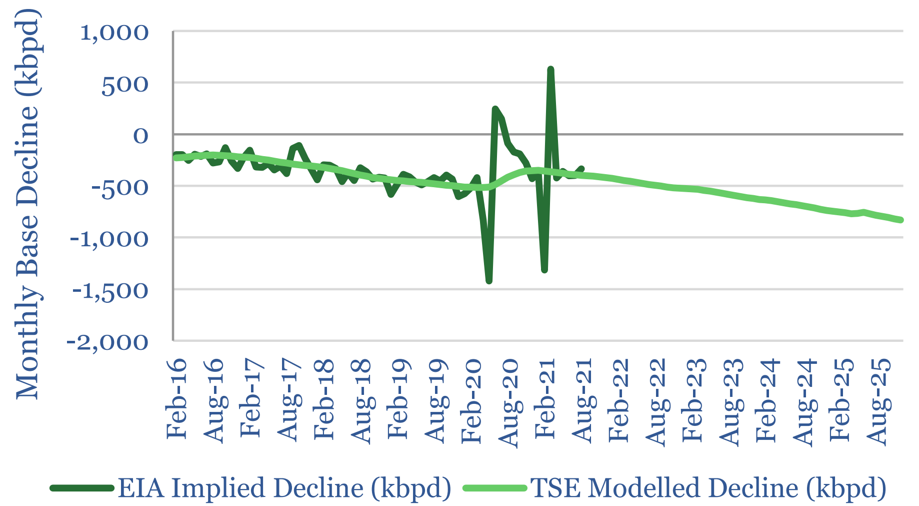
Sources: https://thundersaidenergy.com/downloads/development-capex-long-term-spending-from-oil-majors/

https://thundersaidenergy.com/downloads/exploration-capex-long-term-spending-from-oil-majors/

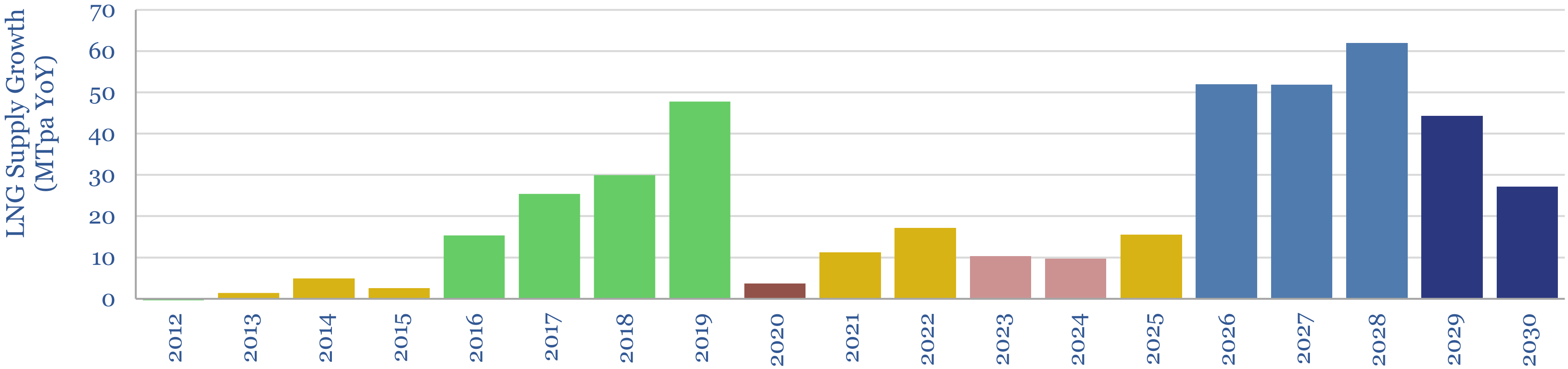
Shale investment? In the US's big three shale basins (Permian, Bakken and Eagle Ford), our 2023+ production forecasts have been revised down by -7Mbpd since 2019 (due to COVID volatility) and -1.5Mbpd since 1Q22 (due to capital discipline). Our 2024 growth forecast is +1.7Mbpd, of which +1.2Mbpd hinges on *adding* 75 rigs (c16% growth) in the next year. This will not happen if weak macro causes weaker oil prices.

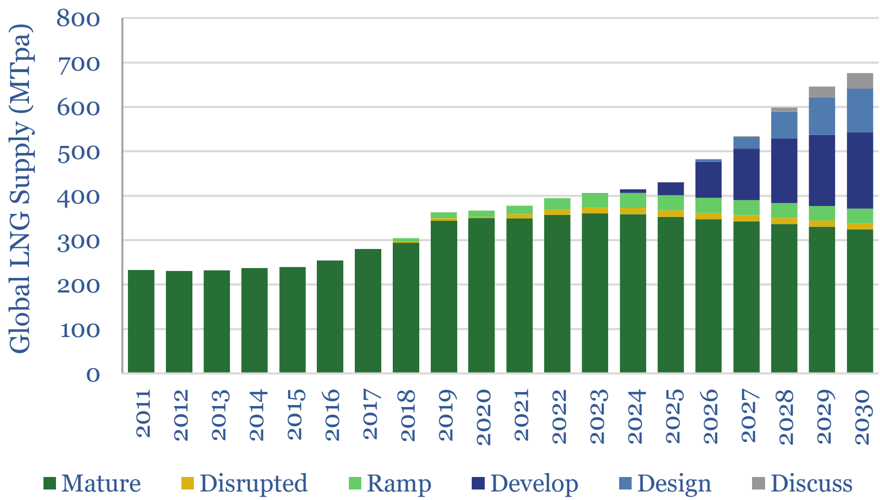


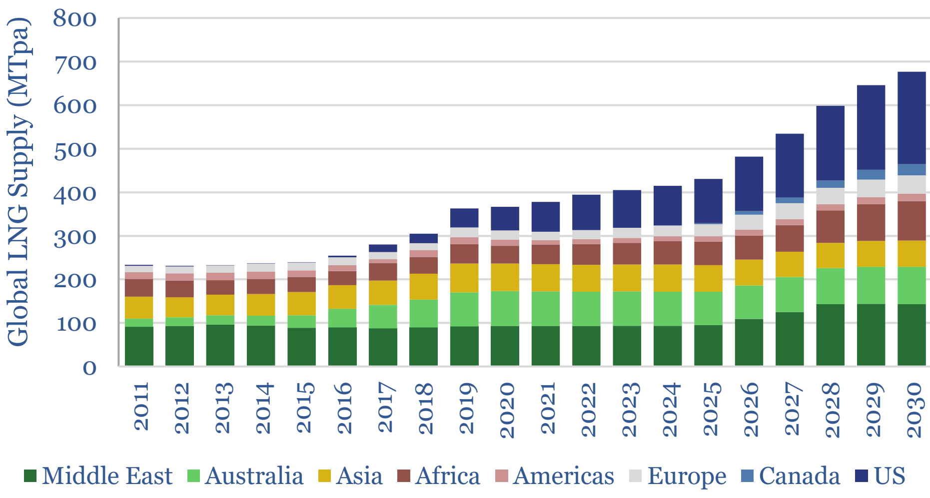




LNG. Global LNG reached 400MTpa in 2022. However, after rising by +20MTpa each year from 2015 to 2022, the world will be lucky to add +10MTpa in 2023 and 2024. The cavalry does not arrive until 2026-30, where each year could bring +50MTpa of new supplies. Half is already under development and hoping for no construction delays. But for the other half, some commentators are concerned about gas supplies, EPC bids re-inflating from $700/Tpa to c$1,000/Tpa, rising interest rates and equivocation from long-term gas buyers.



