

Split Rock Capital Management

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March 31st, 2023

To: All Investors

Re: Annual Letter 2022, Letter to Investors

Dear Investors:

In 2022 Split Rock Capital Management returned -8.12% net of fees.¹ Our annualized return since inception is 10.22% vs 11.58% for the S&P 500 (dividends included). \$100,000 invested at inception has grown to approximately \$198,510 vs. \$216,510 if invested in the S&P 500 (dividends included).

Year	S&P 500 ²	Split Rock (Gross) ³	Split Rock (Net) ⁴
2015 ⁵	1.18%	(0.42%)	(0.47%)
2016	11.96%	13.19%	12.19%
2017	21.87%	19.47%	18.47%
2018	(4.41%)	(1.68%)	(2.68%)
2019	31.49%	13.43%	12.44%
2020	18.40%	12.07%	11.07%
2021	28.71%	35.37%	34.37%
2022	(18.11%)	(7.12%)	(8.12%)
Cumulative Return Since Inception	116.51%	111.62%	98.51%
Annualized Return Since Inception	11.58%	11.22%	10.22%

**Please refer to the disclosures (1 to 5) at the end of this letter as well as the disclaimer on the page 82*

**All results have not been audited*

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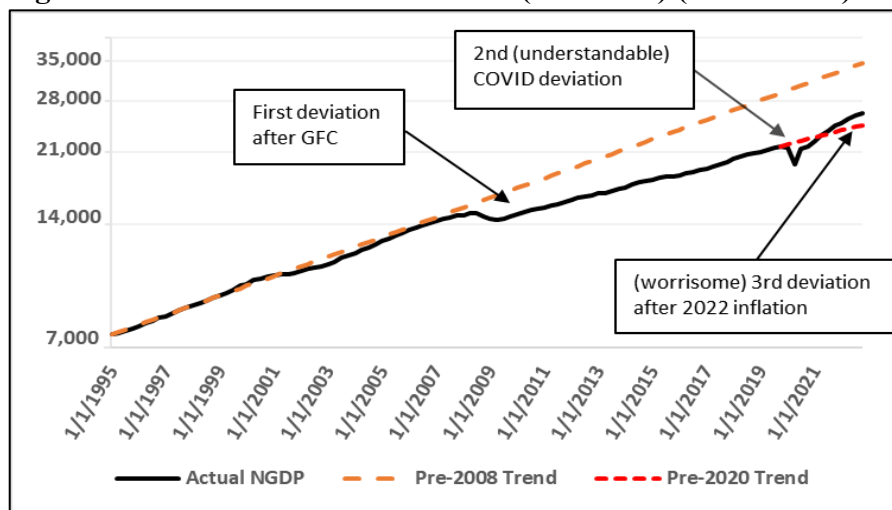
Chapter 1: General Economic and Market Conditions

Nominal GDP Level Target (for the 1000th time)

“[I believe that has some significance for our problem](#)” – Richard Feynman

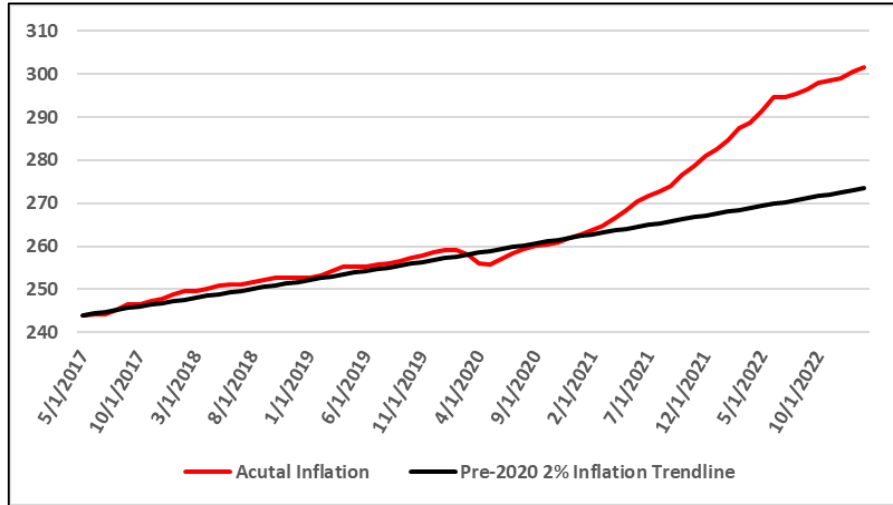
The market and economy continued its relatively wild swings in 2022. This continues a pattern of instability we’ve noted in the economy, in particular, as measured by NGDP. Since 2008 we note in the figure below that NGDP has failed to stay on either of the trendlines: first falling below the pre-2008 trendline and then gyrating below and then above the pre 2020 trendline. While some fluctuations are understandable (there was of course going to be a drop in NGDP during the COVID crisis), what is not understandable is the failure to correct for these past deviations. There was nothing stopping the Fed from returning to the 2008 trendline during the 2010 to 2015 time period. And we fail to understand why the Federal Reserve can’t *presently* get back to the pre 2020 NGDP trendline by 2026 or so.

Figure 1: Nominal G.D.P. Trendlines (Billions \$) (1995 - 2022)⁶



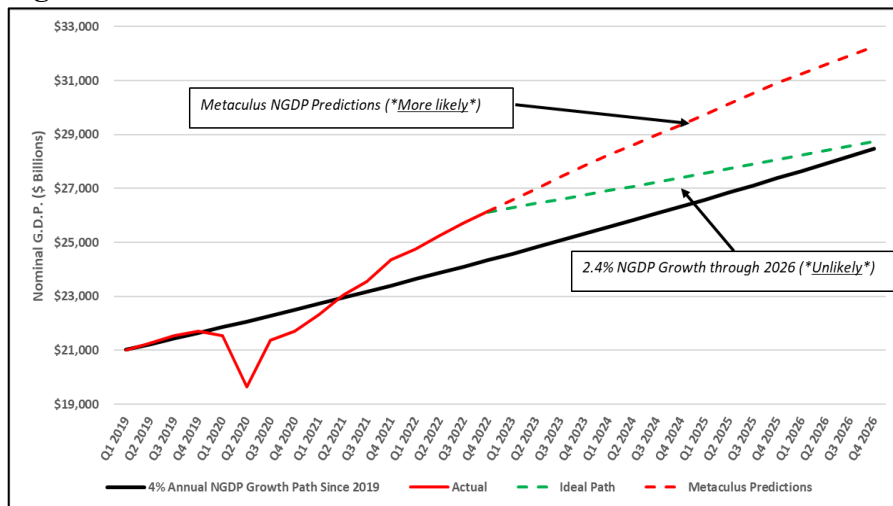
We’ve covered extensively in past letters the importance of staying on trend. Unfortunately, not only has the Fed dismissed NGDP targeting, claiming the public doesn’t understand it, but they’ve also dismissed inflation *level* targeting.⁷ In the above graph, we’d note that NGDP is currently about 7% above the “pre-2020” trendline. However, the deviation is even worse when we look at inflation. In the graph *below* we note that inflation is about 10% higher than the pre-2020 inflation trendline!⁸

Figure 2: Consumer Price Index (Actual and Trend) (2017 - 2023)⁹



What advantages would a level target hold? On the next graph below we illustrated the type of correction we would need to get back to the red NGDP trendline from Figure 1 (approximately 2.4% NGDP growth out to 2026 is needed, represented by the dotted green line below). Unfortunately, the more *likely* scenario, according to Metaculus, is the dotted red line, where NGDP remains above trend indefinitely (or certainly long enough that any far in the future return to trend would be counterproductive).¹⁰ Many will push back on the 2.4% NGDP growth needed for the next three years under such a return to trend. This would be tough on the economy and would certainly raise unemployment. However, keeping inflation in check is also critical. Unemployment is at 3.6% (some of the lowest levels in the past half century). *If now is not the right time for moderately low NGDP growth, in order to get back to trend, then when is?* We could likely get back to the trendline with employment staying below 8% and likely lower than that. And of course, the choice between inflation and unemployment is a false dilemma. If we keep running inflation hot, then we'll still need a rise in unemployment in the future, and a likely *higher* rise in unemployment at that (vs. if we act now to crush inflation).

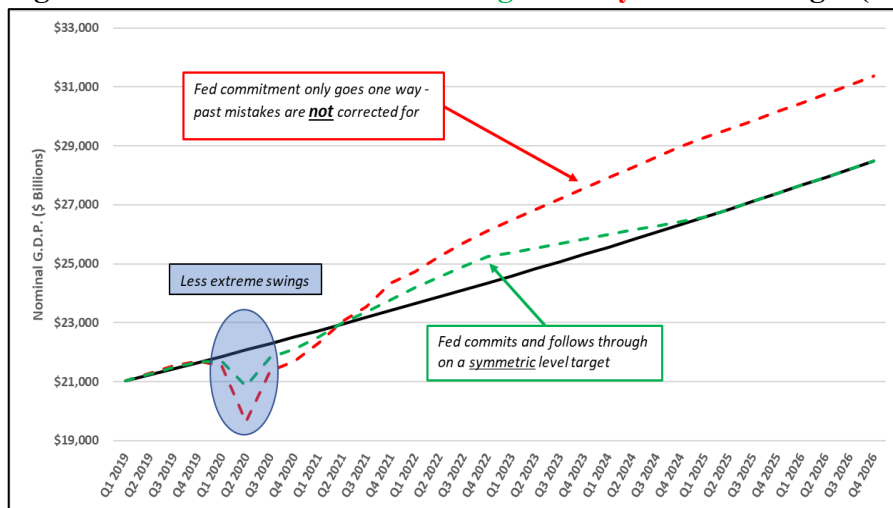
Figure 3: Nominal G.D.P. Trendlines in the Future¹¹



We next move on to the importance of expectations in monetary policy. In 2022 the market correctly saw that the Fed would not make up for past mistakes. Importantly, this correct assumption has not only an obvious impact on *future* inflation, but it also almost immediately affects the then *current* level of inflation. If economic actors know that inflation will be running hot for the next decade, this affects their spending habits *now*. They will spend more

freely in the present in the expectation of future rapid rates of devaluation. In other words it's hard/impossible to target say 2026 inflation without it almost immediately affecting the current 2023 inflation (and NGDP). Below we illustrate, that if the Fed had committed to returning to trend in 2022 (by say 2026) then even the 2022 inflation and NGDP growth would have been moderated (because the market could credibly believe that inflation would lower in the near future). Instead, the market correctly saw the Fed would not return to trend in the *future* which increased the *current* inflation.¹² Expectations management and credibility leads to less wild swings in inflation and NGDP (represented in the green line below). Unfortunately, current policy is more like the red line (i.e., an asymmetric target without corrections for past deviations).

Figure 4: Nominal G.D.P. Level Target vs Asymmetric Target (2019- 2026)¹³



Related to our quote at the beginning of this letter, the FOMC *leadership* needs to start listening to the selective few boots on the ground economist within and outside the Fed, who are arguing for sane, level target policies. Ben Graham has noted that Mr. Market in manic.¹⁴ **While the Fed is far from the only cause of this manic behavior of Ben Graham’s “Mr. Market”, it (and the resulting wild NGPD fluctuations) is certainly a major cause.** And there’s a simple fix to it: adopt NGDL level targeting.

The Debt Ceiling, Trillion Dollar Coin and Federal Reserve Solvency

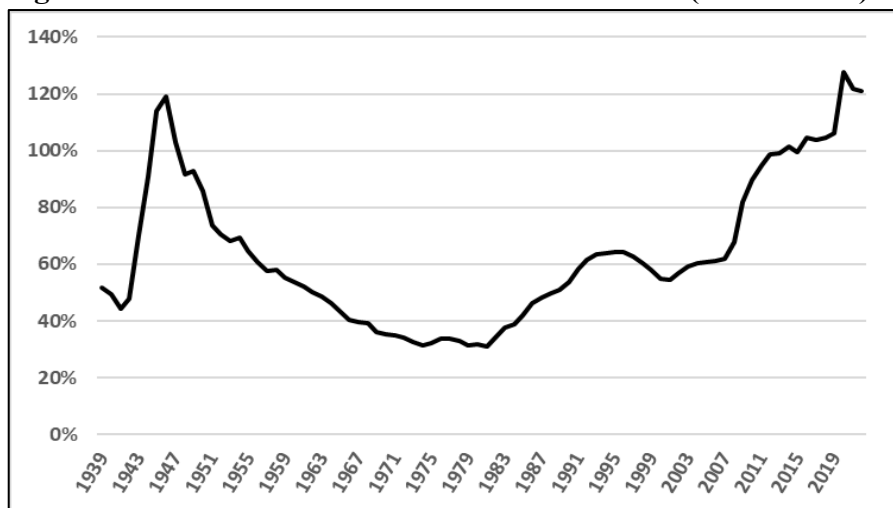
The debt ceiling and the threat of using it to possibly default on Treasuries has come up again in the news. The last debt ceiling crisis was thankfully resolved (temporarily) back in 2013. Of course our preferred option is to get rid of the debt ceiling all together, and rely on Congress to set spending levels. We shouldn't hold treasury bond holders responsible for decisions on spending that congress itself made and agreed to. If Congress wants to cut spending, they should do that in the budget process. Passing a high spending budget, and then threatening to not write the check for it, is no a sane approach to the issue. *Private individuals should not sign overly expensive contracts, and then threaten to not pay the check after signing. Congress shouldn't do this either.*

As a result of the debt ceiling issue, some have floated a potential work around: minting a platinum trillion-dollar coin. As a result of a legal oddity, there remains the possibility that the Treasury could mint a trillion dollar coin and deposit it at the Federal Reserve. This would, in theory, generate one trillion dollars in seigniorage without increasing the debt. That said there are many issues with this. Would the Fed even accept this coin on its balance sheet? Jerome Powell was asked this very question at a recent hearing: "There are no rabbits to be pulled out of hats here. And *that* (i.e. accepting the trillion dollar coin on the Fed's balance sheet) would be a 'rabbit out of a hat'".¹⁵ Clearly this workaround would be encroaching on the independence of the Federal Reserve and is questionable a legal sense.¹⁶ If the Fed were forced in some way to accept the coin, then Treasury and Congress would in effect be in charge of monetary policy (and fiscal policy) and the independence of the Fed would be greatly diminished or eliminated.¹⁷ Congress should not be in charge of the printing presses and there needs to be at least a modicum of separation between spending and printing money. David Wilcox said it best regarding the trillion dollar coin and other "workarounds":

"I'm really quite reluctant to engage on this inventory of potential so called work arounds. Others might give them a more pejorative descriptor. I think what they have in common across all (these ideas) is an effort to divide the will of the congress and several of (these ideas) involve politicizing the Federal Reserve in a way that I think would be dangerous for the vitality and functioning of that institution. I think I would subscribe to Chair Powell's comments recently where he said 'there is really one way to resolve this, and that is for Congress to raise the debt ceiling'. There is a debate to be had about the fiscal trajectory of the country. Let's have that debate, it's a fine issue to think deeply about."¹⁸

To be clear, we are worried about the federal debt and government spending. There are many sane approaches that can bring down the debt over time.¹⁹ As we can see below, the current path over the past two decades is unsustainable.

Figure 5: Gross Federal Debt as Percent of G.D.P (1939 – 2022)²⁰



Wrapping up this section, we note that, with the rapid rise in interest rates, many pundits have begun worrying about the Federal Reserve's balance sheet, noting cash losses for the Fed at \$18 billion (and mark to market losses around \$1.1 trillion).²¹ That's said, it's important to note that the Fed remitted to the Treasury approximately \$850 billion from 2012 to 2021.²² It's important to look at remittances *over time* and not get hung up on a single year's losses (which occurred, by the way, under one of the most rapid rises in interest rates we've ever seen, in a noble effort to fight inflation). That said, it is true that the Fed will soon have negative equity capital.²³ There may be some political risk from these losses, but in a technical sense, the worries are likely overblown. Lawrence White clarifies:

"The Fed itself, is already insolvent. The Fed itself (like SVB) has a very long bond portfolio. And its lost enough money to wipe out its capital. But that doesn't stop them. **In a fiat money system, no one can redeem the Fed's liabilities.** So, they can keep on printing and lending to banks. But they don't need to engage in a hyper expansion (of the Fed's balance sheet) in order to lend more to (commercial) banks. And even if they lend more to banks and don't neutralize the monetary base, they can (at least) neutralize the effects on money held by the public. So, it depends on if the Fed will take those steps. And if they are at all serious about keeping inflation contained, then they will *have* to take those steps."²⁴

Silicon Valley Bank

One of the leading headlines in Q1 has been the collapse of Silicon Valley Bank. There are many others more qualified to opine, but we'll attempt a brief summary here (Split Rock had no exposure to Silicon Valley Bank or Credit Suisse). We've written in past letters about the basic functioning of commercial banks which might be a good primer to re-read before we dive into the details of Silicon Valley Bank (SVB).

SVB was a medium size commercial bank that catered to the VC and tech community in the San Francisco Bay Area. Over time they established special relationships with founders and acquired unique knowledge of the tech startup scene. This led them to "serving as banking partner for nearly half of U.S. venture-backed technology and healthcare companies that listed on stock markets in 2022."²⁵ Going into 2022, SVB ended up with about \$209 billion in assets, and about 93% of their deposits being uninsured by the FDIC.²⁶ While oversimplifying a bit, the problems arose when SVB stored some of its treasuries in longer durations than was prudent. While treasuries themselves are safe, there can be duration mismatches. As an extreme example, long term 25-year zero coupon bonds can have wild swings in their market price, despite being "safe". From peak to trough, ZROZ (a 25 year zero coupon ETF) lost over 50% of its value in 2022 alone. While not as extreme (i.e. SVB didn't hold zero coupon bonds), SVB got in trouble by loading up on longer duration bonds (10 year treasuries, mortgage-backed securities (MBS), etc.) that, when inflation/interest rates rose, these bonds market values declined. Holding shorter duration instruments like 3-month treasuries would have mitigated this risk (interest hedge, etc. could also have been more prudently used – of course this would have lowered the bank's income). Given that banks are highly leveraged institutions, small changes in a bank's portfolio can quickly lead to insolvency concerns. This appears to have happened in this case.

Matters were further complicated by some of the accounting issues that arose. SVB had been, for accounting purposes, holding these longer duration bonds in what is known as HTM ("Hold to Maturity"). This allowed them to carry the bonds at par value instead of the lower market value. Other assets, that are "Available for Sale" (AFS) immediately, are held at their market value. This accounting treatment for HTM assets works as long as the bank's customers don't come in and demand their money. Unfortunately for SVB, this is exactly what happened. There were rumors of solvency issues at SVB which quickly led to customers withdrawing funds. In order to meet these withdraws, SVB was forced to sell assets, many of which were listed as HTM. However, when sold during the forced liquidation, these HTM assets, formerly carried at par, were now forced to be marked to market at the lower price, booking a loss. Liquidity issues quickly become solvency issues when assets are sold well below the HTM carrying price on the bank's books.²⁷ As an (overly) simple example: a bank levered 10:1 would only need a 10% discrepancy in the HTM price vs AFS/market price for the bank to be insolvent if they had a run on their bank. This is essentially what occurred at SVB.²⁸ We note the roughly 20% drop in 7-10 year treasury ETF (IEF) (peak to rough) in 2022 alone.

Of course since SVB collapsed the Fed has moved in to at least temporarily guarantee *all* deposits at SVB as well as Signature Bank.²⁹ In addition, there is still the conundrum and balancing act that must be worked out: 1) The Fed has all but guaranteed deposits that largest four or five banks. These are truly too big to fail and it's very unlikely any of them would be let to fail. 2) Smaller banks don't have this guarantee/subsidy, or its at least not as clear. Many have rationally begun to move their money from the smaller banks to these larger Global Systemically Important Banks (G-SIBs). However smaller banks serve a useful purpose. Local relationships are usually much easier and effective at these smaller banks, where the loan officers have more detailed, boots on the ground, knowledge of companies, etc. that are seeking loans. In the case of SVB, they had significant local knowledge of the tech scene that larger banks like JP Morgan Chase do not have. Moving to a banking system with 4 or 5 large banks would likely affect the number of startups being formed, etc.³⁰ Of course, sometimes, these smaller banks take undue risks and make unwise concessions to startups, etc. in order to compete with the "too big to fail" subsidy that large banks enjoy and these smaller banks do (did) not enjoy.

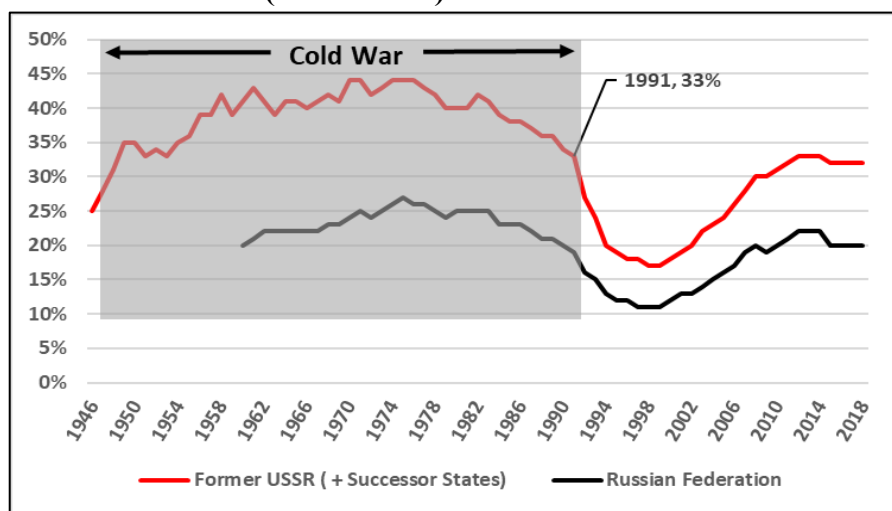
Chapter 2: War in Ukraine and Geopolitics in the Past and Future

Background and History of Ukraine – Russian – NATO relations since 1991

In addition to COVID, the primary news event of 2022 was of course the brutal Russian invasion of Ukraine. We won't rehash the day by day account here (as most are aware of the logistical details) but we instead add some historical perspective.

The Soviet Union collapsed in the 1988 to 1991 period. In geopolitics, there are various classifications of world order among global powers. Prior to 1988, the world was classified as a bipolar world order in which two powers, the United States and the Soviet Union competed (in both cold and hot/proxy wars) for dominance. And one of the critical metrics in any military competition is the size of each nations economy. To quote an old military axiom, “**For war you need three things: 1. Money. 2. Money. 3. Money.**”³¹ Below, we compare the GDP of the US compared to Russia, and see that while the US had a consistent lead, there were no long term trends of pulling away from the competition until the end.

Figure 6: Soviet Union/Russian GDP as a Percentage of United States GDP (1946 – 2018)³²



Certainly one of the contributing factors to the collapse of the soviet union was the downward trend in relative GDP in the USSR starting in the 1980s.

After the collapse of the Soviet Union, the world left the bipolar geopolitical structure and entered a *unipolar* power structure, with the United States being the sole remaining superpower – essentially uncontested. The United States continued to assert its will across the globe, but was relatively constrained (at least compared to other great powers in history). The US continued to lead NATO and, while the Soviet Union had indeed collapsed, there was still negotiations to be done – afterall Russia still had many nuclear weapons and was not completely removed from the geopolitical scene.

While it's debatable what the United States promised Russia in the early 1990s in regards to NATO expansion, it's clear that NATO became more and more of a pressing concern for Russia, especially after Vladimir Putin took over in 2000.³³ One of Russia's (at least overt) claims and wishes was: that NATO not expand eastward into what Putin considered the Russian sphere of influence.³⁴ States that shared a land border with Russia were a particular sticking point (Latvia, Estonia, Belarus, Ukraine, etc.). In Putin's mind, if NATO expanded into these "buffer" states it would potentially weaken Russia's military position and influence. Latvia and Estonia joined NATO in 2004 (following the lead of a reunified Germany which joined NATO as one Germany entity in 1990 and Czech Republic, Hungary and Poland who all joined in 1999).³⁵ Along with other events, like the late [2004 Orange Revolution](#) in

Ukraine, Putin could (at least in his mind) read the writing on the wall (of further NATO expansion near Russia borders) and noted in his February 2007 Speech in Munich:

“I think it is obvious that NATO expansion does not have any relation with the modernization of the Alliance itself or with ensuring security in Europe. On the contrary, it represents a serious provocation that reduces the level of mutual trust. And we have the right to ask: against whom is this expansion intended?”³⁶

Of course things rapidly deteriorated after that. At an April 2008 NATO summit in Bucharest, George Bush gave his support for beginning the process of eventually admitting Georgia and Ukraine into NATO.³⁷ *Germany and France were not as supportive, stating that it would be an “unnecessary offence” for Russia.* Soon thereafter, hostilities began in August 2008, lasting for approximately 12 days. Russia walked away with new control of two regions (South Ossetia and Abkhazia) in Georgia.³⁸

While there was relative calm for a few years, fighting again broke out in February 2014 in the Donbas region of Ukraine. The prelude to the 2014 fighting occurred when the Ukraine president, Viktor Yanukovich, refused to sign onto previously agreed upon economic ties with the EU, and instead began moving Ukraine closer to Russian influence. Large, pro-EU protests erupted in anger against Yanukovich’s actions. Yanukovich was quickly voted out by the parliament that had just approved the pro-EU measures. However, Yanukovich pleaded for support from Russia, which Putin quickly granted (claiming there was a coup attempt against Yanukovich). While Yanukovich was eventually removed from office on February 22, 2014, the pro-EU unrest in Ukraine also triggered other (pro Russian) protests on the opposite side of the political spectrum. On February 27, 2014 Russia troops moved into Crimea region of Ukraine and eventually annexed the Crimean peninsula on March 16, 2014.³⁹ This move was condemned internationally, with significant sanctions on Russia resulting, as well as Russia’s removal from the G8.

Again, there was relative quiet for a few years, but unfortunately this was a fleeting peace. In February 24, 2022, Putin invaded Ukraine after he demanded that Ukraine be legally *prevented* from ever joining NATO (which the US denied and did not agree to). Putin opened up two fronts, centered on Kyiv in the North and Luhansk and Donetsk in the South.⁴⁰ While the war is ongoing, the situation in Kyiv is looking relatively more positive than in the south, though of course there still exists all the horrors of war across many regions of Ukraine.

Context going Forward (“Realism” vs “Liberalism”)

With an admittedly far too brief and far too simplistic history of the Russo-Ukrainian War under our belt, we next move to putting the war in context. In particular we’ll examine various “schools of thought” in relation to global geopolitics and global power balance among world powers.

Foreign policy and geopolitical theorizing has happened for thousands of years and is one of the most important topics to understand when looking at the global economy. While there have been, and continue to be, many schools of thought in this regards, in this section we’ll focus on two main schools of [International Relations Theory](#): 1) Liberalism and 2) Realism. Furthermore, *within* these two categories there are many sub categories such as classical realism, offensive realism vs. defensive realism, republican liberalism, Democratic peace theory, etc.).^{41 42}

That said, at a high level, the **Liberalism** school of international relations broadly states that governments around the world should pursue idealist goals and deemphasizes other morally ambiguous factors of international relations such as geography etc. Many democracies around the world view it as their duty to spread democracy to other nations around the world, arguing that this makes war less likely (as democratic nations are less likely to attack each other, or so the theory goes). This “Liberal World Order” is largely attributed to the liberalist school of international relations.⁴³ Since the end of World War 2, the U.S. has been the main leader in establishing this “Liberal World Order”:

“More specifically, it entails international cooperation through multilateral institutions (like the United Nations (UN), World Trade Organization (WTO) and International Monetary Fund (IMF) [and we’d argue, the World Bank as well]) and is constituted by human equality (freedom, rule of law and human rights), open markets, security cooperation, promotion of liberal democracy, and

monetary cooperation. The order was established in the aftermath of World War II, led in large part by the United States.”⁴⁴

Realism on the other hand takes, what some might argue, as a more pessimistic view of the world.⁴⁵ Realism focuses on various fundamental factors such as geography, demographics, etc. While not necessarily completely eschewing of any sort of moral philosophy, realism in general is less concerned with “right” vs. “wrong” and instead concerned with dealing with the world “as it is”. Realists tend to deemphasize the distinction between “good” and “bad” countries and instead view most, if not all, countries through a similar lense: That is, where all countries are seeking to maximize their power and safety in the world. In particular, noted realist, John Mearsheimer describes a state of anarchy that exists at the international level:

“(Anarchy) simply means that there is no centralized authority, no night watchman or ultimate arbiter, that stands above states and protects them.”⁴⁶

How does the Ukraine crisis relate to these two classifications. At a broad level, the *Liberalist* school of thought would tend to emphasize Ukraine’s sovereignty and their right to decide their own fate on whether to join NATO. Liberalists would tend to view an expansion of NATO and US influences across the world as a good thing.⁴⁷ They’d view Ukraine admission into NATO as one step among many in bringing former Soviet bloc countries into a more democratic and freer world. Robert Kagan expands more on the Liberal World Order’s view of the Ukraine situation:

“I do think the United States is indispensable to a global peace that we are prepared to live in. There is no question that the Liberal world order, which has benefited Americans extraordinarily since World War 2, is a product of American power. World War 1 is the perfect of example of what happens when Russians are being forced to fight a losing war, where effectively, they are just going out and dying. World War 1 was the cause of Bolshevik Revolution. World War 1, effectively ended, because Lenin seized power and pulled Russia out of the war. That was not a great thing for the Russian people to then be ruled by Lenin. The idea that you can just fight a war endlessly at enormous cost to your society, and still hold onto to power...that is the recipe for losing power in Russia. Tsars have lost power as a result of wars. And I don’t rule out the possibility that Putin could lose power as a result of this war” | “We (The United States) have to do everything we can to make sure that the Ukrainian People can hold out and defeat Russia and enjoy their sovereignty and their freedom.”⁴⁸

The *realists* on the other hand would tend to look at the reality of the situation facing Russia. They’d argue that the large open land border across Russia’s western border makes Russia vulnerable, sensitive and concerned about political developments in bordering nations such as Ukraine (“**geography is destiny**”, etc.).⁴⁹ Russia views NATO in particular as, not a peace keeping force, but a potential aggressor and has pushed for border states like Ukraine to remain neutral and act as a buffer in areas within the Russian sphere of influence. John Mearsheimer relates this to the situation that did (and he would argue *continues to*) exist with the U.S and the western hemisphere.^{50 51} In particular, he focuses on the Cuban Missile crisis and the similarities to Ukraine today:

“In international politics, states usually pay attention to international law and they pay attention to moral precepts...as long as they are in their strategic interest. But if there is a conflict between international law and a country’s strategic interest, the country will always privilege its strategic interest (and international law and human rights will be pushed off the table). This is why I think it’s not very helpful to talk about rights. When you talk about whether ‘Russia has the “right” to have a buffer state’, or ‘Ukraine has the right to have its own foreign policy’...these are concepts that, in my opinion, get you into all sorts of trouble. In the international system, might makes right. And the United States would never tolerate a situation where Canada or Mexico invited, in a legal way, China to bring military forces into Toronto or Mexico City. We have a Monroe Doctrine, which is in our strategic interest, and our Monroe Doctrine says ‘no distant great power is allowed to put military forces in the western hemisphere. Period. End of story! What the Russians are doing here, is they are basically articulating their own version of the Monroe

Doctrine. They are saying ‘you cannot turn Ukraine into a Western bastion on our border. It has nothing to do with rights. It doesn’t matter if Ukraine has ‘the right’ to do this or that. We’re saying ‘they *can’t* do it’. Just like the U.S. is saying ‘Cuba cannot invite the Soviets to bring military forces into the western hemisphere’ (during the Cuban Missile crisis and continuing to this day). So, for me, when you talk about great power politics, rights in the final analysis, just don’t matter. **Might makes right.** And the United States is a mighty powerful country. It’s a mighty powerful country on purpose. And it does whatever it thinks is in its strategic interest (regardless of ‘rights’).”⁵²

As far as the current situation on the ground, many have wondered about the eventual outcome of the war as well as the likelihood of nuclear weapons being deployed. Since we, once again, have no edge in predicting these, we simply note the Metaculus odds for various outcomes. Current odds for whether a nuclear device is detonated in Ukraine by 2024 stand at 1.7%.⁵³ The odds for a nuclear weapon being detonated as an act of war by 2050 are certainly higher, at 32% (With a wider spread global nuclear war by 2070 standing at 12%).⁵⁴ As for more a conventional war, the odds that Ukraine will control Sevastopol by 2024 stand at 5%, and the odds that Ukraine will control Donetsk and Luhansk by Jan 2024 stand at 8%.⁵⁵ Odds of Russia controlling new territory (other than Crimea, Donetsk and Luhansk) stand at 77%.⁵⁶ Meticulous has many other interesting prediction markets as well.⁵⁷

China and Taiwan

One of the main central chokepoints over the next half century will likely be Taiwan and the shipping lanes of the South China Sea. One of the most critical points to understand about the geography of the region is the concept of the “first island chain” and the “second island chain” (both illustrated below)

Figure 7: First and Second Island Chains⁵⁸



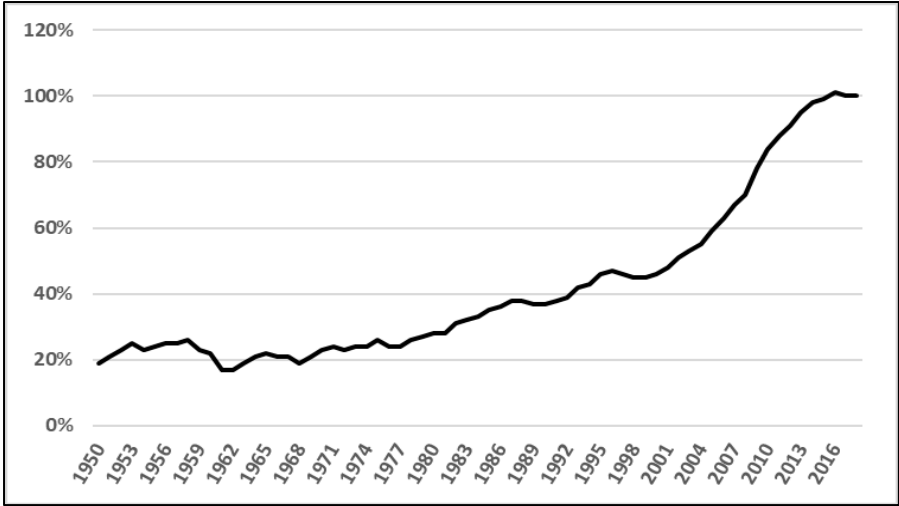
By looking at the Chinese coastline, we note that the First Island Chain could potentially control and encircle many of the Chinese ports and their shipping routes/outlets to the Oceans outside of the South China Sea.⁵⁹ And of course we notice that Taiwan is directly in the middle of the first island chain line. Taiwan is commonly referred to as an “unsinkable aircraft carrier” denoting its critical function to serve as a potential base for any military action across the South China Sea and surrounding areas.⁶⁰ Given its strategic importance, both the United States and China view Taiwan as a non-negotiable and potential flash point for a war.

We turn to Shirvan Neftchi of the Caspian Report to explain further:

“China is a trading power. It has the highest share of global exports of goods, yet it does not have guaranteed access to the world’s oceans. The first island chain *contains* China’s power projection, placing its vast economic empire at the mercy of the world’s leading naval powers. For Beijing, ‘business as usual’ is not a sustainable formula. The chokepoints between the islands and the archipelagos can be closed by U.S. carrier battle groups, with relative ease. [Malacca](#), [Sunda](#), [Lombok](#), [Karimata](#), [Makassar](#), [Mindoro](#), and [Luzon](#) are all susceptible to naval blockades. Should that happen, specifically in the Malacca Strait, it would cripple China’s economy which in turn would harm the communist party’s grip on power. If, within the next decade, Washington and Beijing were to come to a blow, both would look to dominate the islands and archipelagos that make up the first island chain. In the South China Sea, the U.S. Navy’s mission would be to close the chokepoints and keep them closed.” || “Meanwhile, in the East China Sea, the tactical situation is slightly different but no less urgent. The [Liuqiu Islands](#) and Taiwan, split the PLA Navy fleets in two: the northern and eastern fleets operate in a sperate command area from the southern fleet. So, in war time, China’s immediate goal would be to secure the [Taiwan Strait](#) and allow its fleets to merge and bring reinforcements as needed. Taking Taiwan, or at least incapacitating its armed forces, would resolve China’s divided naval forces. More importantly, controlling Taiwan would allow China to poke through the first island chain, and secure access to the world’s oceans.”⁶¹

Potential geopolitical conflicts between India and China are also a risk (“[string of pearls](#)” vs “[necklace of diamonds](#)”, etc.). And while its unpleasant to contemplate any war between China and the U.S., it’s important to at least consider the consequences. As with our analysis on the Soviet Union, we next examine the relative GDP levels of the United States and China over time – noting China has persistently caught up with U.S. GDP over the last 70 years.

Figure 8: China GDP as a Percentage of United States GDP (1950 – 2018)⁶²

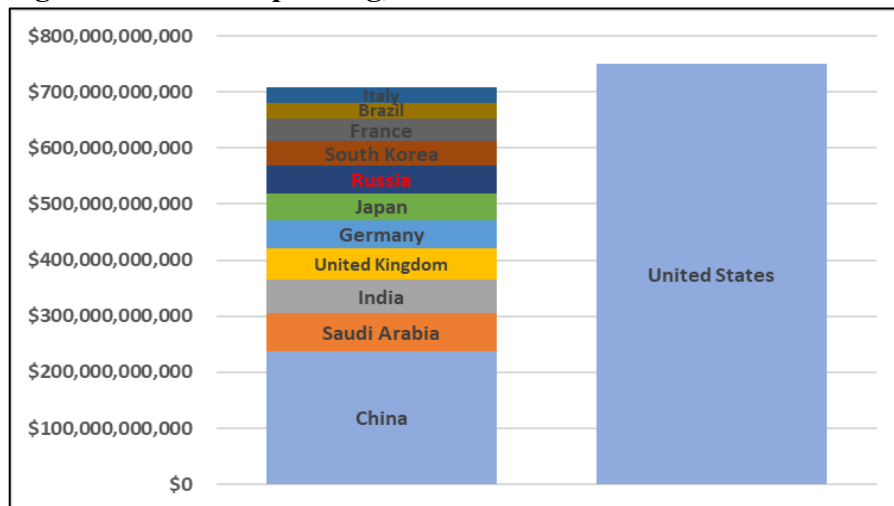


Going forward, it remains to be seen whether China can significantly pass the U.S. in GDP.⁶³ China has significant demographic headwinds to contest with, with many predicting China’s population will drop to 1.313 billion by 2050 and below 800 million by 2100.⁶⁴ China must also contend with the potential [middle income trap](#). That said, Metaculus has the China to USA GDP ratio at 1.33 by 2050.⁶⁵ As did with Russia, we note that Metaculus has the odds that the US would respond to a Chinese invasion of Taiwan (by 2035) at 68%.⁶⁶ Odds for China controlling Taiwan after an invasion stand at 67%.⁶⁷ If the US does intervene in a Chinese invasion of Taiwan, odds stand at 70% that China would in turn retaliate against the US directly.⁶⁸ Unfortunately the odds of a nuclear conflict as well

as further uncomfortable discussions on the strategy for the United States nuclear deterrent may become more and more common in the coming years.⁶⁹

If we look at military spending across the globe, the US (for now) is spending a large portion of the spending. It remains to be seen how this progresses in the future.