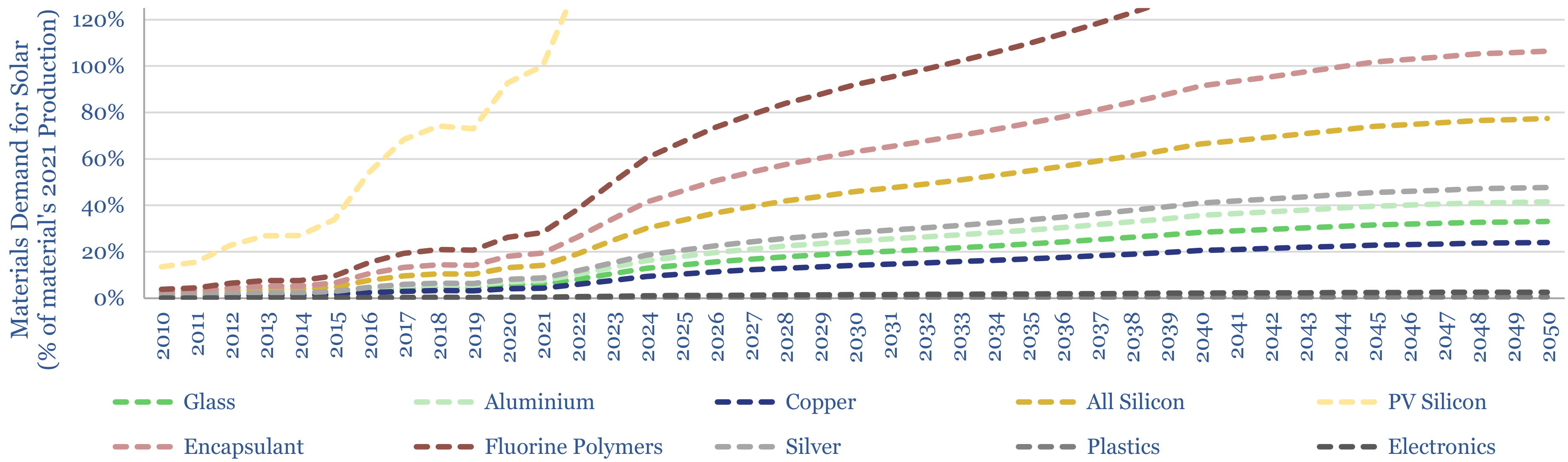


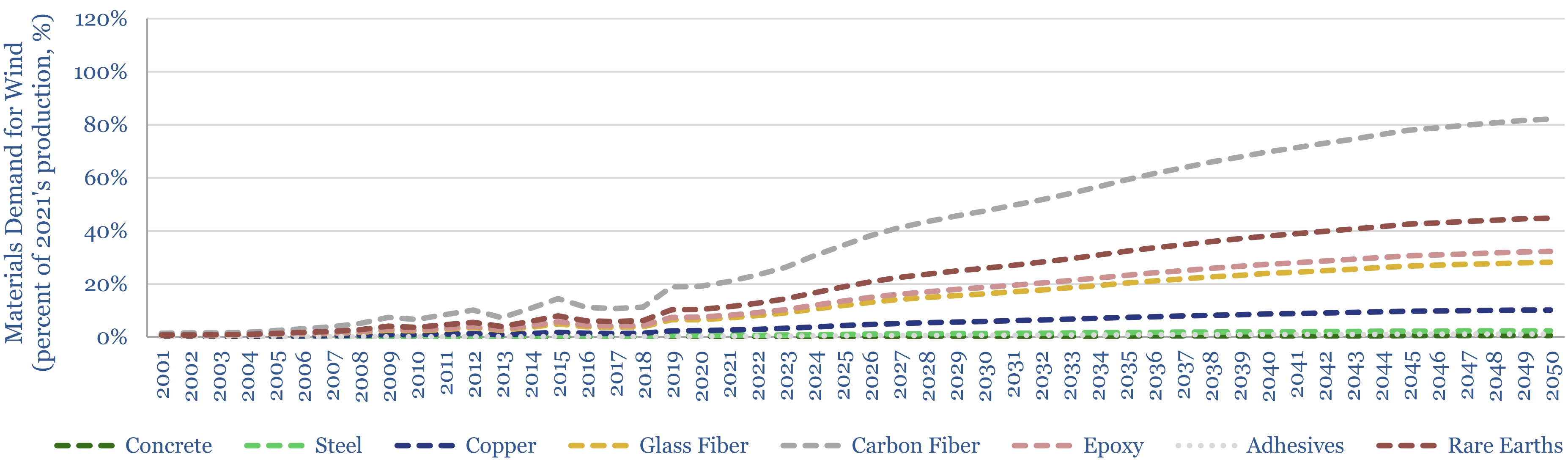


Source: Thunder Said Energy. **Source:** https://thundersaidenergy.com/downloads/long-term-lng-supply-model/

Research Note: https://thundersaidenergy.com/downloads/category/lng/

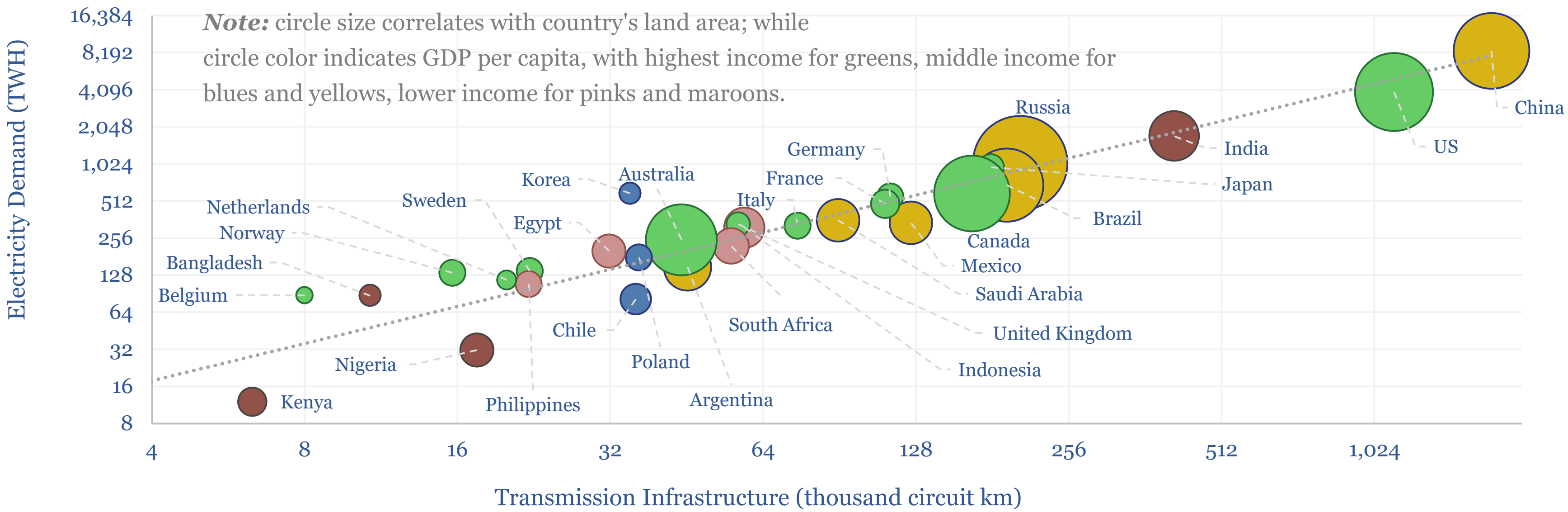
Materials for +650GWe peak solar and +330GWe gross wind additions will be soft bottlenecks. The charts below the percentage of each material's total current global supply that would be absorbed just for wind and solar projects.