Figure 9: Defense Spending, United States vs Selected Countries (2022)⁷⁰



Wrapping up this section, we examine what school of thought is most applicable in the current geopolitical environment, realism or liberalism? In our opinion, the schools of thought have more similarities that might be first apparent. Each side tends to frame the other in an extreme light when, in reality, they overlap on many things. There are realist tendencies that exist in the liberal school of thought and vice versa. One might argue that the expansion of NATO, while partially framed as ‘letting the citizens of Ukraine choose their own destiny’, most likely also had *realist* considerations among these liberalist policy makers. The liberal policy makers certainly calculated that the odds were in their favor to push – and these exact sort of calculations could be contributed to the cold hearted realist school of thought. Indeed, while many liberal policy makers are outwardly surprised at the invasion of Ukraine, in our opinion, there are many such policy makers who saw this coming and even purposely took actions to provoke the fight, while simultaneously standing behind only the ‘liberal’ justifications in public. The invasion should not have been a surprise to anyone following geopolitics in the region over the last twenty years.

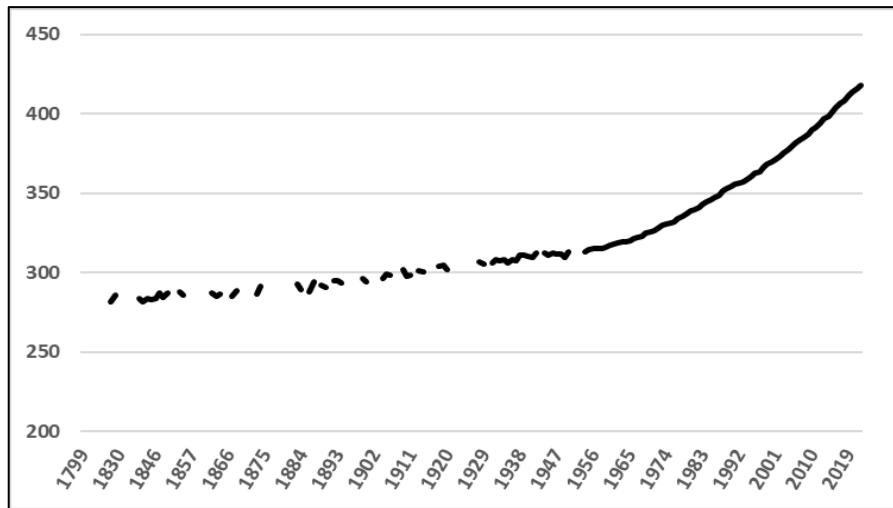
As it has throughout history, technology will continue to drastically affect the battlefield and political landscapes. The technology of the printing press allowed the Catholic Church to charge money for indulgences and forgiveness of sin – which angered Martin Luther and (partially) led to the Protestant Reformation. The advent of cannon fire in military units rendered castles obsolete. The machine gun increased the relative strength of defensive tactics, leading to trench warfare and the elimination of line formation/infantry tactics over open battle fields, as well as cavalry charges as offensive strategies. Billy Mitchell ushered in the era of aircraft as a potent military weapon during his 1921 demonstration bombing run to a group of skeptical generals and government officials. Today, autonomous and remote-controlled drones (dropping grenades, etc.) as well as other advanced weapons and communications technology are rewriting the battlefields once again and risks ruin for any general who is “fighting the last war”.

Chapter 3: Climate Change and The Future of Carbon Emissions

Climate Change and in particular, ESG Investing, have been growing in relevance over the past few years. Many investors are now making ESG investing a cornerstone of their investment philosophy. Given these facts, we figured it would be beneficial to establish some background data on the changing climate as well as looking at possible climate scenarios that could potential occur on our globe over the next century.

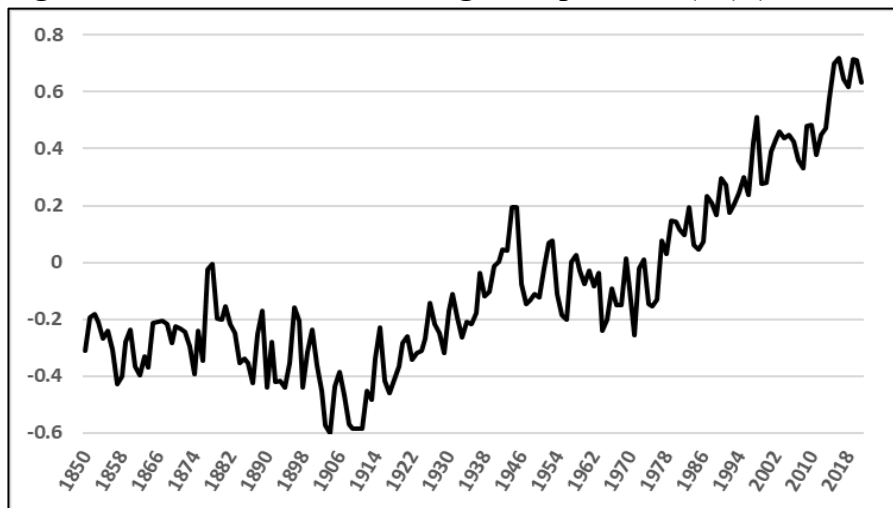
Of course, the most recognizable graph regarding climate change is the drastic increase seen in carbon dioxide concentrations since 1800.

Figure 10: Atmospheric CO₂ Concentration PPM (1800 – 2022)⁷¹



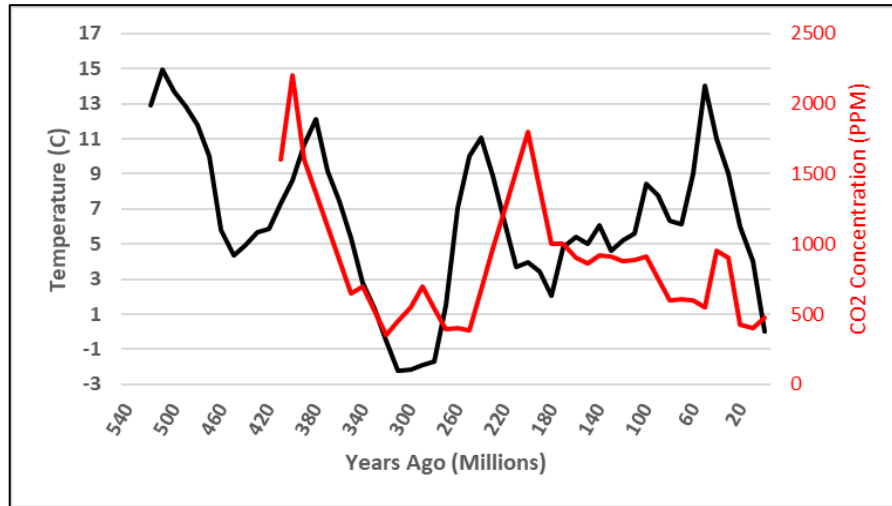
During a similar time frame, the global average temperature has risen as well. Of course, while the degree of causation from this correlation is furiously debate, it certainly warrants further examination.

Figure 11: Relative Global Average Temperature (°C) (1850 – 2021)⁷²



Over a much longer timeframe we examine the changes in CO₂ and temperature.

Figure 12: CO₂ Concentration (PPM) vs Temperature (°C) (Past 500 Million Years)⁷³



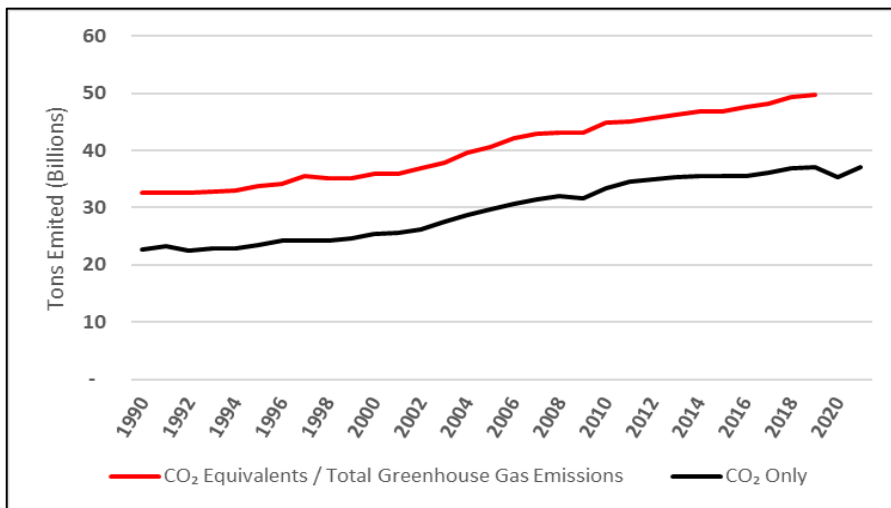
In looking at climate we'll try to construct a very rough (and admittedly inexact) cause and effect chain. Listed in the steps below:

- 1) At a very high level, one could state that the ultimate goal is to prevent drastic changes in the climate, most commonly measured by changes in the *earth's temperature*.
- 2) In order to affect this temperature, we look to the main input of temperature: *CO₂ concentrations*.⁷⁴
- 3) In order to effect CO₂, we look at the main input of CO₂: *greenhouse gas emissions*.
- 4) In order to effect greenhouse gas emissions, we look at the main input of greenhouse gas emissions: energy mix of
 - a. *polluting fossil fuels* vs.
 - b. *renewable energy*

With our previous graphs listing out CO₂ concentration and temperature, we've covered 1) and 2) above. We next move to step 3) greenhouse gas emissions.

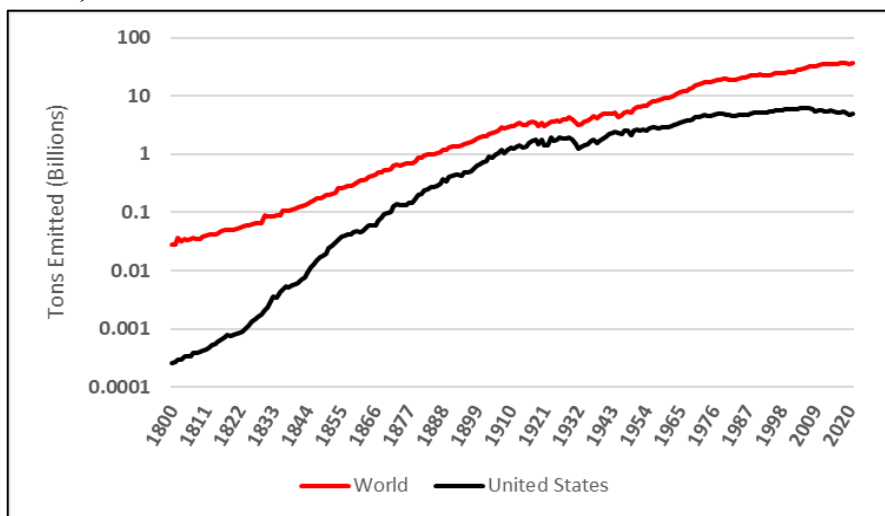
To begin, there is no single measure for pollution in our atmosphere. In addition to CO₂, humans emit many different chemicals into the atmosphere such as methane (CH₄), nitrous oxide (N₂O), etc. Each of these effect different parts of the atmosphere and in various magnitudes. Efforts have been made to standardize these effects, with the most popular being “Carbon Dioxide Equivalents”.⁷⁵ In the below graph we note the difference in measuring simple CO₂ vs the more inclusive “CO₂ equivalents” (or “total greenhouse gas emissions”)

Figure 13: World Annual Actual CO₂ Emissions vs. CO₂ Equivalents (Total Greenhouse Gas Emissions) (1990 – 2022)⁷⁶



Unfortunately, the data going back further, is more easily measured using CO₂ only, which we list below back to 1800 (on a logarithmic scale).

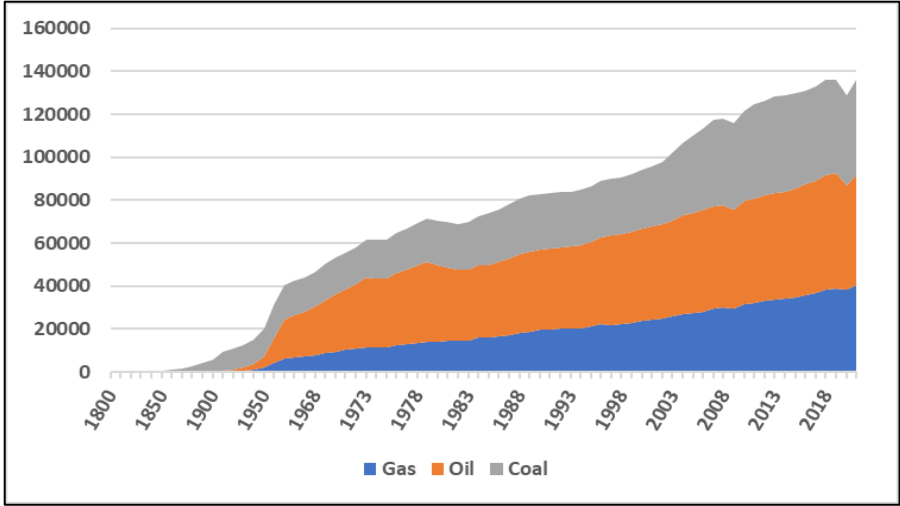
Figure 14: Annual Actual CO₂ Emissions World vs. United States (1800 – 2021)⁷⁷



While the growth *rate* of emissions has slowed for the world as whole, emissions are still increasing at an absolute level.⁷⁸ For the United States, energy usage has actually dropped from an all-time high in 2005. That said, there are likely [issues with where emissions are counted](#).⁷⁹

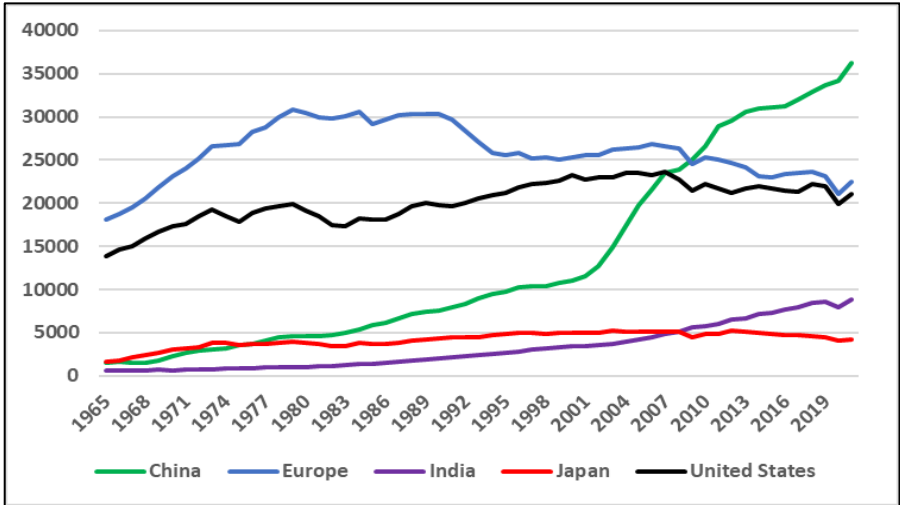
Moving to Step 4) (The mix of fossil fuels used vs renewables and their contribution to rising emissions) we can see the breakdown of fossil fuel usage, by source, since 1800.

Figure 15: Global Fossil Fuel Consumption by Type (THw)⁸⁰



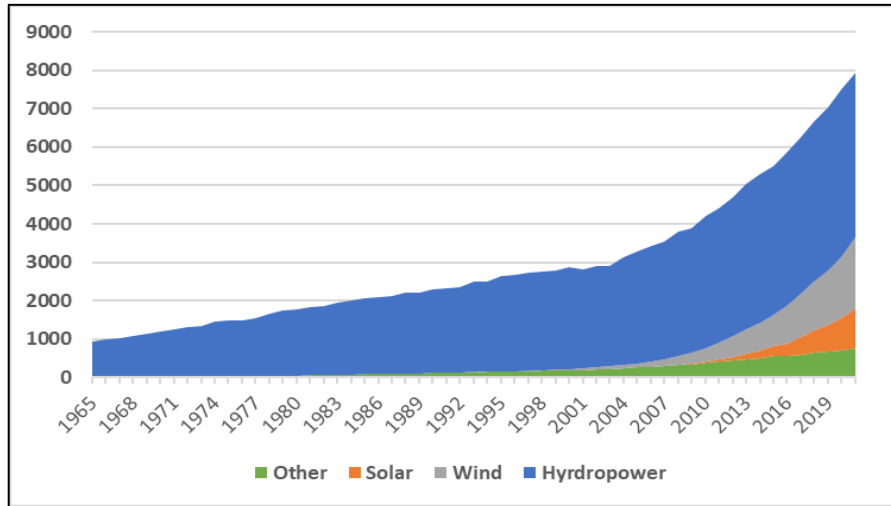
And here’s a breakdown by country:

Figure 16: Global Fossil Fuel Consumption by Country (THw)⁸¹



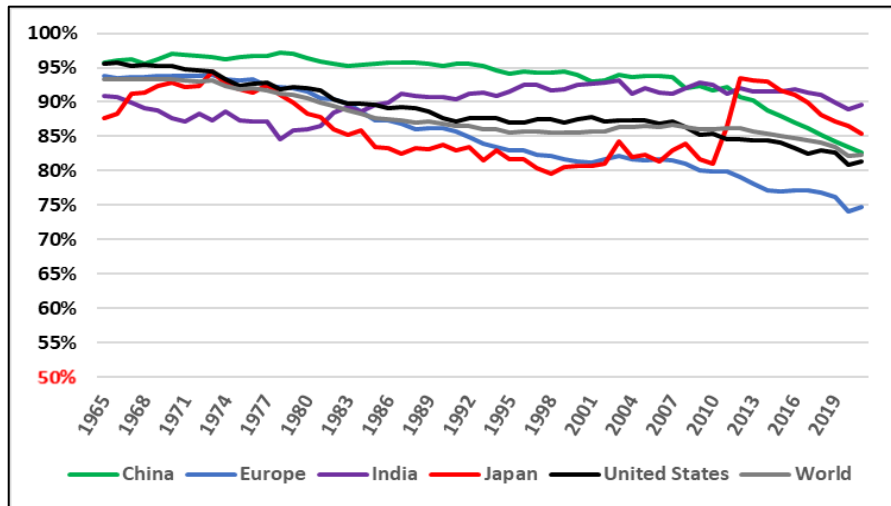
Next, we note the trend and distribution of renewable energy *only*.

Figure 17: Renewable Energy by Type (TWh)⁸²



While this trend in rising renewables might signal a positive sign, there is still cause for concern. While the *absolute* capacity of renewables has increased, the *share* of total energy usage used by fossil fuels has not budged much since 1990.

Figure 18: Share of Primary Energy from Fossil Fuels⁸³



This final graph is, our opinion, one of the most critical. *Despite the massive gains in renewable energy growth trend over the years, it's barely been able to offset the relative share of fossil fuel use.*⁸⁴ Humans have a general tendency of using more and more energy, not only in total, but per capita as well. Since 1800, total world energy usage has increased from 5,653 TWh to 159,000 TWh in 2021 (1.5% per year growth).⁸⁵ On a *per capita basis* this increased from 5,600 kWh to 19,000 kWh per person from 1800 to 2021 (0.5% per year growth). Renewable energy installed must grow *faster* than these rates if we are to get to net zero. (In addition, while increasing CO₂ concentrations can't continue forever, there are many who have written that energy usage could extended indefinitely. By looking at past growth rates of energy usage, these authors carry these trends out many centuries in the future and make projections on what society would look like when/if energy usage (total and per capita) is many orders of magnitude greater than today.⁸⁶)

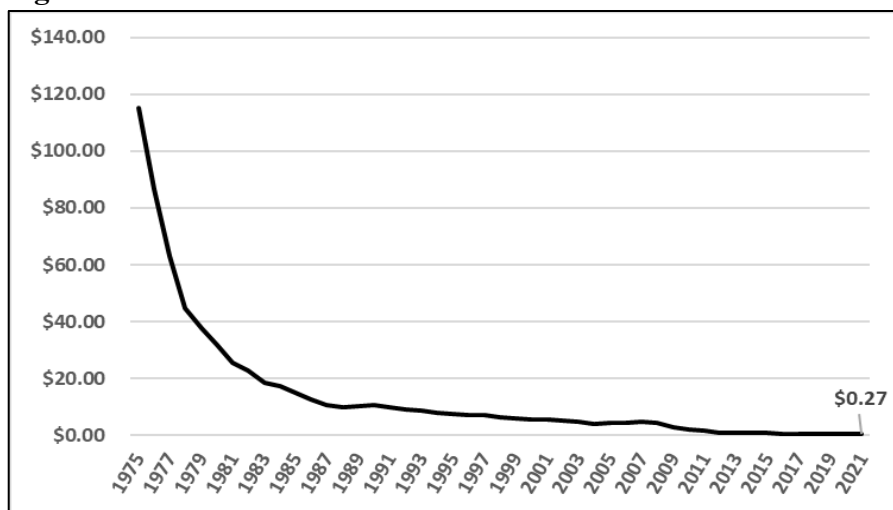
Of course, there may be other ways to get to net zero. We could continue to use fossil fuels, but if we were to either capture the emissions at the source or find an economical way to remove already emitted CO₂ from the atmosphere, then this too may be an alternative path to helping the climate situation. We'll explore a few options in the next section.

Various Renewable Energy Sources and other CO₂ Remediations

Clearly humans must find a zero emissions source of energy in the long term if we are to continue the ever-increasing per capita energy usage out in the future centuries.

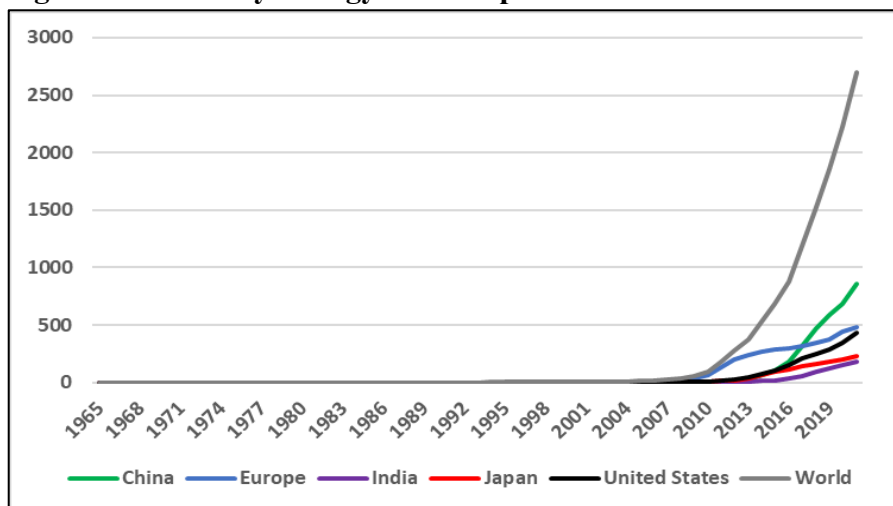
Solar – Solar power is one of the most discussed sources of renewable energy and for good reason. We can see the amazing drop in prices for solar over the past few decades. This was codified in what is known as “[Swanson’s Law](#)”, stating that for every doubling of solar manufacturing capacity, prices fall by 20%. This is a specified version of the more general “[Wright’s Law](#)” which states there is a learning curve effect across many products, where an X% reduction in cost for every doubling of manufacturing capacity (where X varies based on the type or product being produced).

Figure 19: Solar Panel Prices⁸⁷



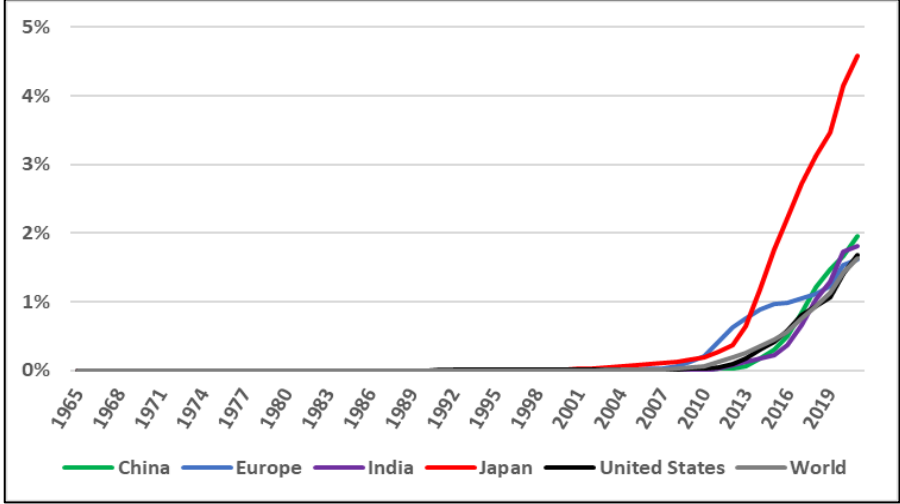
This increase in efficiency has led to the massive deployment of solar power over the same time frame:

Figure 20: Primary Energy Consumption from Solar⁸⁸



Of course as we hinted at earlier, some sort of perspective relative to total energy usage is important. We can see that solar, while going through an amazing and apparently exponential growth curve over the last 10 years, is still only 1-3% of primary energy production. The central question is whether this exponential growth continues, or whether it plateaus off at some relatively low percentage of total energy usage.

Figure 21: Share of Primary Energy from Solar⁸⁹



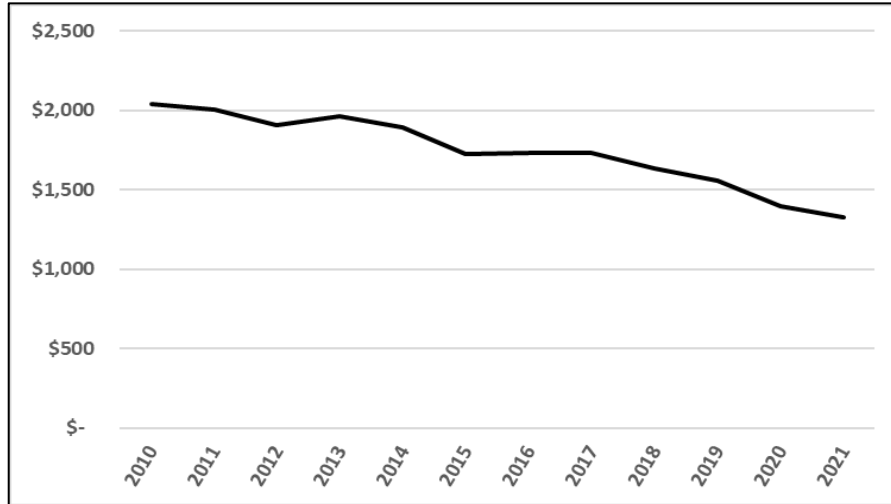
Of course with growth rates like these, the important consideration is: will these growth rates continue? If so, it won't be long before solar is much closer to 100% of primary energy production. However, in our view this will be exceedingly difficult. Going from 0% to 2% of energy installed is different than going from 2% to say 50%.⁹⁰ As of now, it's estimated that approximately 12,000 TWh of combined wind and solar generation will be needed, by 2030, to stay on track with the net zero 2050 goals. As of now, the stated policy commitments have the world at less than 8,000 TWh of combined wind and solar by 2030.⁹¹ It will be interesting to see if these goals are met (as well as future goals in 2040, 2050, 2100, etc.).

While there are various factors that will likely at least damper these solar (and wind) growth rates (such as raw materials cost, limits on solar efficiency and access, etc.) one of the likely challenges will involve battery technology and adoption. After exploring wind briefly in the next section, we'll then move on to the all-important section on batteries.

Wind Power

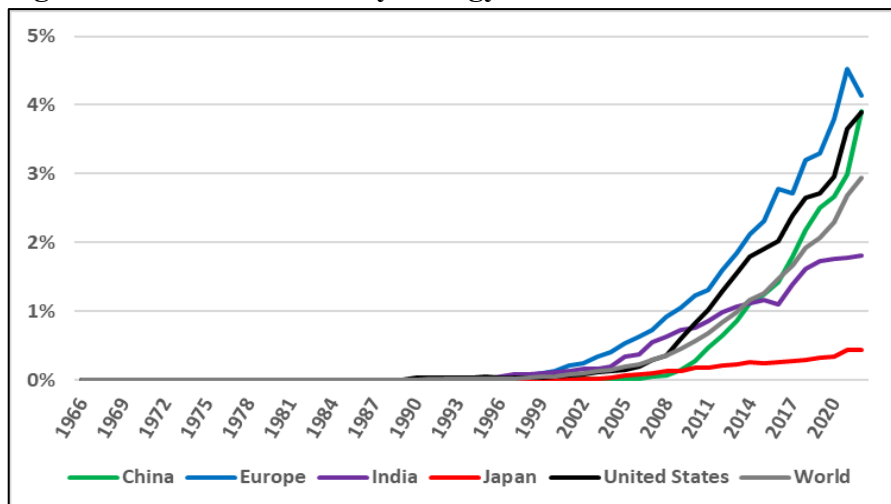
As with solar, we'll first look at the cost of wind power and note the drop since 2010. While not as extreme a price drop as solar, it is still not negligible.

Figure 22: Cost for Installed Wind Power (Onshore) (2010 – 2021)⁹²



As with solar power, we've seen a rapid rise in the use of wind energy over the last half century, with many countries reaching a similar share as solar: deriving about 4% of their primary energy needs from wind power. That said, there are similar issues with solar.⁹³ As you add more and more wind power as a percentage of total power, intermittency becomes an issue and the need for large scale, cheap storage options become paramount (and/or much larger than present transmission line capabilities). That said, it is true that at some specific locales, wind and solar can tend to complement each other (wind energy is plentiful when solar is not, and vice versa). That said significant storage would still be needed.⁹⁴

Figure 23: Share of Primary Energy from Wind⁹⁵

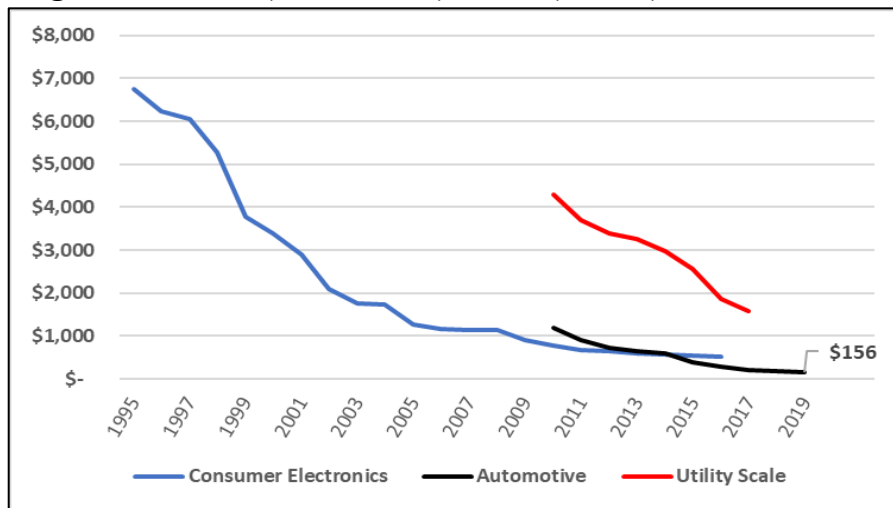


Batteries

Solar power is a wonderful technology however it does come with some current drawbacks, one of which is intermittency. In order to power the grid at night or inclement weather, large swathes of batteries will need to be installed if solar is to continue its rising share of primary energy production. At its current 1-3% adoption rate, solar power had less of a need for large battery installations; most can simply remain connected to the grid to draw power at night or when the sun intensity is less during cloudy weather, winter etc. However, if solar were a *majority* or close to 100% of energy production then large battery installations would be needed to cut the usage of fossil fuels acting as a backup power source. As renewable energy (solar and wind) grow in their share of energy production, you need more and more backup power (either in batteries or from the grid burning fossil fuels). As you eliminate the fossil fuel burning as backup option, you need more and more resource intensive batteries. It remains to be seen if such a large share of energy produced by renewables is likely or cost effective.⁹⁶

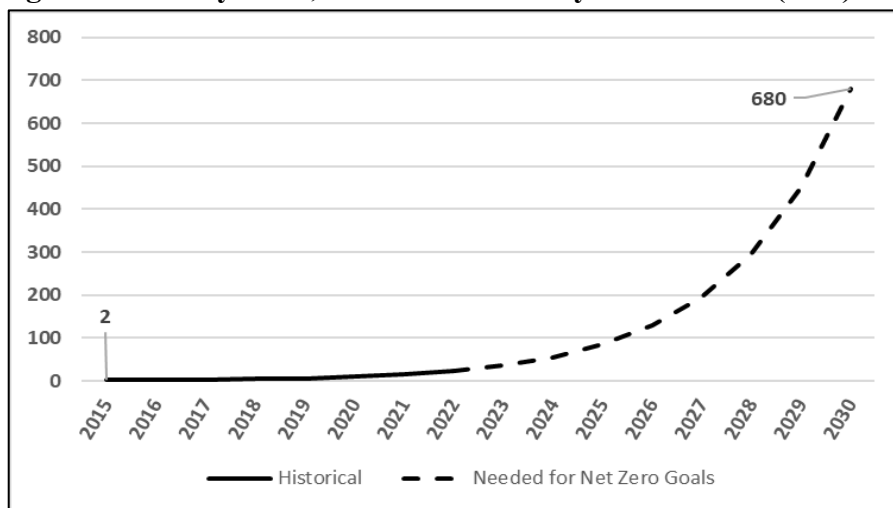
Like solar panels, we first note the amazing decline in battery costs over the last few decades.

Figure 24: Li-ion (Lithium-ion) Prices (\$/kWh)⁹⁷



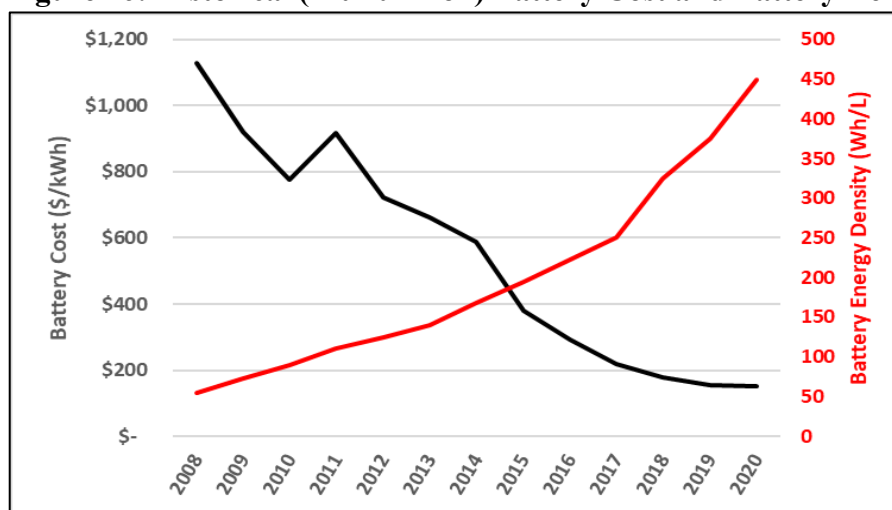
That said, we next look to the necessary utility(grid)-scale, cumulative battery installations that will be necessary to meet the 2050 net zero goals. The projected (dotted) line below is rising at over 52% per year!

Figure 25: Utility-scale, Cumulative Battery Installations (GW)⁹⁸



As with solar, this cost decline has led to a large increase in installed batteries.⁹⁹ However, as with solar panels, it remains to be seen whether these massive cost declines and increases in installed battery capacity can continue.¹⁰⁰ There are likely some fundamental material science/physics issues with getting cost to decrease at such an amazing rate in the future.¹⁰¹ In addition, batteries also have an issue with energy density, with gasoline being something like 50 times more energy dense than most battery packs.¹⁰² That said, we note amazing progress in battery density over the last decade and half. As usual, we need these trends in growth rates to continue (or at least not completely flatten) to meet the net zero goals set out for 2050 and beyond.

Figure 26: Historical (Lithium-ion) Battery Cost and Battery Density¹⁰³



In addition, while the above increase in battery capacity is amazing, it's again important to note its current relative size (limited by current battery costs, etc.). As [Bill Gates has mentioned](#) in a video from late 2018:

“That is so disappointing. Vaclav (Smil) said: take Tokyo with 27 million people, you have three days of a cyclone every year. Its 22 GW (rate) over 3 days. Tell me what battery solution is going to sit there and provide that power? *Let's not joke around. You're multiple orders of magnitude away. People will say 'oh, \$100/kWh (for batteries)'. That's nothing! That doesn't solve the reliability problem.* And remember: electricity is 25% of greenhouse gas emissions. Whenever we came up with this term 'green energy' I think it screwed up people's minds. I was at this conference in New York, and all these financial guys were on stage saying 'we're going to rate companies based on their CO₂ output. And we're going to say: this company puts out a lot of CO₂...and financial markets are magical. And all of sudden CO₂ will stop being emitted'. And I was saying 'ok, how are you going to make steel? Do you guys on Wall Street have something in your desks that makes steel? Where's the fertilizer and cement going to come from? Do planes fly through the sky because of some number you put on a spreadsheet.' The madness of the so called 'finance is the solution'...I just don't get that. There is no substitute for how the industrial economy runs today. And the paradigmatic country is India. Will India pay a premium price to have materials to build buildings? Will they pay a premium for air conditioning? Basically, the answer is 'no'. The voters there *will* not and probably *should* not deny themselves, when their greenhouse gas emissions, per person, is only a 20th of what the U.S. has already emitted. And so, who should go first and get emissions down to make up for what they've done in the past? Of course, that should be us (the United States).” || “So, the idea that we have the current tools (to solve the climate crisis) and it's just: 'these utility people are evil people and if we would just beat on them and put it solar panels on our roof top'...*That (line of thinking) is more of a block than climate denial.* The 'climate is easy to solve' group is our biggest problem.”¹⁰⁴

Expanding on Mr. Smil's Tokyo example, 22 GW for Tokyo alone (over the long period of 3 days nonetheless) is approximately equal to the total 24 GW of global installed battery capacity as of 2022.