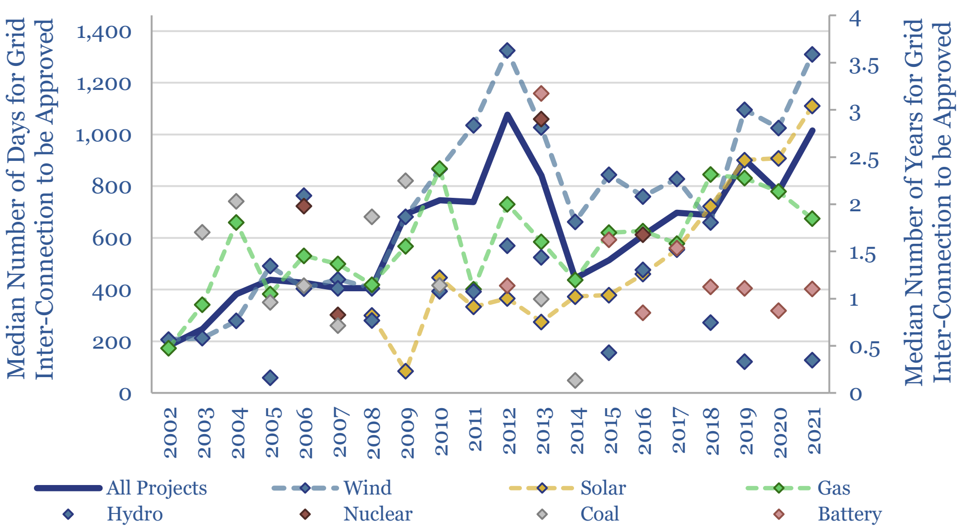


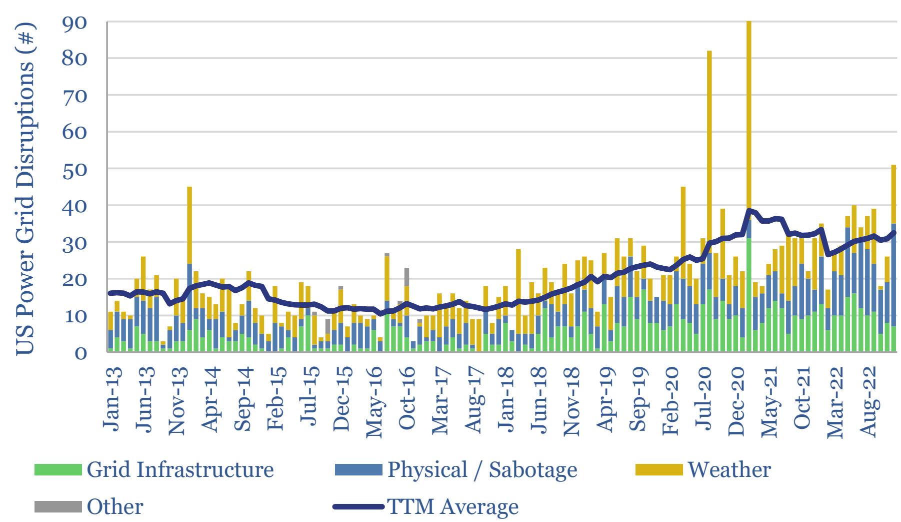


Solar Source: https://thundersaidenergy.com/downloads/solar-energy-payback-and-embedded-energy/
Wind Source: https://thundersaidenergy.com/downloads/onshore-wind-the-economics/

Power grids will likely be the biggest bottleneck for integrating renewables at the desired pace. Today's global grid contains 7M km of power transmission lines and 110M km of smaller distribution lines. Each GW of wind and solar statistically requires 500km of new transmission and 8,000km of new distribution.

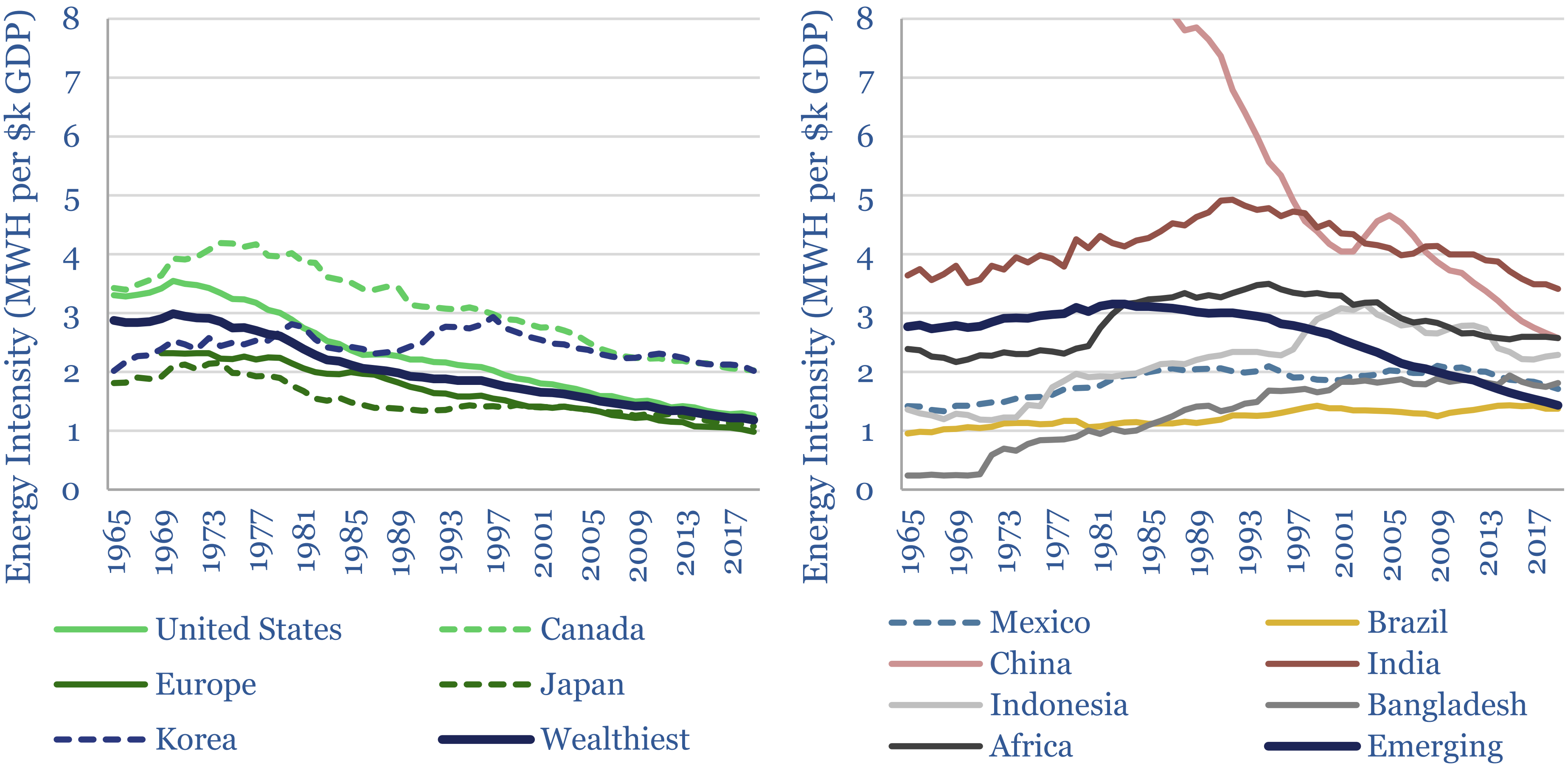






Power Grids Research: https://thundersaidenergy.com/downloads/category/power-grids/

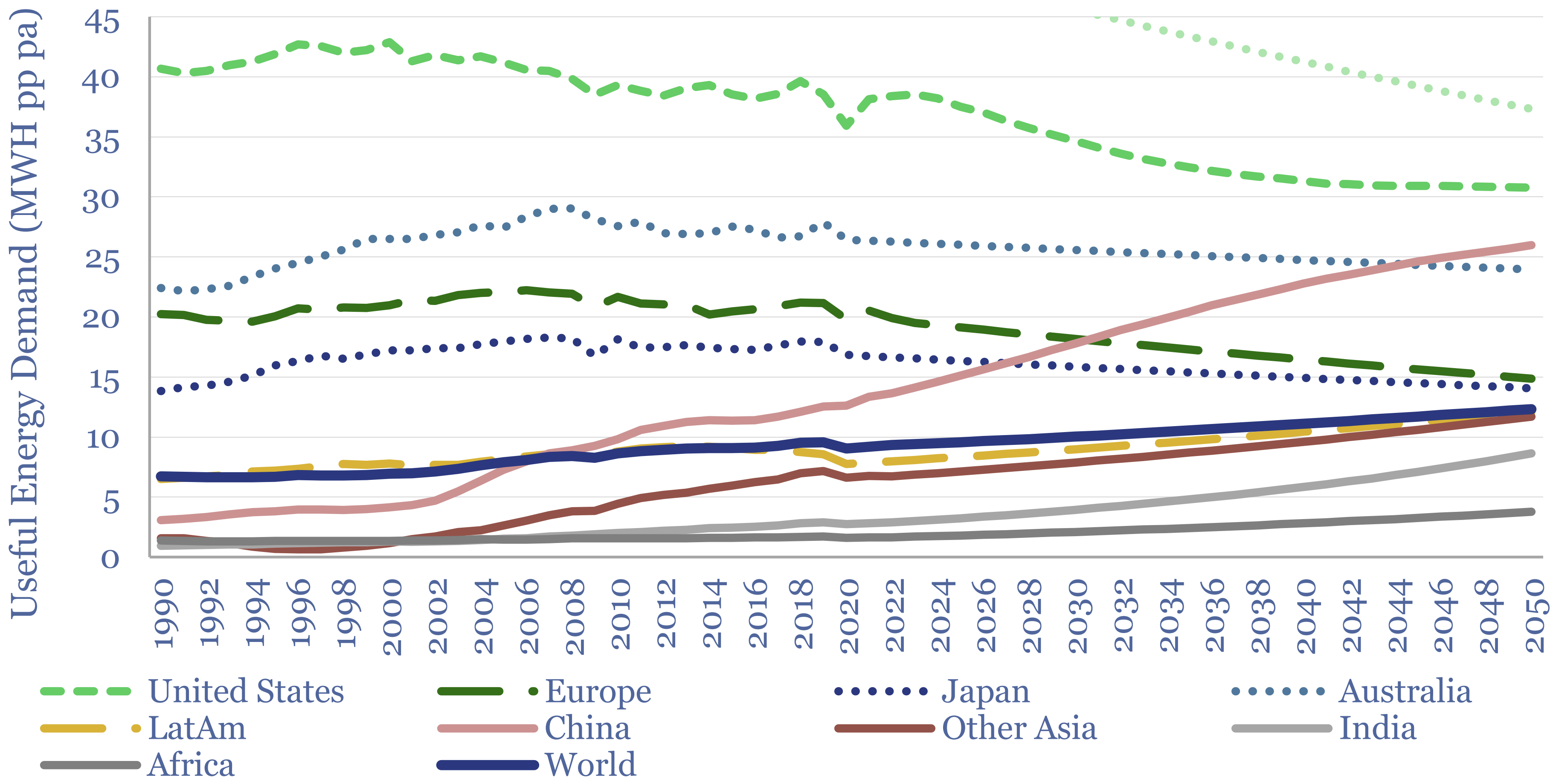
Where are our numbers different from other commentators'? An important controversy centers around the pace of future demand destruction due to efficiency gains. Historically, global energy intensity of GDP has improved at 1% pa since 1970. We think it steps up to 2.3% pa in the energy transition (from 0.8% pa to 1.1% on a primary basis, from -0.3% pa to +0.3% pa on a secondary basis, and the rest is wealth effects). The IEA's Net Zero scenario sees a step-up "above 3% pa", hence global energy demand is envisaged to start declining, falling 20% by 2050. We think global energy demand grows 20% through 2050. Or at least it would want to, if supply was available. If not, prices must rise to destroy demand. Links below.



Source: https://thundersaidenergy.com/2023/03/02/energy-efficiency-a-riddle-in-a-mystery-in-an-enigma/

Source: https://thundersaidenergy.com/downloads/global-energy-demand-by-region-and-through-2050/

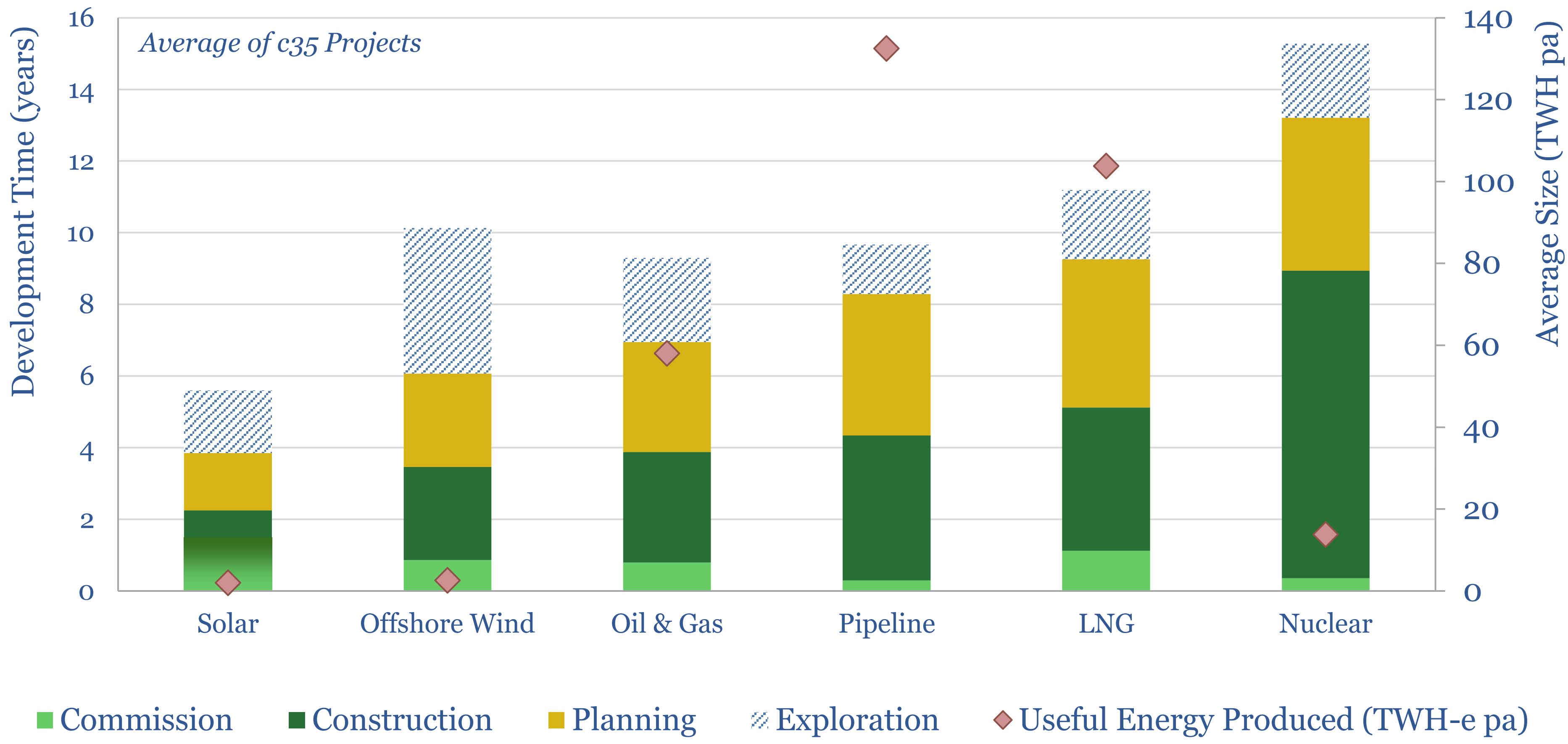
Energy demand: will global energy use grow by 50% or fall by 20% between now and 2050? The 'top billion' consumers globally account for 26MWH per year of useful energy, while the remaining 7bn are at 6MWH pa, and the 'bottom 4 bn' are at 3MWH per year. Our bridge to 120,000 TWH is below.