Looking closer to the Northeast, Wade Schauer has estimated that grids powered by 50% Solar, 50% wind (100% renewable) would need something like 277 GW compared to the current 11GW to survive the 2019 Polar Vortex (approximately 18-40 hours or storage needed).¹⁰⁵ This moves down from 277GW to something like 228 GW if you are willing to use nuclear power as another source of energy. The same author is predicting less than half of the 277GW being installed by 2040, so significant work and pledges remain to be done (above and beyond the current, already aggressive, plans). And of course, these numbers are based on a specific polar vortex. Much worse weather systems, with longer periods of severe weather, would require even more batteries to be installed.¹⁰⁶

Another paper, focusing on Germany, found that storage/energy capacity needed to be about 56 TWh (based on 35 years of weather data).¹⁰⁷ In the cited paper, hydrogen storage is the main method of energy storage. For reference, Tesla Megapacks run a bit less than \$500,000 per MWh of installed storage.¹⁰⁸ Germany uses about 550 TWh of energy per year. The world uses about 22,000 TWh of energy per year. Further estimates show that the U.S. could get to 80% renewable energy usage with 5.4TWh of batteries (Total U.S. energy usage is about 4,000 TWh).¹⁰⁹ As of 2021, there was approximately 16GWh of utility scale battery storage in the U.S (about 0.2% of what's needed in the 80% renewable scenario).¹¹⁰ Clearly there are wide margins of errors as well as drastically different assumptions, but we list these estimates to show the magnitude of change that is needed if we are to get anywhere close to 100% renewable. That said, solar combined with batteries is making progress on the cost competitiveness front.¹¹¹

One further detailed examination of Spain noted that a purely renewable grid would be required to store 16 days' worth of electricity *for 4-6 months* in order to balance the load (Largely because of the variability and unpredictability of wind power *over long periods time*).¹¹² As noted, "To date, all renewable power systems are balanced by something externally...usually fossil fuels".¹¹³ And as noted, at least in the case of Spain and continental Europe, many of these peaks and troughs in available renewable energy tend to correlate across countries. Large scale transmission lines across the continent would help, but may not be a panacea.

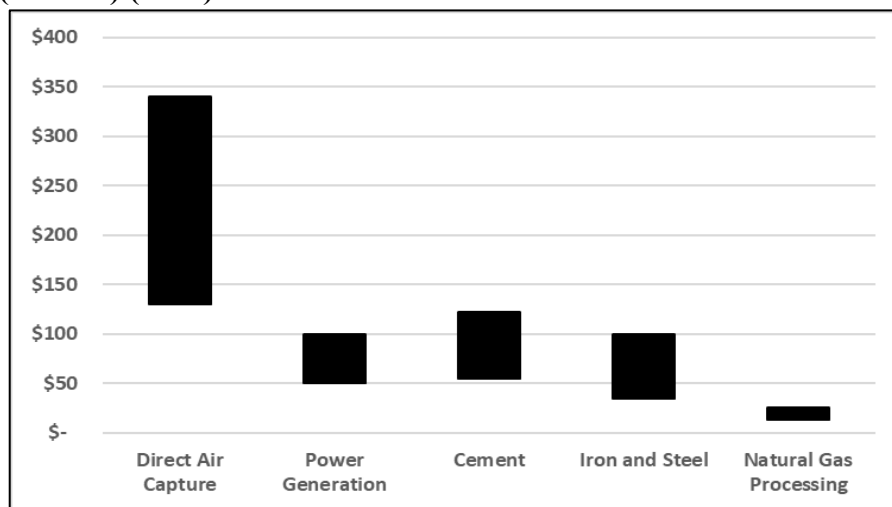
Of course, batteries aren't the only solution to intermittent solar and wind power. Pumped hydro is a natural form of battery that has been used, however this is largely dependent on favorable geography. A massive order of magnitude expansion of pumped hydro would be challenging. Compressed Air is another option that is commonly discussed.¹¹⁴

Large scale increase in electrical transmission would also ease the need for localized energy storage. That said, there remains significant zoning challenges, etc. to rapidly expansion the electric transmission capacity in the United States (zoning approval, etc.).

Carbon Capture

Another alternative to producing a relatively clean energy such as solar, another option is to produce relatively dirty energy and then either capture the emissions at the source of production (point source capture) or by removing CO₂ directly from the atmosphere (direct air capture).¹¹⁵ Given the high concentrations of CO₂ at the point of production, point source capture is obviously cheaper. That said, direct air capture may also be a long-term solution, with an advantage being that it's agnostic towards the source of the energy production as well as the location. We note the estimated costs in the table below:

Figure 27: Estimated [ranges] of levelized cost of CO₂ Capture by Sector (\$/tonne) (2019)¹¹⁶



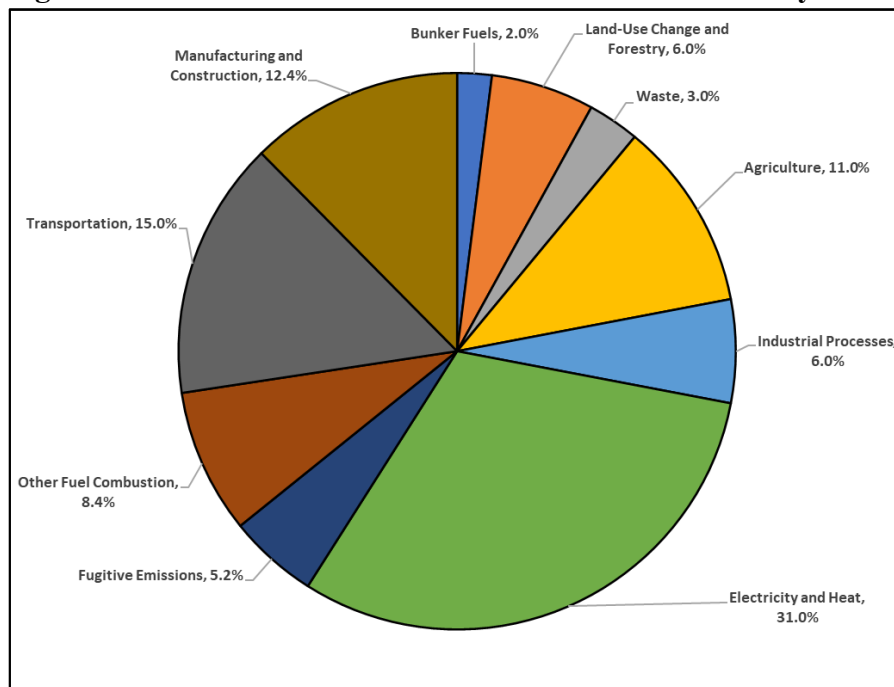
For approximate orders of magnitude calculations, the world emitted approximately 40 billion tons of CO₂. Using the direct air capture low-end cost of \$130/ton, this equates to \$5.2 trillion *annually* to remove all emitted CO₂ for that year (approximately 5% of world GDP). Using the high-end estimates for direct air capture (\approx \$350/tonne, we arrive at something like \$13 trillion. To get to net negative emissions and begin cleaning up from prior years emissions (i.e., lowering ppm), we'd need to spend ever more. Clearly there needs to be drastic reductions in cost for direct air capture to work.

Looking to the other source on the table above, we should note that these carbon capture costs are additional costs. Obviously the “non-green” version of steel and cement is lower because they don't have to deal with this carbon capture cost. Again, we turn to Bill Gates to expand further on this in an early 2021 talk:

“Now an area like cement, where we haven't really gotten started yet (as we have with electric vehicles), the green premium today is almost double the price. That is, you pay \$125/ton of cement today, but it would be almost double that (\$250/ton) if you insisted that it be ‘green cement’. And so, in 2050 we (the U.S.) will be talking to India and be saying to them ‘please us green products, as you're building basic shelter and simple air conditioning or lighting at night for students.’ And unless we're willing to subsidize it, or the price is very low, then they'll say ‘no’ and they'll say ‘this is a problem that the rich countries created and that India is suffering from and you (the U.S.) need to take care of it’. So only by bringing that green premium down very dramatically, about 95% across all categories, will that conversation go well so that India can make that shift. And so the key thing here is the U.S.'s responsibility is to not just to zero out its emissions. That's a very hard thing. But we are only 15% (of world emissions). Unless we, through our power of innovation, make it so cheap for *all* countries to switch across *all* categories, then we simply aren't going to get there (to our 2050 climate goals). So, the U.S. really has to step up and use all of its innovative capacity every year for the next 30 years.”¹¹⁷

Expanding on Bill Gates' discussion on the breakdown of emissions, we next look at the mix of emissions by *sector*, noting that electricity (and heat) make up only 31% of emissions. Areas like cement production, that Bill Gates mentions above, must also be considered.

Figure 28: Global Manmade Greenhouse Gas Emissions by Sector¹¹⁸



For example, while the electrification of cars is a potentially positive development, it's important to look at where the electricity from the grid is coming from. If electricity is produced via coal, then an electric car isn't doing anything for pollution.

We next move to a specific type of carbon capture: [direct air capture](#).¹¹⁹ There are many projections concerning the development of this potentially revolutionary technology. As mentioned earlier, if a cheap direct air capture option were to be available, this would drastically reduce the climate stress. Some estimates put estimates for direct carbon capture prices first dropping below \$50/ton by 2040.¹²⁰

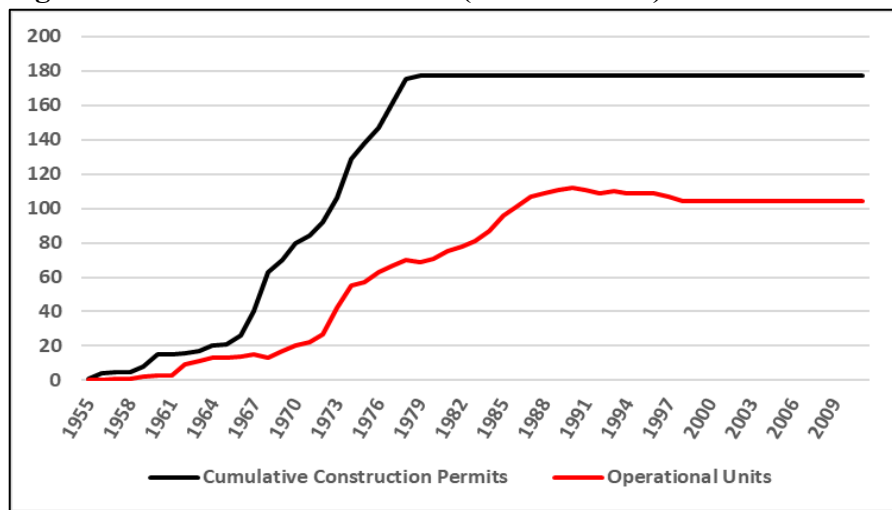
If one is to believe that we can scale to the \$50/ton removal cost for carbon capture by 2041, then it would take about 40 billion tons per year emitted * \$50/ton = \$2 trillion/year to offset the world's energy emissions. Going net negative and removing all 1.5 trillion tons that have been cumulatively emitted would cost \$75 trillion (or a bit less than world GDP of \$96 Trillion). *This in turn leads to some interesting cost-benefit calculations and brings into question how much should be done before 2041* (if we do indeed have reason to believe that we'll reach the \$50/ton goal in less than two decades).

Nuclear Power

Nuclear power is a (in)famous energy source with no shortage of strong opinions on all sides. One side, the anti-nuclear crowd, is completely against any sort of energy being derived from nuclear power, in fear of a nuclear meltdown or other nightmare scenarios. On the other side, the pro-nuclear crowd proclaims that nuclear can solve almost every energy problem known to man without listing any of the limitations. In this section will try to take a more sober look at nuclear power, listing some of the benefits and drawbacks.

Shortly after the first atomic bombs were developed in World War 2, concepts of nuclear power were developed. In fact, theories as well as some early experiments on nuclear power predate the first atomic bomb test near the end of World War 2. After the war, nuclear power was quickly put into practice, with the first nuclear power plants coming online in the mid-1950s. As we can see in the graph below, the number of operating nuclear power plants, quickly expanded throughout the 1960s and 1970s. Worldwide there are close to 440 nuclear power plants.

Figure 29: Nuclear Power Plants (United States)¹²¹



That said, it is also obvious that something drastically changed soon after. Since 1978 no new nuclear power plants have been built in the United States (although two reactors are currently under construction).¹²² While there are many causes for this lack of new construction, the primary driver has been a general reluctance on the part of the public to build nuclear power, largely because of safety concerns.¹²³

Safety

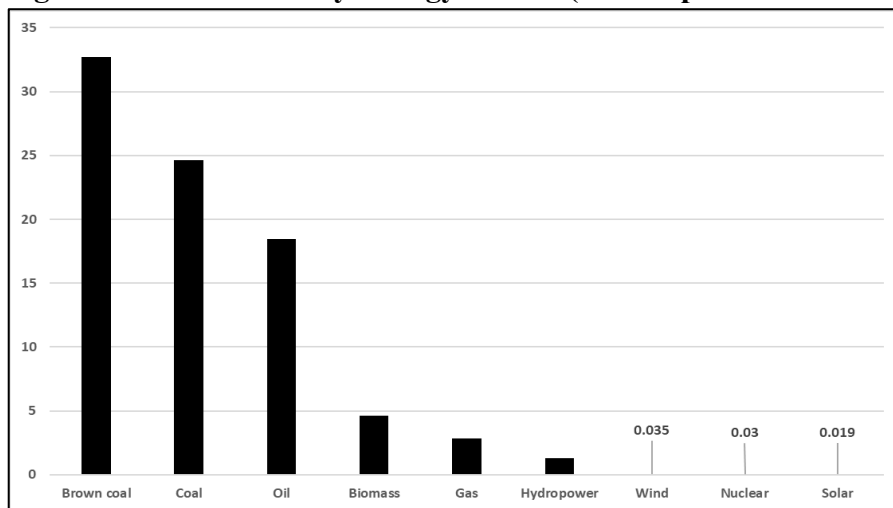
While we'll avoid a deep dive into nuclear physics here, we note that there certainly is a theoretical, and sometimes practical, chance of severe disasters resulting from nuclear power (Chernobyl, etc.). That said, it's important to view this risk in context and compare them to alternative sources of energy (which also carry risks). In the United States, Three Mile Island is the most famous nuclear accident. It's no coincidence that there haven't been any nuclear power plants built since the Three Mile Island accident in 1979. While there are varying estimates of the results of the nuclear meltdown at Three Mile Island, most experts agree that the total radiation released to nearby residents was approximately equivalent to a chest x-ray (although on the high end, some researchers have found that the excess deaths in the area following the meltdown measured somewhere from 100 to 350 extra deaths).¹²⁴ No single death was immediately attributed to the meltdown.

Of the accidents around the world, Chernobyl was certainly the worst. While the estimates for total deaths have a huge range, most experts estimate that a total of 1,000 to 4,000 excess deaths occurred in the years after the Chernobyl incident (with the initial immediate fatality rate around 31 deaths).¹²⁵ While Chernobyl was a horrible tragedy, there were many avoidable mistakes made that were made. Basic safety measures and management practices would likely have prevented the disaster from occurring in the first place. While much less severe, the Fukushima meltdown was also the result of many critical errors in the design process of the plant (such as building

sea walls to heights that could handle well know realistic estimates of tsunami waves in that area). Although again, for context, Fukushima resulted in one known attributable death (with estimates for cancer rates increasing about 1% above baseline). The earthquake and tsunami killed 18,500. We'll explore later how new reactor designs can lead to large potential safety gains.

While any death or potential death is a tragedy, we always must ask: compared to what? Below we list the approximate death rates from other sources of energy and see that nuclear is among the safest.

Figure 30: Death Rate by Energy Source (Deaths per TWh of Electricity)¹²⁶



While the potential of nuclear accidents is certainly scary to deal with, these risks must be taken into context. Furthermore, there are new designs that potentially offer greater safety measures. Along with this, we note that having a low volume of cumulative production also limits any learnings that can take place among safety engineers and designers of nuclear power plants. If the world had stopped building airplanes at airplane number #180 in the early 1900s, or even aircraft #1,800, the exemplary airplane safety record would be nowhere close to its current mark.

Costs

In addition to the gains in per unit safety from building ever more nuclear power plants, costs are another metric that could drastically improve if the volume of nuclear power plants increased. This is most popularly cited (and hinted at earlier in regards to solar panels) in the relationship between airplane production vs costs. In 1936, Theodore Paul Wright discovered that for every doubling of aircraft produced, the per unit production cost decreased by 20% (known as Wright's Law).¹²⁷ This exact relationship will likely not hold for nuclear power plants, but certainly the general trend would be held. Building only 180 cumulative plants over almost 70 years does not lend itself to any sort of [learning curve](#) and the accompanying cost reductions that has happened with airplanes, cars and many other manufactured products.

Diving into some further details on the historical costs of nuclear power plants, we note that, adjusted for inflation Indian Point Power plant reactors, built in the 1960s, cost approximately \$3 billion (in 2021 dollars). Power Beach Nuclear Power Plant was built for a bit less, coming in at \$600 Million in 2007 dollars.¹²⁸ The currently "in construction" reactors 3 and 4 at the Vogtle Nuclear Power plant have been in construction since 2009, and the ever-increasing estimated costs were recently pegged at \$28.5 billion! (and subject to likely *increases* going forward).¹²⁹ *Clearly there is some sort of anti-Wright's law going on with nuclear power.*

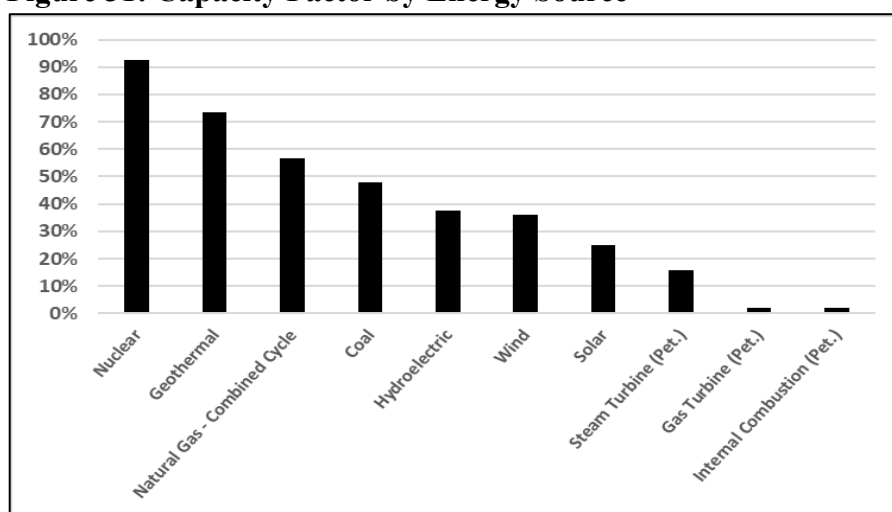
Again, increasing production and not (borderline) criminalizing nuclear power would be a good start. It may take many years or even decades for the skills and expertise to be (re)developed, but it is a worthwhile path to pursue.

However, unless private companies have a reasonable expectation of a clear and non-antagonistic regulatory environment, it's unreasonable to expect private companies to develop this expertise.

Benefits

With some of the potential pitfalls already discussed, we now move onto the benefits. Nuclear power remains one of the most reliable and dependable energy sources once the plant is built. The down time is much lower than other types of energy sources (especially many of the more popular renewable sources). In the industry, “capacity factor” is a metric that is used to measure an energy source’s time spent producing electricity. In the below graph we note the capacity factors for a variety of sources, noting that nuclear is at the top. It is one of the most, if not the most, dependable source of energy we have (and often acts as a “grid battery” backup to other sources of renewable energy – an issue that may become more pressing as we increase our share of intermittent sources of renewable energy like solar and wind).

Figure 31: Capacity Factor by Energy Source¹³⁰



In addition to capacity factor, other metrics have been produced to attempt to compare costs, etc. across energy sources. In particular, while the levelized cost of electricity (sum of costs over lifetime of energy source % sum of electricity produced over the lifetime of the energy source) is a step in the right direction, there are other considerations and caveats that must be addressed. In particular, variable sources of energy like wind and solar impose additional costs on the electric grid compared to a more “always on” source like nuclear. As discussed earlier, solar and wind may produce energy when it isn’t needed, and extra battery storage may be needed to “smooth” out this demand/supply imbalance. These additional storage costs are often not considered in the levelized cost of electricity calculations. Further calculations such as levelized cost of storage, levelized avoided cost of energy, as well as minimum backup requirement (MBR) are also important considerations when making any decision on energy sources.¹³¹ Nuclear power performs increasingly well (compared to variable solar and wind) as you add these important considerations: having an on demand power source is much more valuable than a variable power source (all else equal).

New Reactor Designs

There are endless types of classifications for various types of nuclear reactors. That said, one of the most common classifications is by coolant type. By far the most common type of coolant is a light water-cooled nuclear reactor, with over 93% of existing nuclear powered reactors being of this type.¹³² In general, most nuclear power plants work by having control rods inserted into nuclear reactor core (usually made of low enriched uranium) and having these control rods absorb neutrons and thereby control the rate of nuclear reaction. This controlled nuclear reaction produces heat which is used to heat water and create steam. This steam is then used to turn an electric turbine and thereby produce electricity for the grid. In a water-cooled reactor, cool water (usually from the ocean or other large water source) is continuously pumped into the reactor to produce steam. It’s important to note that the water used as

coolant here must be pressurized to a high level (in order for the water to reach very high temperature, say 300°C, without boiling – with the high temperature also being better for efficient electricity production) with the pressure sometimes reaching 150 atmospheres (with large containment buildings being necessary to contain the steam that would be released if pressure was lost).¹³³ Also important to note with these water cooled, solid fuel reactors, you must continually supply power to keep the cool water flowing in order to prevent a meltdown. This brings up some potential safety issues (as we saw with Fukushima) when power was lost to the plant as a result of the tsunami breaching the (too low) sea wall barrier. There was nuclear meltdown soon after, as the supply of cool water was no longer present.

While there are many other types of nuclear reactors, some already in existence, and some theoretical, we'll focus on one type in particular: Molten Salt Reactors with two sub types using either 1) solid fuel or 2) liquid fuel. As explained below:

“Molten salt reactors (MSRs) are characterized by the use of a fluoride or chloride salt as coolant. Two major design variants are being considered, characterized by **solid or liquid fuel**. The solid fuel option (often referred to as fluoride-cooled high-temperature reactors or FHRs) is more similar to other nuclear reactor concepts: *salt is used to transfer heat from solid fuel to a secondary loop*; fuel is typically made of small particles (i.e., TRISO) dispersed in a graphite matrix to form blocks, pebbles, or plates. *In the liquid fuel design, instead, actinides (referring to the actinide series on the periodic table of elements – consisting of thorium, uranium, plutonium among others) are directly dispersed in the salt that, kept at high temperature (above 500°C), flows in and out of the reactor core. In the core, the salt is heated up by the fission reactions and heat is then transferred to a secondary loop when the fuel salt itself flows through the heat exchangers.* Compared to light-water reactors, MSRs are expected to be more economical because of higher power conversion efficiency, low-pressure containment, and absence of active safety systems.”¹³⁴

In general, in the salt reactors, salt is heated to about 300 °C at which point it starts melting. From there the salt is further heated up to potentially 1300°C (which of course is beneficial as the higher the temperature, the more efficient the conversion to electricity will be). Importantly it does not need to be pressurized.¹³⁵ **Liquid molten salt** is the only of the four main types of coolants for reactors that operates at high temperatures (for efficiency) and low pressure, making it safer (the other three types are #1 – **water**, already covered earlier, which operates at 250-350C and with high pressure #2 **liquid metal**, which operates at low temperature and low pressure and #3 **gas**, which operates at both high temperature and high pressure).¹³⁶ As Kirk Sorensen says,

“These salts don't want to react with anything else. This is another very good feature in a reactor. You don't want to build a reactor out of stuff that wants to be something else (that wants to burn or react, etc.). Whatever you've made it out of, you want it to be the rock bottom of stability. There should be no step further down that is chemically favorable because that's how things burn. *Fluorine* is so reactive with everything, but once it's made of salt, like *fluoride*, then it's incredibly chemically stable and non-reactive. Some people will say 'oh you're working on liquid *fluorine* reactors and I would say 'NO! I'm working on liquid *fluoride* reactors, and there's a big difference between those two. One is going to explode, the other is going to be super stable.”¹³⁷

As mentioned in the above quote, one of two types of FUEL is usually added in small quantities to the (lithium beryllium) salt mixture: 1) Uranium Fluoride or 2) [Thorium Fluoride \(LFTR\)](#).^{138 139}

For reasons we'll explain below, we'll focus our energy on the Thorium reactor.¹⁴⁰ There are some potential advantages to a thorium reactor that we summarize below (from a [great talk](#) given by thorium evangelist, Kirk Sorensen who we've already quoted earlier). These advantages include:

- 1) No need to be near a water source (true for molten salt reactors in general, not just thorium).¹⁴¹

- 2) Not pressurized (again because salt boils at much higher temperatures above 1400°C you don't need the massively high pressures. This results in a smaller building size for the reactor which potentially allows for a higher quantity of smaller, cheaper reactors utilizing the learning curve that comes with higher volume modular production. When one combines this with the independence from water sources, these smaller reactors can be much more flexible and modular in regard to where and how they are located.
- 3) Higher operating temperatures can be used for industrial process like concrete and steel manufacturing, desalinization, shale oil extraction, etc. which require high temperatures (steel requiring temperatures of 500°C to 900°C and glass/cement requiring temperatures of 1000°C to 1200°C).^{142 143} Fertilizer production as well as using hydrogen and CO₂ to produce synthetic fuels also becomes possible using these higher temperatures. Right now, the relatively low temperature nuclear reactors mainly cover electricity production (only approximately 30% of global fossil fuel emissions). With higher temperature ranges in these future reactors, it's possible to start eating into the other 70% of sources of greenhouse emissions (again, see concrete/steel production, etc.). And of course, nuclear powered, carbon free energy sources could also be used to power carbon capture devices, thereby giving these nuclear power plants *negative* carbon emissions.
- 4) In a molten salt reactor (not specific to thorium), there is a freeze plug of salt that is continuously cooled to stay frozen. If the plant loses electricity (from a tsunami, etc.) then the plug melts and the liquid fluoride mixture drains into a drain tank (which is specially designed to cool the mixture – molten salt reactors must be kept hot in order to produce energy. When the plug melts the molten salt cools and becomes solid).¹⁴⁴ Of course with solid fuel reactors, this sort of emergency draining is not possible because these old reactors are “instable by design”.¹⁴⁵ In general, molten salt reactors must be kept hot in order to produce energy, whereas water cooled reactors must be kept cooler (ie having a constant supply of cold water) in order to prevent it from melting down. Molten salt reactors, by design, are safer by default whereas water cooled reactors must have a constantly running process (and energy source) to keep them safe (which if stopped, results in disaster).
- 5) Thorium is much more abundant than other nuclear materials on both the earth and moon.¹⁴⁶ Thorium is found on earth at about 10 parts per million vs. 0.018 parts per million for Uranium-235 (gold is 0.002 or 10% as abundant as U-235, but gold is only 0.02% as abundant as thorium!).¹⁴⁷ Again we turn to Kirk Sorensen:

“Let's we were looking at U-235 as if it was its own thing (its less than 1% of all uranium). Uranium 235 is on par with the abundance of silver and platinum. Can you imagine burning platinum for energy? That would be nuts. But that's what we are doing with our nuclear energy sources today. We're burning this extremely rare stuff (U-235). And we are not burning the common stuff like U-238 and thorium. We're leaving that stuff unburned. If you want to just burn U-235, then yes, we'll run out of it. It's not that it's that uncommon, its just difficult to find sources U-235 that are rich enough to make it worth mining.”¹⁴⁸

- 6) Thorium would be 200x more efficient – drastically reducing the amount of nuclear waste produced.¹⁴⁹ In a normal reactor, the vastly more common U-238 is not fissile whereas the much less common U-235 is fissile. Therefore, one must go through the process of enriching uranium whereby the concentration of U-235 is increased.¹⁵⁰ After this U-235 is used as fuel in the nuclear reactor, it still contains very radioactive isotopes that must be stored for thousands of years. Thorium-232, first and foremost, is not fissile and can't explode (adding to the safety benefits). When one shoots a neutron at T-232, it absorbs it and eventually decays to U-233 (which is fissile). This is known as a breeder reactor, where U-233 and plutonium is “breed” from materials like thorium or uranium.¹⁵¹ As explained below:

“Thankfully, U-233 is also relatively long lived, which means at this point in the cycle the irradiated fuel can be unloaded from the reactor and the U-233 separated from the remaining thorium. The uranium is then fed into another reactor all on its own, to generate energy.

The U-233 does its thing, splitting apart and releasing high-energy neutrons. *But there isn't a pile of U-238 sitting by.* **Remember, with uranium reactors it's the U-238, turned into U-239 by absorbing some of those high-flying neutrons, that produces all the highly radioactive waste products.** With thorium, the U-233 is isolated and the result is far fewer highly radioactive, long-lived byproducts. **Thorium nuclear waste only stays radioactive for 500 years, instead of 10,000, and there is 1,000 to 10,000 times less of it to start with.**^{152 153}

Thorium can also potentially be used to burn up existing nuclear waste, reducing current nuclear waste lifespan from 240,000 years to less than 500 years.¹⁵⁴

- 7) Thorium half-life is much greater (i.e., much less radioactive) than uranium and plutonium. Thorium-232 has a 5-billion-year half-life, while U-235 has a 700-million-year half-life, U-238 has a 5-billion-year half-life and Plutonium PU-239 has a 24,000-year half-life (PU-238 has an 87 year half-life).¹⁵⁵ (As mentioned in bullet point above, thorium is only radioactive for 500 years instead of 10,000+ year like other nuclear reactor material).
- 8) Various fuel source costs as well as staffing costs would potentially be lower in a Thorium reactor. Some estimates have the costs for a 1GW thorium reactor at \$780 million (2014 dollars) vs \$1.1 billion for a uranium reactor (an almost 30% savings). Those same estimates have staffing costs dropping from \$50 million for the uranium reactor to \$5 million for the thorium reactor.¹⁵⁶
- 9) Thorium is much more abundant than other types of nuclear power, with the potential to power the earth for centuries, and beyond. See figure 50 later in the letter for a comparison.
- 10) The risks of proliferation are reduced, though not eliminated, because thorium can't undergo fission by itself.¹⁵⁷

Of course there are disadvantages as well. The technology is certainly less well tested, and further development would be needed to bring thorium reactors to scale. In addition, there are potential issues with long term salt storage (corrosion issues, etc.), among [other issues as well](#).¹⁵⁸

While we would like to see more open exploration in this space (thorium being one of them) it's our view that 90% of the gains will be from just adopting nuclear energy more in general. Selecting the type of reactor, etc. is the final 10% but not the large battle at the moment. In addition, unless there can be a better trade off made between certain safety regulations, etc. It's not clear that even vastly superior nuclear technology can overcome the regulatory cost structure that currently inhibits nuclear power. An interesting thought exercise to go through would be looking at bare minimum costs to run a thorium nuclear plant and using that as an approximate or even goal of where we could be headed as far as cheap, virtually limitless energy.¹⁵⁹

Fusion

Fusion power and its energy producing potential have been in the news of late. In December of 2022 a major milestone was reached with net energy “gain” being achieved for the first time. As a brief overview: as opposed to fission power (where energy is captured when atoms are split apart), fusion power by contrast, is energy captured when atoms are joined together. With *fission* power, a neutron is shot at a chemical isotope (most commonly U-235 or P-239), which splits the nucleus into smaller isotopes and also releases more neutrons. These extra neutrons in turn hit other nuclei and a chain reaction is started. Energy is released during this splitting and is captured in the

most common type of nuclear power plant existing today. In this way, small amounts of matter can be converted into large amounts of energy (energy = mass * speed of light (**squared**)).

By contrast, with *fusion*, two types of hydrogen nuclei (deuterium and tritium) are combined (requiring extremely high pressures and temperatures of 100 million °C or more). When these are combined, a neutron along with a helium isotope are produced. And of course, a massive amount of energy is also released. For an order of magnitude perspective, fusion is about 4 times as energy efficient as fission. However, fission is about 1 million times more efficient than normal chemical reactions (fossil fuel power, etc.).¹⁶⁰ With fusion, there's a theoretical mass to energy conversion efficiency of up to about 1% (with fission being an order of magnitude lower around 0.1%).¹⁶¹ So while fusion power would be a great advancement, most of the gain (1 million times) to society is from the switch from chemical reactions to *fission*. Furthermore, it's likely that many of the high safety factor costs as well as high operating costs associated with current fission nuclear power would also be associated with fusion power.

Coming back to the recent advancement of net energy gain in Fusion in late 2022, it's important to look at various types of classifications of fusion "breakeven". The most recent breakthrough is classified as "scientific breakeven". In this scenario, approximately 2 million joules of energy were pulsed at the target (from 192 lasers, situated around the target in all directions). This creates a massive amount of heat and pressure need for a fusion reaction, compressing the fuel to 100 times the density of lead.¹⁶² The fusion reaction creates even more heat needed to keep the fusion reaction burning (i.e., "ignition"). This "ignition" was first achieved in 2021, however that's not a net energy gain. In that case, about 70% of the laser's energy was produced. However in December 2022, net energy gain was finally achieved when 2.05 MJ of laser light produced 3.15 MJ of fusion energy (i.e. "scientific breakeven") had been achieved, with a Q plasma value of 1.54).¹⁶³ While this is a major milestone, it's important to note that this reaction lasted about only a fraction of a second and was only done once. A sustained reaction would need to be run continuously every 10 seconds, not just once.¹⁶⁴

In addition, there are other important milestones to reach in order for fusion to be practical beyond simply "scientific breakeven". The next breakeven step is called "engineering breakeven". In the case above, the laser produced 2 MJ of energy. However, in order to produce those 2 MJ, there was actually many hundreds of Megajoules **more** in energy needed (these lasers were extremely inefficient at conversion). Of course, a theoretical fusion power plant that needed say 300 MJ of energy to produce 2 MJ of laser power which in turn creates 3 or 4 MJ of fusion energy is not going to be economically practical in any sense. What's needed is for the total fusion energy produced to be great than, not the 2 MJ laser, but instead it *needs to be great than the 300 MJ of total energy going into the plant*.¹⁶⁵ Most experts concur that we are far away from achieving this milestone with the 2030s being the earliest of the predictions.¹⁶⁶

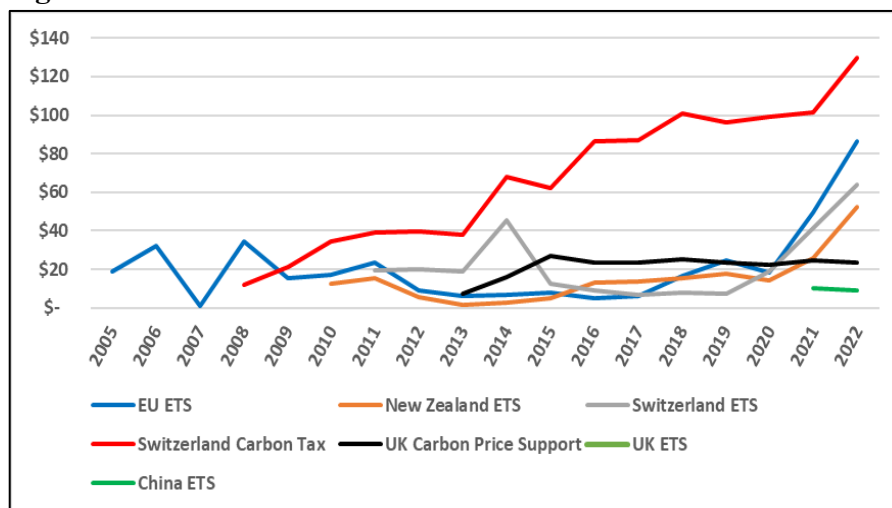
After engineering breakeven, the next milestone would be "economic breakeven". Even if a nuclear fusion plant as a whole can produce more energy than it takes in, it still must produce this energy in enough quantity and low enough cost for it to be a viable alternative to other energy sources.¹⁶⁷ As a first realistic example, ITER is an experimental fusion reactor being built in France with a projected completion date of 2035. ITER will attempt the first shot at engineering breakeven: "creating 500MW of heat from fusion for periods of 400 to 600 seconds" (using 300MW of electrical power).¹⁶⁸ However there have been massive amounts of money spent to build it and presumably to keep it running. It's unlikely that ITER will pass the economic breakeven threshold, at least in the early years after it (if?) reaches engineering break even. The total estimated ITER costs currently range between \$18 billion and \$65 billion. Other successor projects like DEMO are already being planned (with Q plasma values around 25).¹⁶⁹

Finally, as we did with other climate change predictions, we'll take a look at various prediction contests as a rough estimate on when we can expect fusion power. As usual, we don't have any expert knowledge that would allow us to disagree with these estimates so we'll outsource it and say they are our best guess as well. Metaculus has the world first deriving over 0.1% of its energy from nuclear fusion in 2048.¹⁷⁰ It has the world first deriving 10% of its energy from fusion in 2064.¹⁷¹

Carbon Pricing

One common scheme for incentivizing a reduction in carbon emissions is to put a price on any firm that emits carbon as a way of at least partially capturing the externality costs that these emissions inflict on society as a whole (usually done via either a carbon tax or carbon pricing/cap and trade system).¹⁷² Here, we'll cover the carbon pricing (otherwise known as 'cap and trade'). There are two main metrics we'll look at here when judging current and proposed carbon pricing schemes: 1) the price of carbon emitted and 2) The percentage of total global emissions that are covered under carbon pricing schemes. Europe has implemented the most famous carbon pricing mechanism and we show the price history of carbon emissions over the life of the EU project below (noting that too many permits likely caused depresses prices early in the program, while also noting the rise in prices of late).¹⁷³ Of note, most carbon pricing schemes have so far focused on CO₂, however there has been some progress made to also putting a price on emissions for other harmful emissions like methane, etc.¹⁷⁴