Source: https://thundersaidenergy.com/2023/03/02/energy-efficiency-a-riddle-in-a-mystery-in-an-enigma/

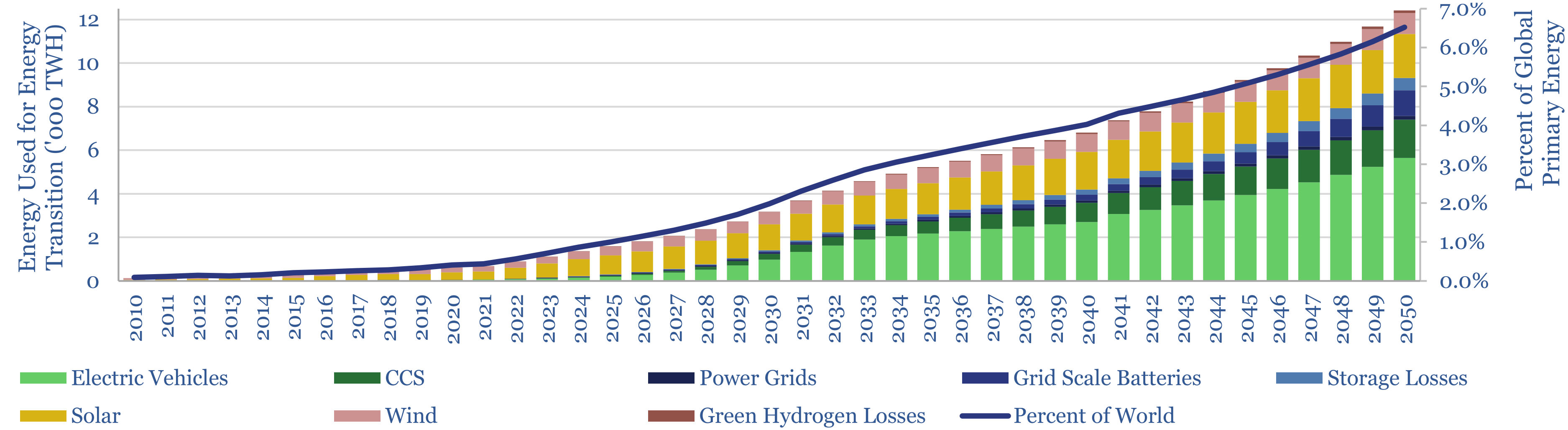
Source: https://thundersaidenergy.com/downloads/global-energy-demand-by-region-and-through-2050/

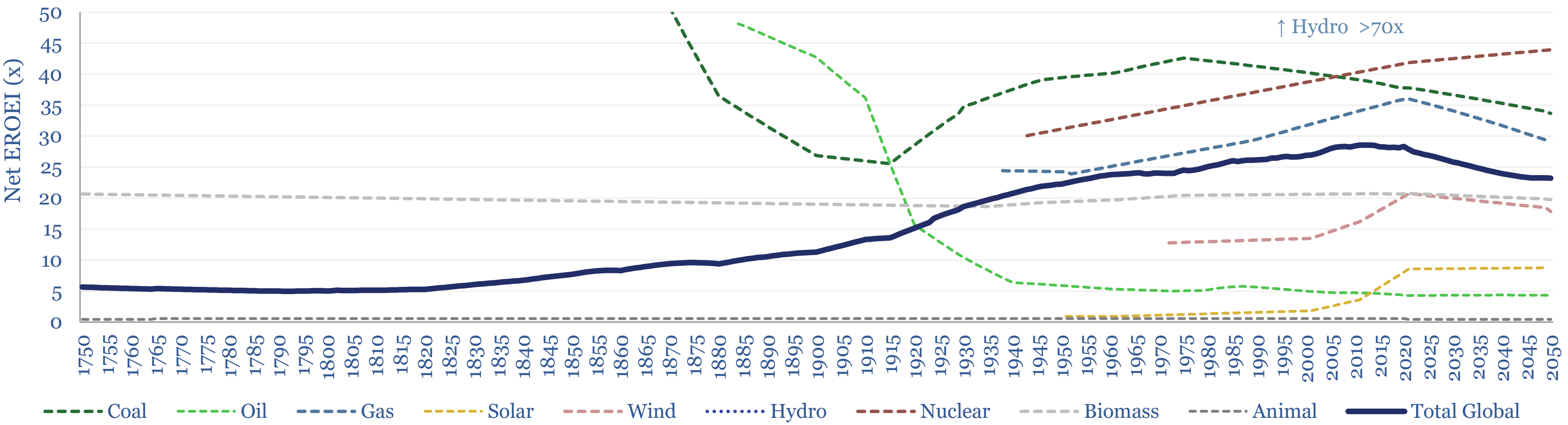
Full cycle development times average c4-years for large solar projects, 6-years for large offshore wind, 7-years for new pipelines, 7-years for new oil and gas projects, 9-years for new LNG plants and 13-years for new nuclear plants. As a rough split, these timings break down as 40% planning, 50% construction and 10% ramp-up/commissioning. The best projects in each category are often around 50% faster than average. Thus overall, we think it may take a long time, perhaps even a total change of mindset, to improve the supply outlook in global energy. And even then, there are headwinds from interest rates and bottlenecks.



Source: https://thundersaidenergy.com/downloads/energy-development-times-first-consideration-to-full-production/

Building is getting harder? Reaching net zero requires building wind, solar, grid infrastructure, energy storage, electric vehicles and capturing CO2. Energy is needed for all of these things. And global net EROEI is falling. The total energy costs of energy transition reach 1% of total global primary energy in 2025, 2% in 2030, 4% in 2040 and 6.5% in 2050. Energy transition and investment go faster with energy surpluses.



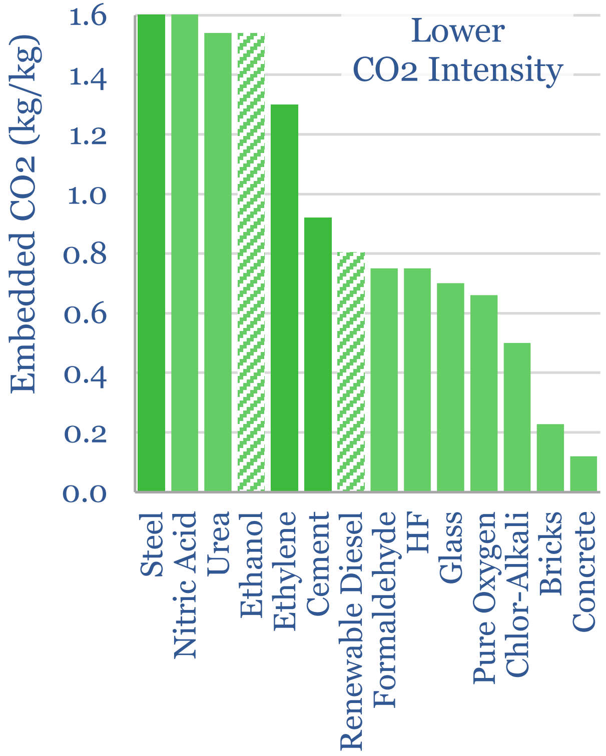


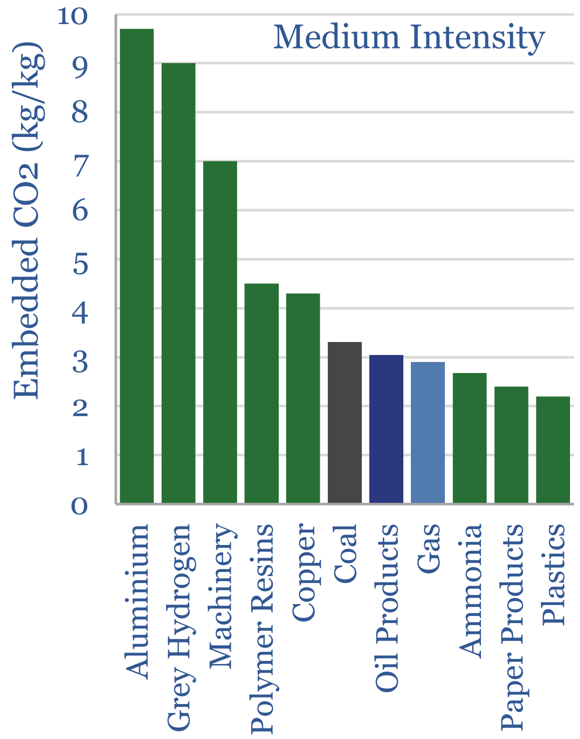
Source: https://thundersaidenergy.com/downloads/energy-costs-of-energy-transition/

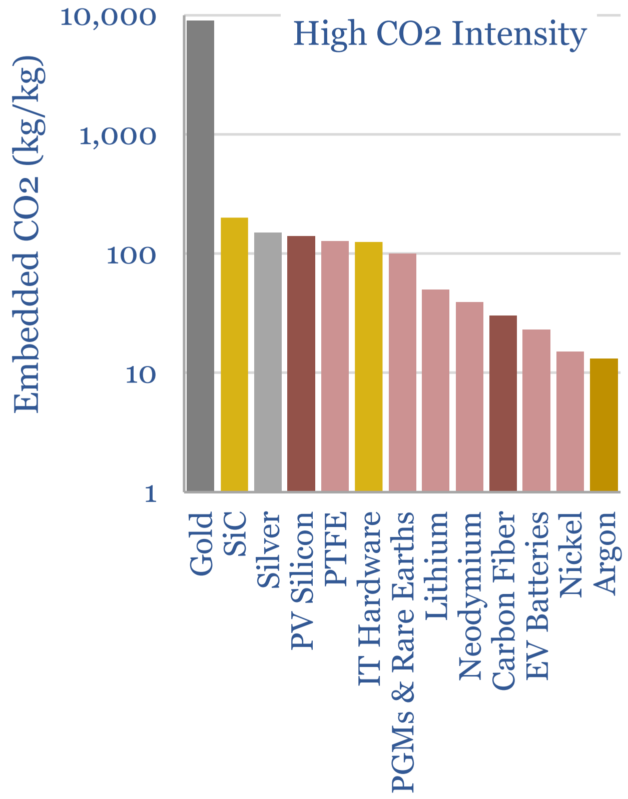
Research Note on EROEI: https://thundersaidenergy.com/2023/03/23/eroei-energy-return-on-energy-invested/

Energy transition: circular reference errors?

If producing a material emits 1 ton of CO_2 per ton of material, and the cost of abating CO_2 is $100/ton, then all else equal, decarbonizing the material is going to increase its costs by $100/ton. This creates a risk of circular references. Because these materials, in turn, are needed to construct decarbonization technologies.