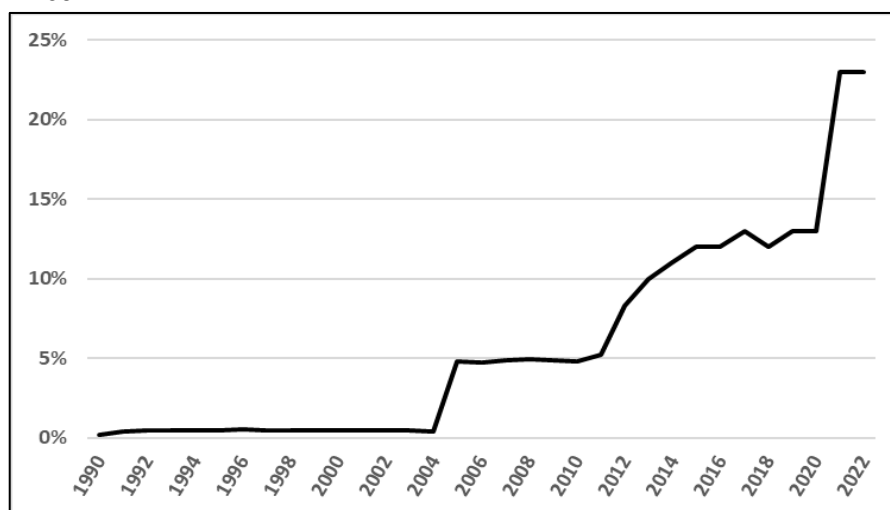
Figure 32: Various Carbon Prices¹⁷⁵



While the recent rise in prices would signal good news for lowering carbon emissions, we must take a more global view of carbon pricing. When we examine the average *global* price of carbon emissions, we note that the average **price is only \$6/ton in July 2022** (up from \$3/ton in September 2021). For reference, many experts commonly cite \$75/ton in 2030 (for advanced economies; \$25/ton for developing economies) as the price needed to reach the stated climate goals that will keep global warming under 2°C.¹⁷⁶ We list other countries around the world in the graph below, noting the wide range of carbon prices by country and region. Finally, for a sense of scale, the U.S emits about 5 billion tons of carbon a year. At \$75/ton that works out to approximately \$375 billion per year (or 1.6% of nominal GDP). However it's important to note that other estimates (incorporating net negative emissions, etc.) have prices needing to rise in the \$200/ton to \$250/ton range.¹⁷⁷ The total revenue for the European Carbon Emissions Trading System (ETS) was approximately \$37 Billion in 2021.¹⁷⁸

This brings us to the next major issue: the fact that only a small portion of global emissions actually covered by carbon pricing schemes. As of 2022, only about 23 percent of global emissions are covered by carbon pricing schemes.¹⁷⁹ That said, there is some room for hope when looking at the trend of this coverage since 1990.

Figure 33: Percentage of Global Greenhouse Gas Emissions Covered by Carbon Price ¹⁸⁰



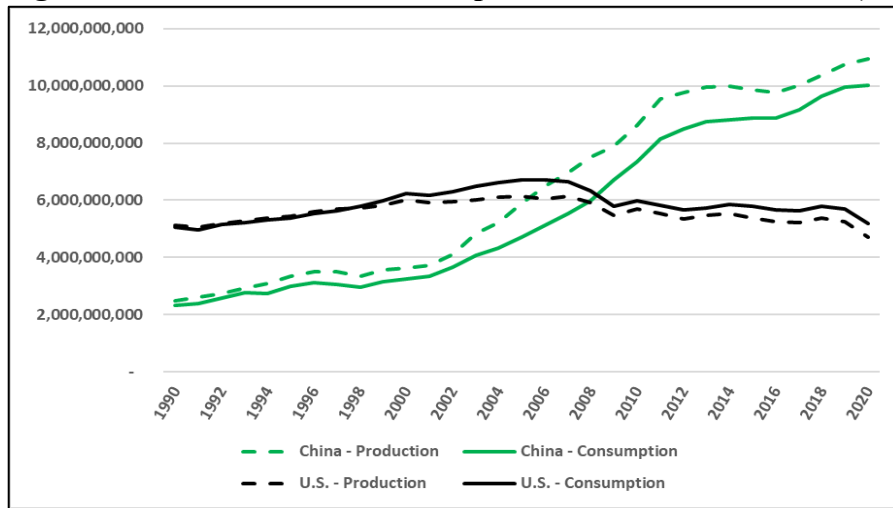
Looking at the data another way, we replicate a table from a 2019 World Bank report that shows which sectors are covered and which are not under the then current carbon pricing mechanism. In many cases there are significant portions of the economy *not* covered by carbon taxes or carbon trading schemes (ETS).

Figure 34: Sectoral coverage and GHG Emissions Covered by Carbon Pricing Initiatives¹⁸¹

Jurisdiction	Coverage	Credit Issued by Sector												
		Industry	Power	Transport	Aviation	Buildings	Waste	Forestry	Agriculture	All Fossil Fuels (Tax only)	Solid Fossil Fuels	Liquid Fossil Fuels	Shipping	
EU	52%	✓	✓		✓						✓			
China	33%	✓	✓	✓	✓	✓					✓			
Japan	67%	✓	✓			✓					✓			
Switzerland	44%	✓	✓			✓								
California	85%	✓	✓	✓										
Canada	80%	✓	✓				✓				✓			

When diving into the details on these various schemes, many potential problems can arise. A common issue is whether to measure (and price) only direct emissions within a country or to include items imported through trade. We replicate one such attempt below to show carbon emissions when including trade and when not adjusting for trade.

Figure 35: Production vs. Consumption-based CO₂ Emissions (tonnes)¹⁸²

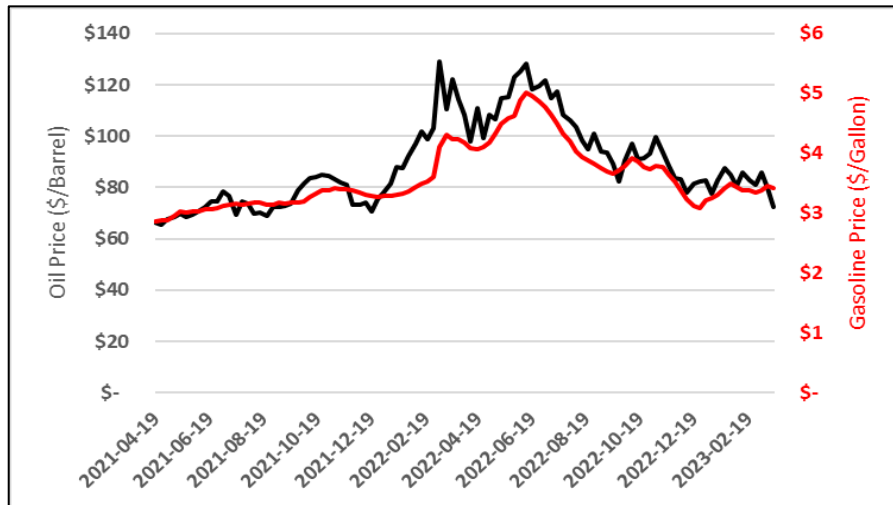


We can see that there are some differences in emissions depending on how they are measured (at point of use vs source of production, etc.). There are further ongoing efforts to incorporate the entire supply chain into the emissions picture. In particular, Scope 1, 2 and 3 emissions reporting attempts to triangulate the source of emissions through the supply chain (with Scope 1 measuring direct emissions, usually at source of production, and Scope 3 being the widest measure of emissions attempting to quantify the total emission across *all* parts of the supply chain, not just at the end of the supply chain).¹⁸³

Trends in Oil Demand/Production + Peak Oil

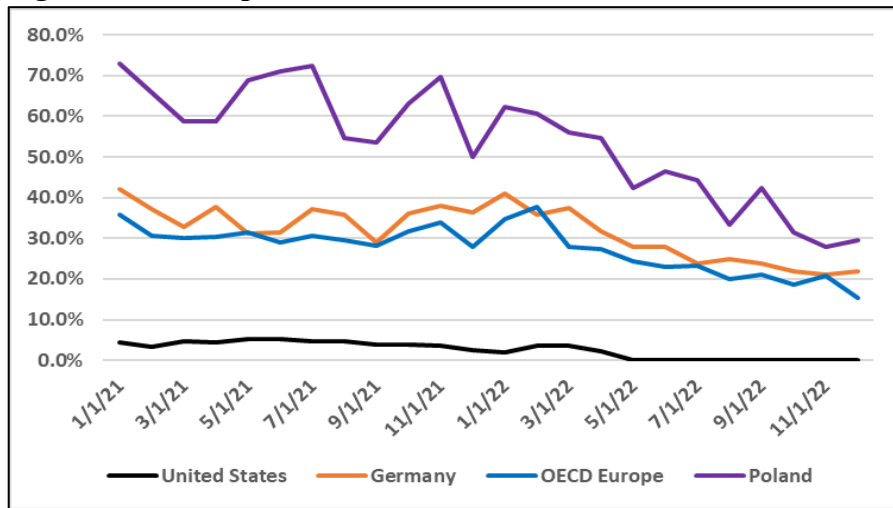
With the war in Ukraine, one of the less important, though economically interesting developments, has been the large move in oil and gasoline prices since the start of the war in February 2022. Below we list the price of oil and the price of gasoline (in the U.S.) over this time frame, noting the summer 2022 spike soon after the start of the war.

Figure 36: Oil Price vs Gasoline Price (2021 – 2023)¹⁸⁴



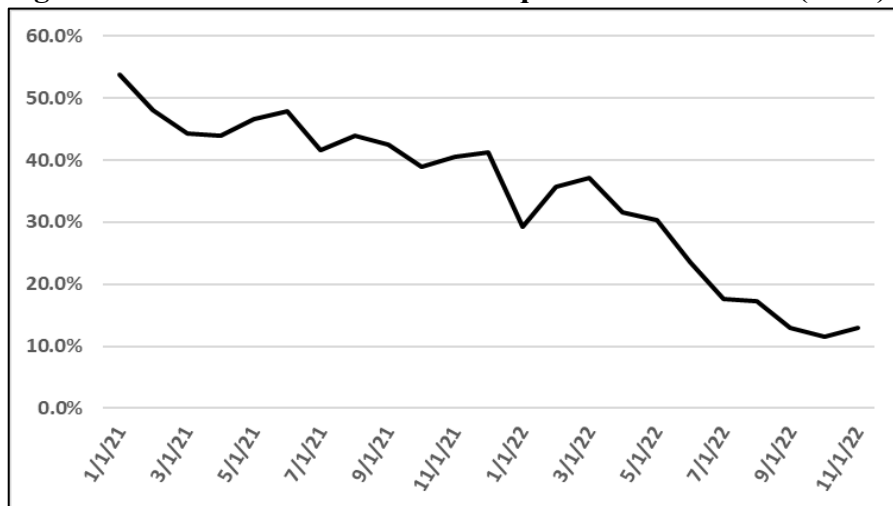
Part of the explanation for the rise in prices is the cutting off of Russian oil supply. We can see below that Russia, one of the main oil producers in the world, has been drastically cut off from supplying oil for many countries around the world.

Figure 37: Oil imports from Russia vs. Oil Demand¹⁸⁵



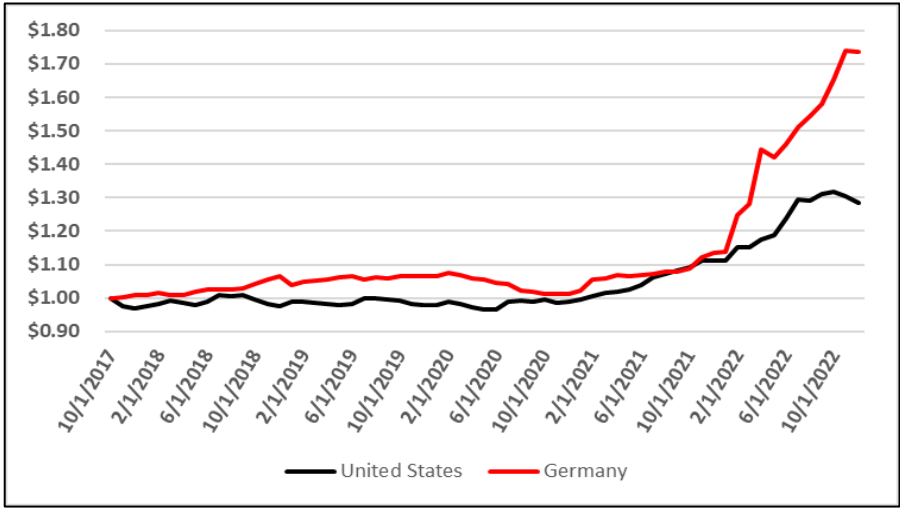
Natural gas also followed a similar pattern of a reduced EU reliance on Russia LNG as shown below.

Figure 38: EU reliance on Russian Liquefied Natural Gas (LNG) Imports¹⁸⁶



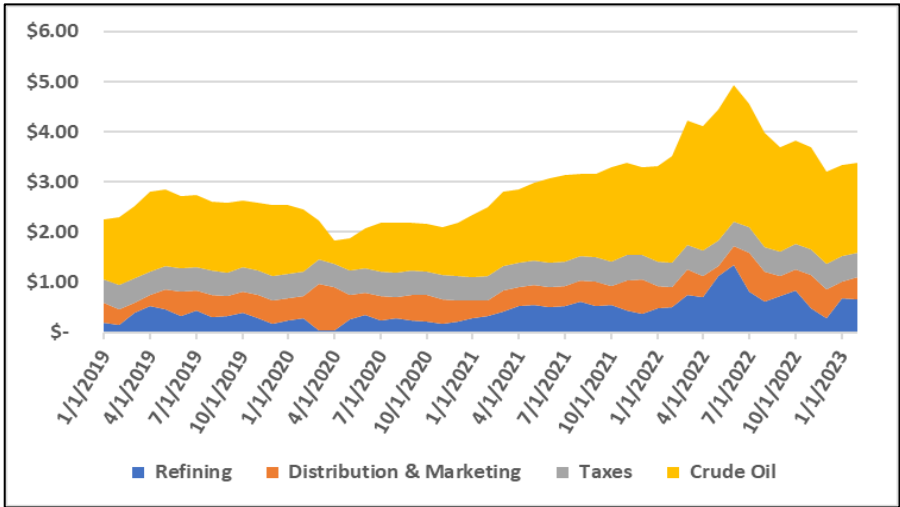
This sudden of a change, while understandable, has also unsurprisingly resulted in higher overall energy prices in Europe relative to the U.S.

Figure 39: Gasoline Prices, United States vs. Germany (Indexed to \$1)¹⁸⁷



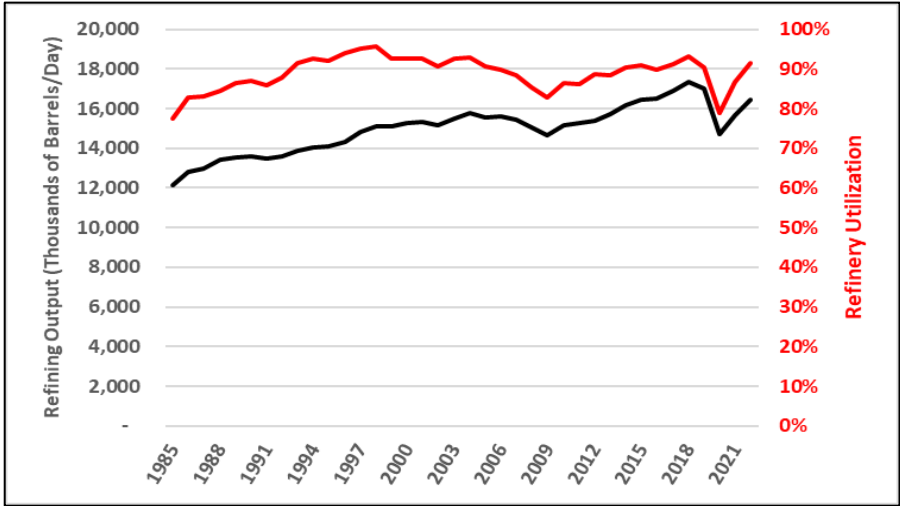
Of course, while the recent drastic price moves can largely be explained by the recent geopolitical events, it also important to look at longer term trends and examine how these long term trends effect the price of oil and energy of expanded time frames. We'll first examine a rough breakdown of cost inputs to the price of gasoline at the pump in the U.S. We note that the price of crude oil makes up only a bit over half the price of gasoline.

Figure 40: Component Costs of at the Pump Gasoline Costs (U.S.)¹⁸⁸



We've touched a bit on the inputs to the price of crude oil above, and will dive into a bit more detail in the next section as well. For now we'll treat "taxes" as well as "distribution and marketing" as relatively fixed even though there is likely some at least theoretical "wiggle room" on the policy front regarding taxes. That leaves us with refining costs. Below, we'll take a look at refining capacity in the US since 1985. We find that overall refining capacity has barely increased in the last 40 odd years.

Figure 41: Refinery Output and Utilization (United States)¹⁸⁹

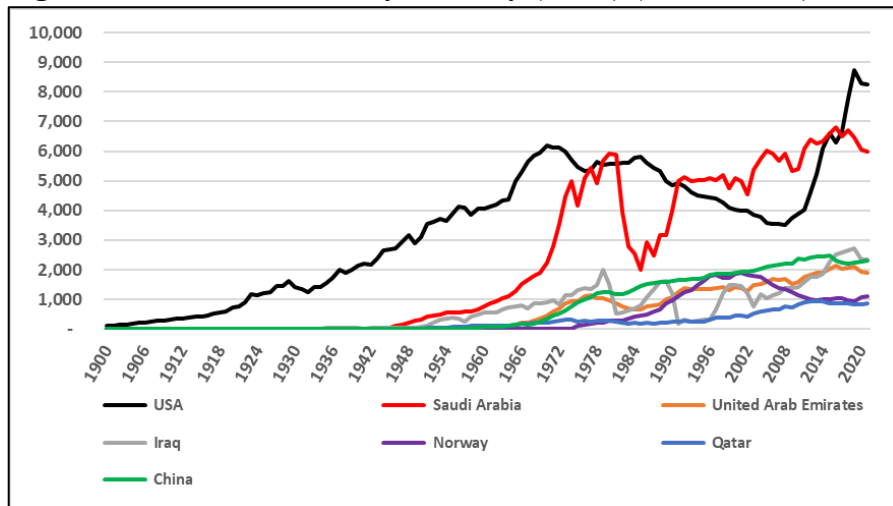


While this isn't necessarily a problem, it's important to note tradeoffs that come with national policy choices like this. No new significant refinery has been built in the United States since 1977 and it's unlikely that there will be any new refineries built in the U.S. in the next few decades, if ever.¹⁹⁰ While a decrease in overall demand would mitigate this to a degree, it also means the US will be more reliant on importing refined oil products from around the world in the future, which can carry certain risks as well as potential costs (which again, these policy choices will affect that price you pay at the pump for gasoline – we must simply be aware of the tradeoffs). Capacity utilization, shown above, is also important to look at. We've ranged from 77% to 95% of the time frame above. Right now there seems to be some spare capacity, but historically, the refineries in the US have operated at close to capacity. There certainly hasn't been an oversupply of refining capacity in the US.