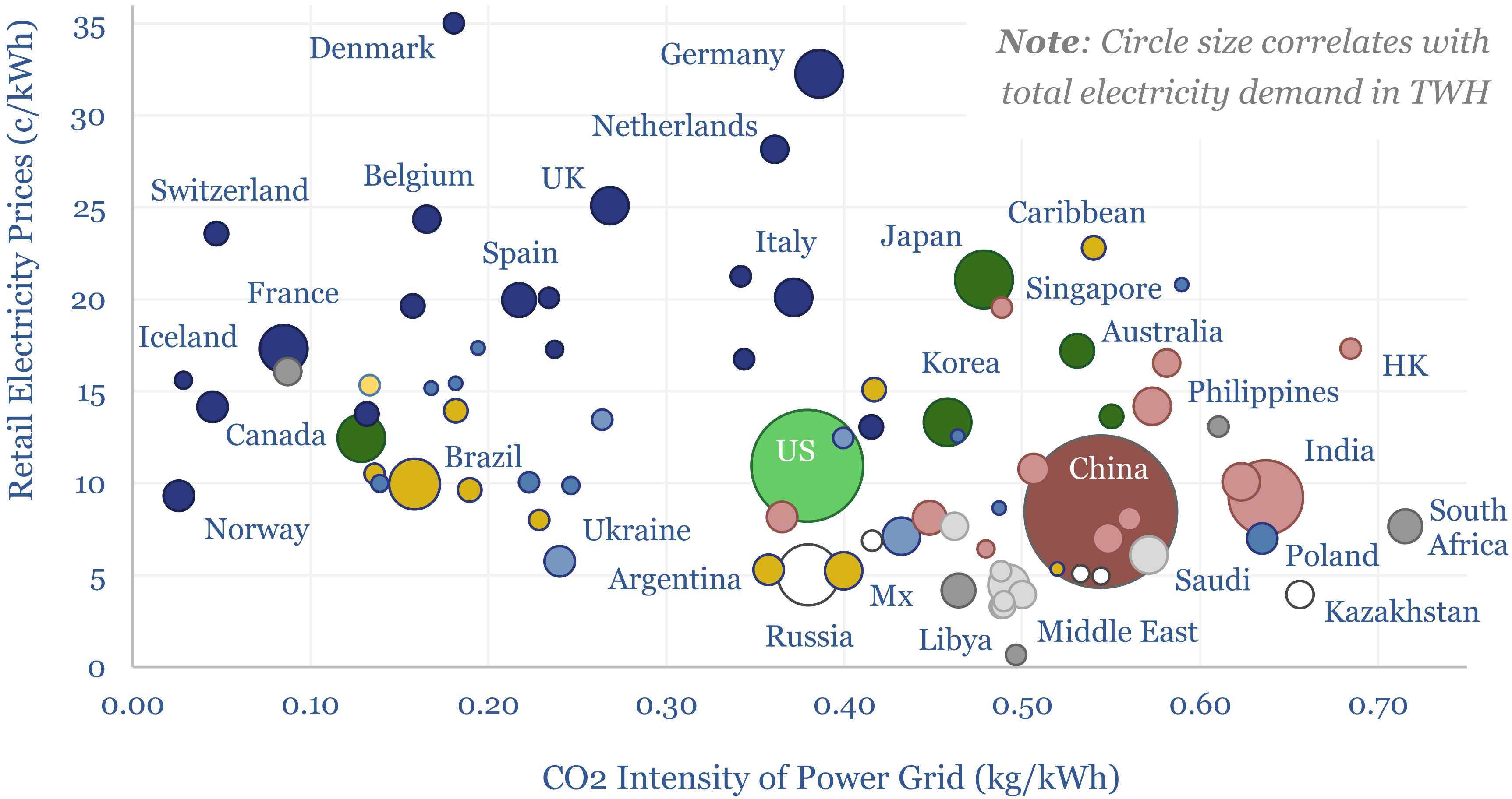




Source: https://thundersaidenergy.com/downloads/breakdown-of-global-co2-emissions/

Note and Case Study: https://thundersaidenergy.com/2021/12/02/green-steel-circular-reference/

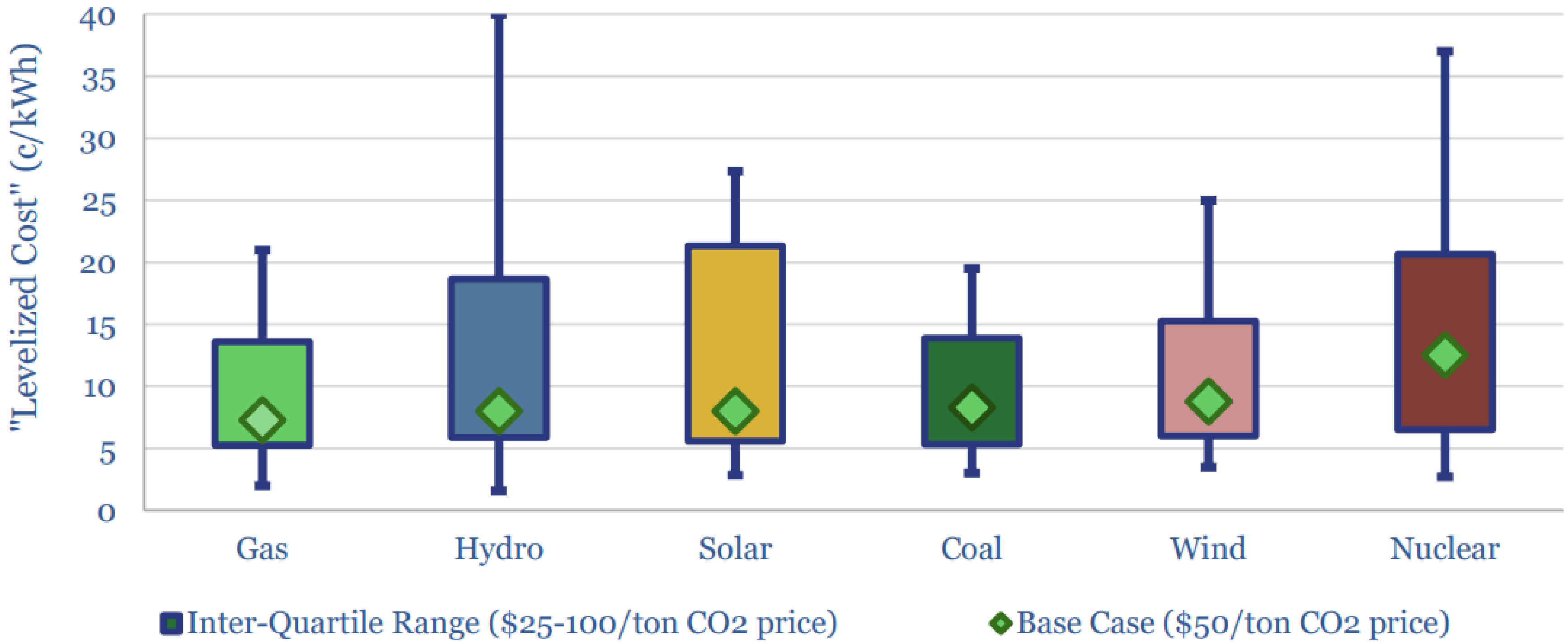
Energy arbitrages? Electricity prices average 11c/kWh globally, while CO2 intensity averages 0.45 kg/kWh, but the correlation is -35% (-45% ex hydro/nuclear/Caribbean). Does the world bifurcate into a high-cost and low-carbon energy geographies, versus low-cost and high-carbon energy geographies? And what arbitrage opportunities will this create?



Source: https://thundersaidenergy.com/downloads/global-electricity-prices-vs-co2-intensities/

Energy diversification? 'Levelized cost' can be a useful concept. But it can also be mis-used, as though one 'energy source to rule them all' was on the cusp of pushing out all the other energy sources. Cost depends on context. Every example in our chart below can beat 3-5c/kWh in the best contexts and exceed 15-20c/kWh in the worst contexts. The ranges are broad.

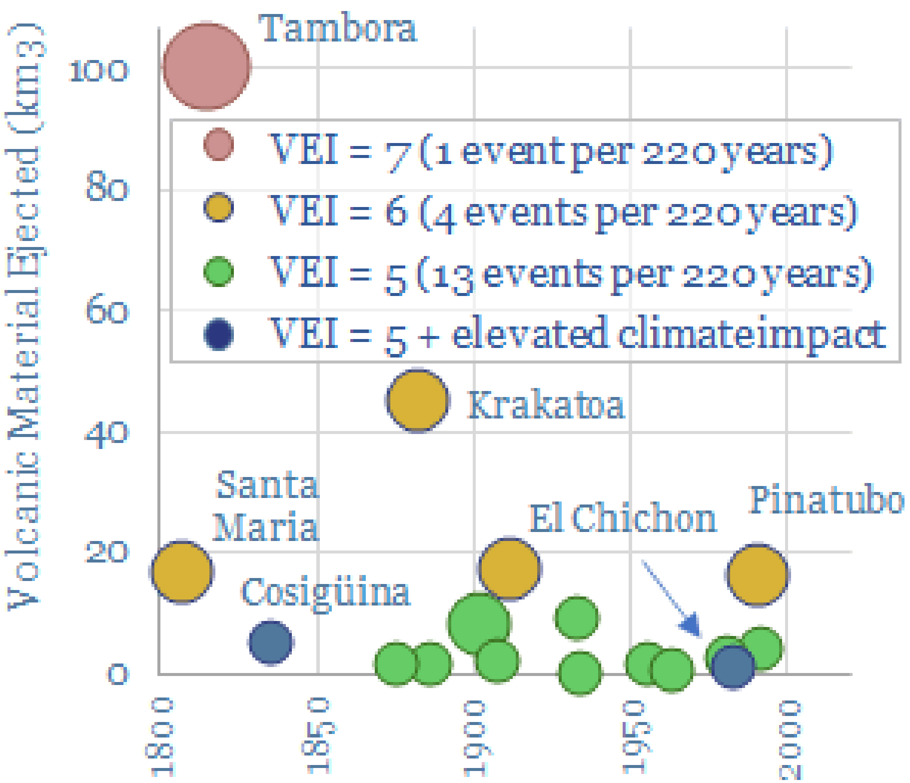
Fig 1. *True levelized costs for different electricity sources will range from 5-15c/kWh*

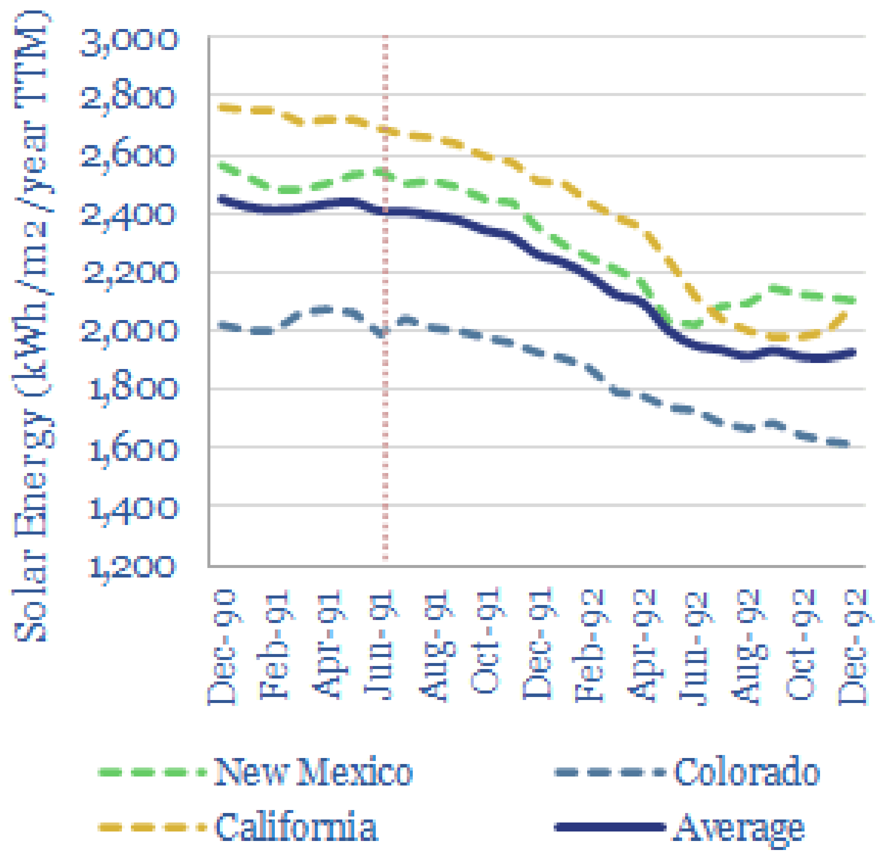


Source: Technical Papers, Companies, TSE Modelling [Download the data?]

Source: https://thundersaidenergy.com/downloads/wind-and-solar-capacity-additions/

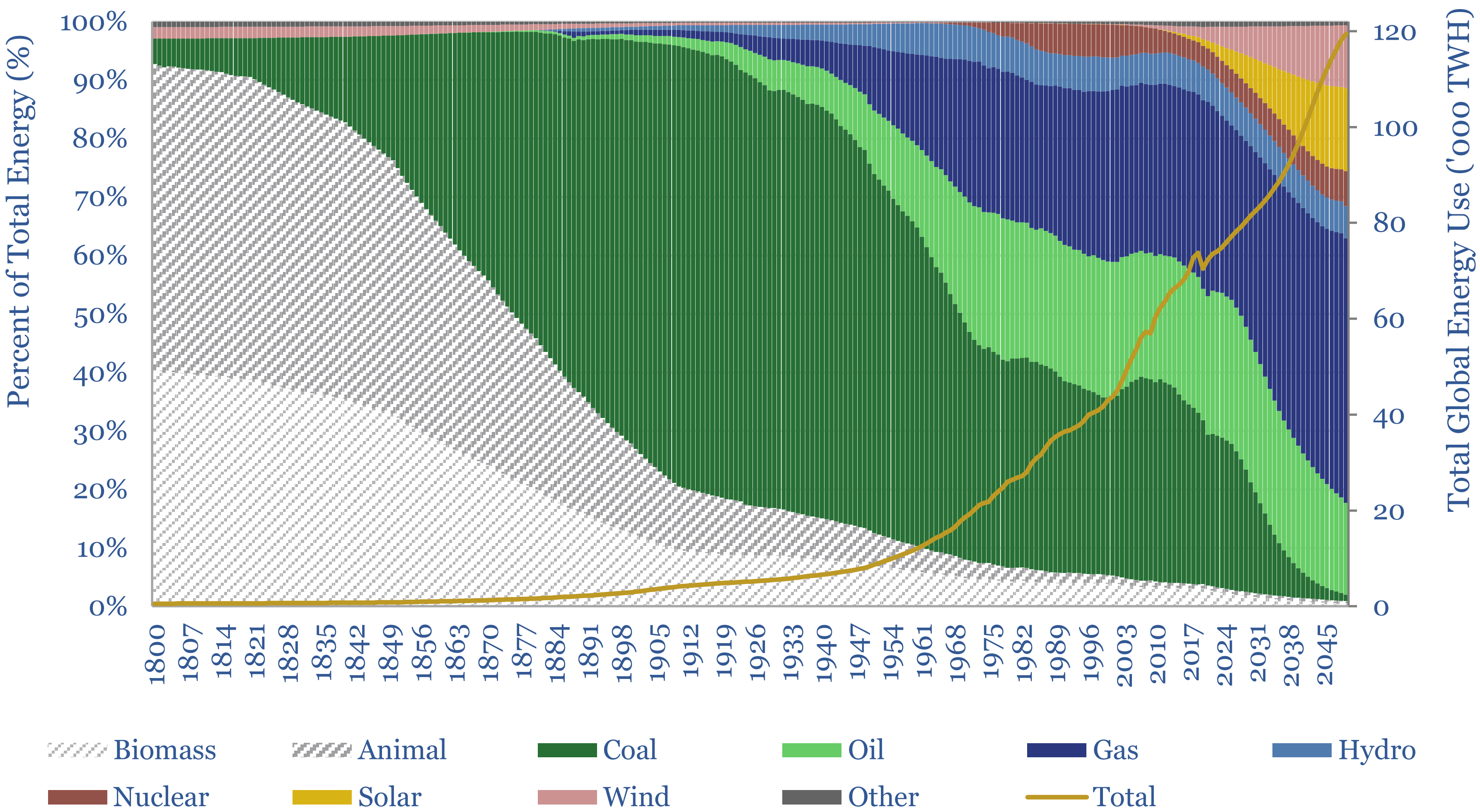
Energy resiliency? A very large volcanic eruption happens once every 30-years. One technical paper has quantified how incoming solar energy measured by weather stations in the US (California, Colorado, New Mexico) fell by 20% in 1992, the year after the eruption of Mount Pinatubo, 12,000 km away, in the Philippines in 1991. What implications for energy transition?





Source: https://thundersaidenergy.com/downloads/energy-security-volcanos-versus-solar-panels/

Total Global Energy Consumption runs at 70,000 TWH (equivalent to a kitchen toaster running constantly for every man, woman and child on the planet). Of this useful energy, c30% is from gas, c30% is from coal, c25% is from oil and the remainder is from 'clean' sources. Wind and solar are currently c3,000TWH. By 2050, total global demand will be 120,000 TWH.



Source: https://thundersaidenergy.com/downloads/the-2050-energy-mix-a-simple-model/

www.thundersaidenergy.com

contact@thundersaidenergy.com