There have also been recent (some of which are also valid) concerns about the amount of drilling approved. As The Economist recently put it: "Mr. Biden approved roughly 6,500 (oil and gas well drilling) permits to Mr Trump's 6,300...A standard lease to start drilling on public land is ten years. It is common for companies to wait to apply for a permit, which allows them to start drilling, towards the end of a lease. That means the vast majority of permits issued under Mr. Biden is on land leased during previous administrations. Compare the number of acres leased under each president, and Mr. Biden seems to be the most lease-leery president in modern history."¹⁹¹ That said, the final Inflation Reduction Act was a bit more drilling friendly.¹⁹²

Next, we'll cover the long-term trends in the oil price, production, etc. First, we'll examine oil production since 1900 throughout the globe. It's no surprise that the main data points to notice are Saudi Arabia dominance of worldwide oil production as well as the U.S.'s rapid rise of late (primarily from the fracking revolution). Also note that as of 2021 that total global production of oil was approximately 50,000 TWh.

Figure 42: Oil Production by Country (TWh) (1900 – 2021)¹⁹³



That said, this fracking comment brings up an important point. While production totals are important, it's also important to look at cost, as oil in certain regions of the world is easier to extract than others. This leads to drastically different production prices. While somewhat dated, the below table lists the marginal prices to produce a barrel of oil around the globe.

Figure 43: Marginal Production Cost of Oil, by Country (2014) (\$/barrel)¹⁹⁴

<u>Country</u>	<u>Marginal Production Cost</u>
Russia (Arctic)	\$ 120
Russia (Onshore)	\$ 18
Canada (Tar Sands)	\$ 90
United States (Shale)	\$ 73
Venezuela	\$ 20
Qatar	\$ 15
Oman	\$ 15
Iran	\$ 15
Iraq	\$ 6
Saudi Arabia	\$ 3
United Arab Emirates	\$ 7

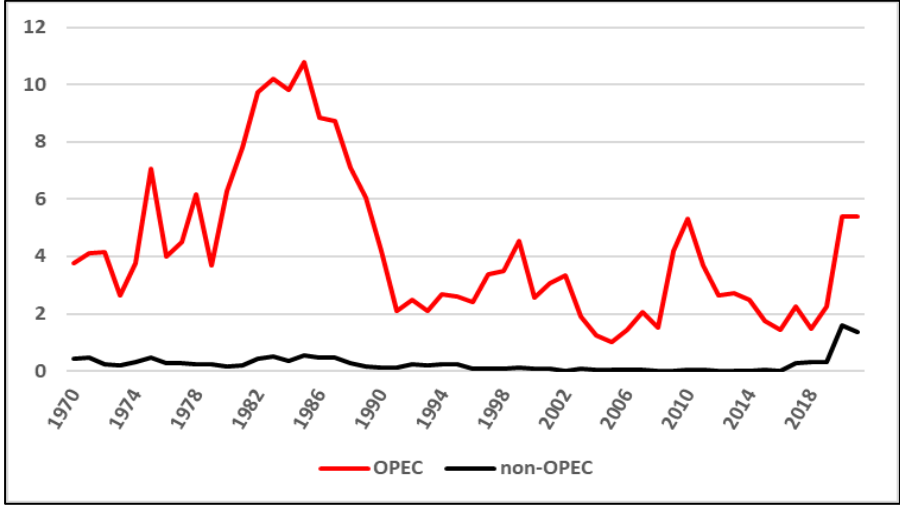
While many are aware of the massive oil production coming from the middle east, most will be surprised at just how large the price differential is.¹⁹⁵ Saudi Arabia’s productions costs at \$3/barrel were less than 5% of the then price of oil (hovering around \$100/barrel). This gives Saudi Arabia massive leverage on the global oil market. In addition, when you factor in spare capacity, it becomes evident just how much leverage Saudi Arabia has.

Figure 44: Spare Oil Capacity (2022) (Million Barrels per Day)¹⁹⁶

County	Sustainable Capacity	Short-Order Spare Capacity	90-Day Spare Capacity
Saudi Arabia	12.2	1.2	2.1
United Arab Emirates	4.1	0.6	1.2
Iraq	4.8	0.3	0.6
Kuwait	2.8	0.1	0.2
Russia	10.2	0.1	0.2
Others	12	0	0.8
Total	46.2	2.2	5.1

Taking a historical look at the surplus production capacity in OPEC vs non-OPEC countries, we note the large advantage of OPEC countries.

Figure 45: Surplus Crude Oil Production Capacity (Million Barrels per Day)¹⁹⁷



While these are the largely agreed upon spare capacity figures, it’s important to take a higher level view. If there was concerted political will (which there isn’t) to produce much more barrels per day of oil out of the middle east, it would certainly be technically possible in the long term. The marginal price of production might increase if oil production capacity were say doubled over the next few decades in the middle east, but as we saw above in figure 43, there is plenty of spread between production prices and market prices in the middle east. Of course, this will not happen, but it does help put in perspective the global oil production situation. While there are various *budget* considerations for many of these countries, one of the major factors is also how many years of production are left (given current oil production rates vs. total oil reserves still left in the ground). It will be no surprise to see below, that much of the proven oil reserves left in the world are in OPEC countries.

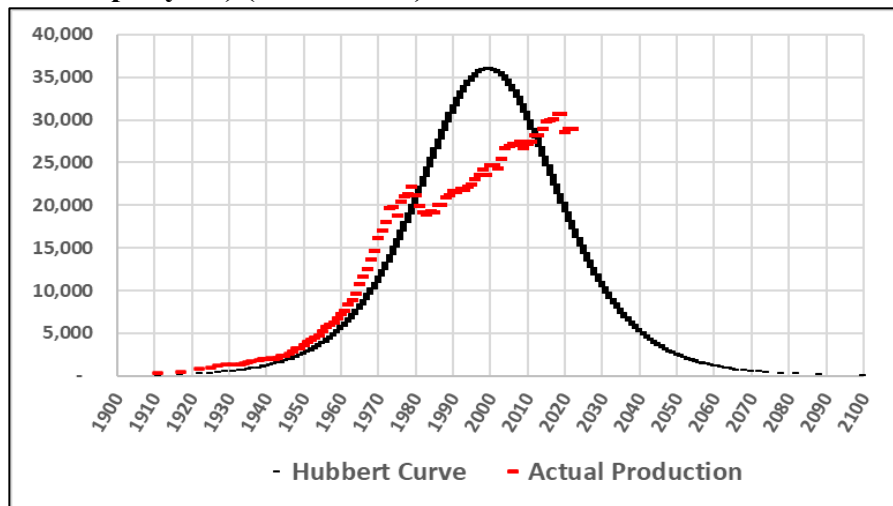
Figure 46: Oil Reserves by Country ¹⁹⁸

Country	Proven Reserves (millions of barrels) (US EIA)	Other Production (2020 - barrels/day)	Years of Production in Reserve
Venezuela	303,806	527,063	1,578
Saudi Arabia	258,600	9,264,921	76
Iran	208,600	2,665,809	214
Canada	170,300	4,201,101	111
Iraq	145,019	4,102,311	97
Kuwait	101,500	2,625,145	106
United Arab Emirates	97,800	3,138,249	85
Russia	80,000	9,865,495	22
Libya	48,363	408,074	324
United States	47,107	11,307,560	11
Nigeria	36,890	1,775,940	57
Kazakhstan	30,000	1,756,705	47
China	26,022	3,888,989	18
World	1,661,905	76,137,732	60

We can see that there is ample supply of reserves in most of the countries (over 1,500 years in the case of [low output] Venezuela and a solid 76 years in high output Saudi Arabia). At today’s production rates, none of the countries will run out of oil anytime soon. Of course, this doesn’t guarantee that all this oil can be extracted at the same low prices that exist in many countries today, but the world will not be running out of oil anytime soon. Any reduction in oil demand, if there is any, will be voluntary (likely in the name of helping the climate, etc.)

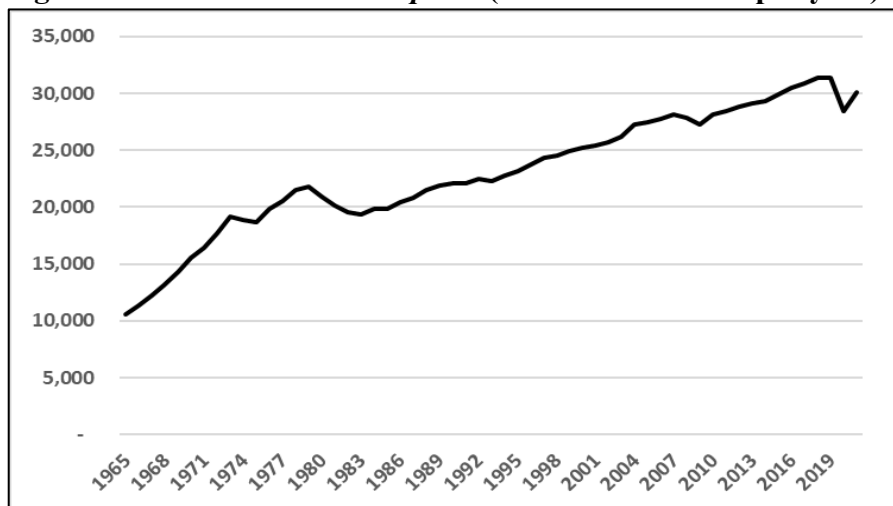
In the past, many have brought up the topic of “Peak Oil”. In the 1950s, M. King Hubbert theorized that oil production would peak around the year 2000 and decline thereafter (represented in the bell curve shaped black line below). Below is a derivative of the Hubbert curve, for *world* oil production. We can see that actual production has deviated from the predicted decline. Actual production continues its upward trend.

Figure 47: Peak Oil, World Production, Predicted vs. Actual (millions of barrels per year) (1900 – 2100) ¹⁹⁹



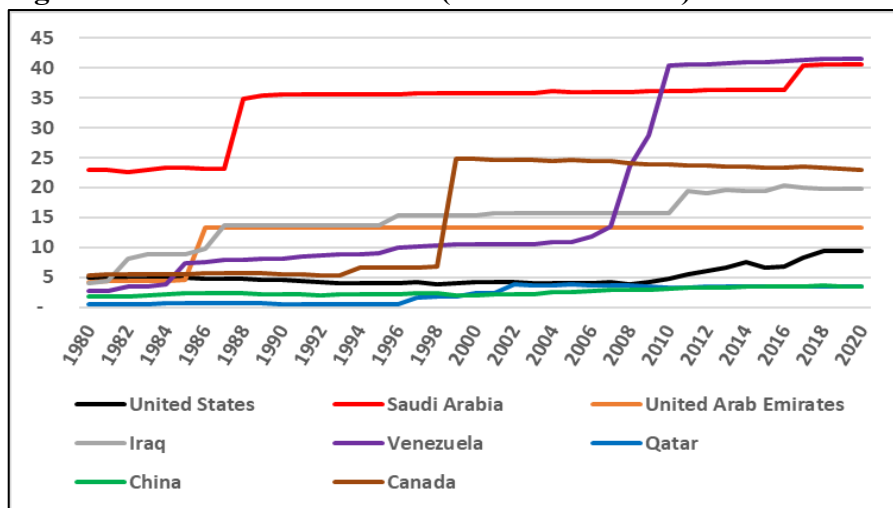
Of course, it becomes obvious, at least in hindsight, that something went drastically wrong with this prediction, as we see in the actual production figures shown in the red line above). Oil *production* did not drastically fall. We see this around the world as well, noting the increasing *consumption* of oil around the world.

Figure 48: World Oil Consumption (millions of barrels per year)²⁰⁰



The main fault with most of the peak oil theories is they underestimate technological advance and human ingenuity. Especially when there is an economic incentive to do so (as there is with the oil price), humans are quite capable of making advances that turn previously known oil reserves into economically viable extraction options and/or discovering new, previously unknown oil reserves all together. By looking at a time series of our earlier “Proven Reserves” figure above, we note below that the actual reserves have actually been *increasing* over time as we make new discoveries and technological advances. The figure 46 above is not static and the proven reserves will likely increase over time. (For reference related to previous graphs, 7.2 barrels = 1 tonne oil).

Figure 49: Proved Oil Reserves (billions of tonnes)²⁰¹



To wrap this section and tie it back to the previous section, we'll next compare our "Years of Production in Reserve" graph for oil and expand it to other commonly used elements. This will tie together much of our previous discussions on batteries (lithium), oil and nuclear power (uranium, thorium, deuterium/fusion).²⁰²

Figure 50: Global Production vs. Reserves, Various Raw Materials²⁰³

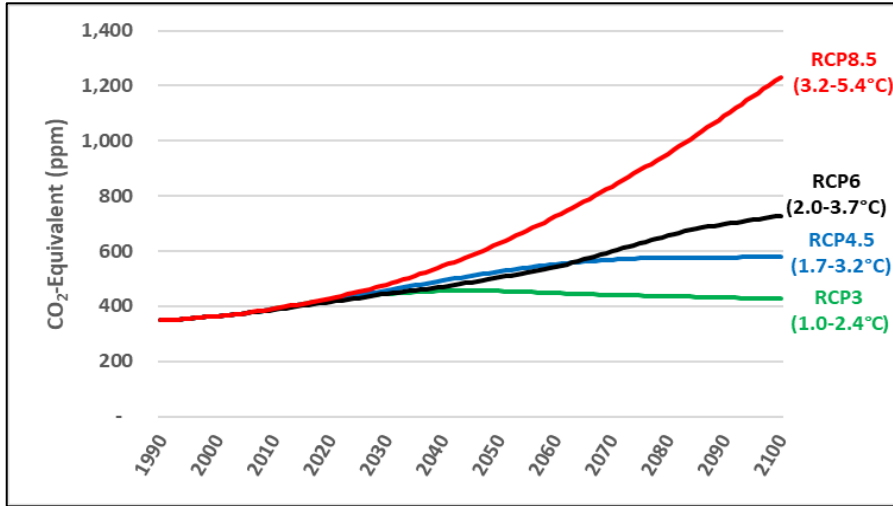
Commodity	Current Price	Current Annual Global Production	Current Estimate of Total Global Reserves	Years of Production in Reserve ^a
Oil	\$73/barrel	27 billion barrels	1.6 trillion Barrels	60
Coal	\$173/tonne	7.7 billion tonnes	735 billion tonnes	95
Natural Gas	\$6/thousand cubic ft (2018)	132 trillion cubic Feet (tcf)	6,923 trillion cubic feet (tcf)	52
Lithium	\$10,000/ton (2020) \$70,000/ton (2022)	130,000 Tons	21 million Tons	162
Cobalt	\$33,000/tonne	190,000 tonnes	8,300,000 tonnes	65
Nickle	\$27,000/mt	2.8 million mt	100 million mt	36
Iron	\$120/mt	2,500 milion mt	175,000 million mt	70 ^p
Lead	\$2,425/tonne	4.5 million tonnes	88 million tonnes	20
Copper	\$9,500/tonne	20 million tonnes	800 million tonnes	40
Tin	\$24,000/mt	310,000 mt	5.5 million mt	18
Silicon	\$2,500/mt	8.5 million tons	ample	100+
Uranium	\$33/lb	48,000 tonnes	8 million tonnes	166 (up to 60,000) ^c
Thorium	\$30,000/tonne	5000 tonnes	6.3 million tonnes	1250 (up to billions) ^d
Dollar Value (rough) of reserves (all above raw materials) ^e ->			\$530,310,300,000,000	
Deuterium (Ocean Water - Fusion)	\$13/gram	-	13 octillion joules (equivalent)	26 billion ^f
Solar Hitting Earth	-	173,000 TW ^g	-	-
Luminosity of the Sun	-	385 yottawatts (3.85x10 ²⁶) ^h	-	-
Luminosity of the Milky Way Galaxy	-	40 undecillion watts (4x10 ²⁷) ⁱ	-	-
Energy in the Universe	-	20 quidecillion watts(2x10 ⁴⁹) ^j	-	-

Future Scenarios

Geothermal energy remains another possible solution. That said, current technology is not quiet there. Geothermal energy (in order to get to high temperatures below the earths surface) must drill fairly deep to get to these hotter temperatures. Current drill bit technology isn't there yet, though experiments should continue. Any breakthrough in drilling technology could potentially open up this bountiful source of clean energy.

We should judge ourselves by our predictions made at certain points in time. One of the most popular is the projected temperature rises that will result for a given level of CO₂. Our prediction is that concentrations will rise for at least the next few decades, so in 2040 and 2050 we should be able to judge the effects of higher concentrations on temperature to judge the accuracy of the below predictions. It's our view that the globe will not be at carbon neutral by 2050 and that temperatures are likely to rise *more* than 1.5°C (2.7°F) by 2100, implying something like the RCP4.5 or RCP6 scenarios below.²⁰⁴ We wouldn't be surprised if we were at 600-800ppm by 2100, though prediction markets are slightly more optimistic – **predicting that the globe at a 2.3°C temperature rise and 588ppm by 2100.**²⁰⁵

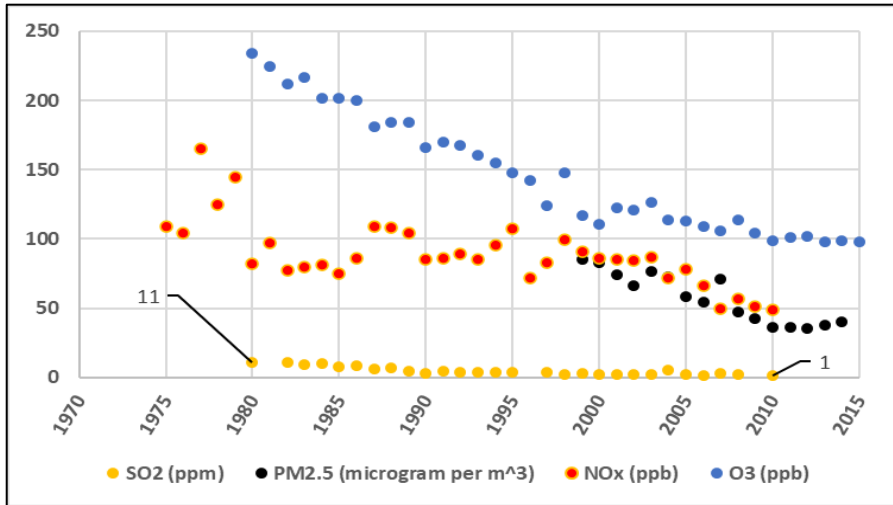
Figure 51: IPCC (AR5) Representative Concentration Pathways (2014)²⁰⁶



That said there is hope for significant change. While much smaller in scale to the global climate change issue, various cities around the world have reduced their local air pollution and smog figures. There are various ways to measure including some of the molecules listed in the figure below. Expanding on this further:

“The reduction in particulate matter has not been as dramatic as ozone. This makes sense, though, since ozone is a secondary pollutant whose precursors (NO_x and VOCs) largely come from vehicle tailpipes. NO_x and VOC emissions from vehicles has decreased significantly in recent years, especially with fleet turnover. In contrast, coarse and fine particulate matter come from many different sources, e.g. road dust, agriculture, cooking, etc. which is difficult to control since rain is the major control method.”²⁰⁷

Figure 52: Los Angeles Air Quality, Various Compounds (1970 – 2015)
 (Note: different units in graph legend: ppm, ppb and micrograms/m³)²⁰⁸

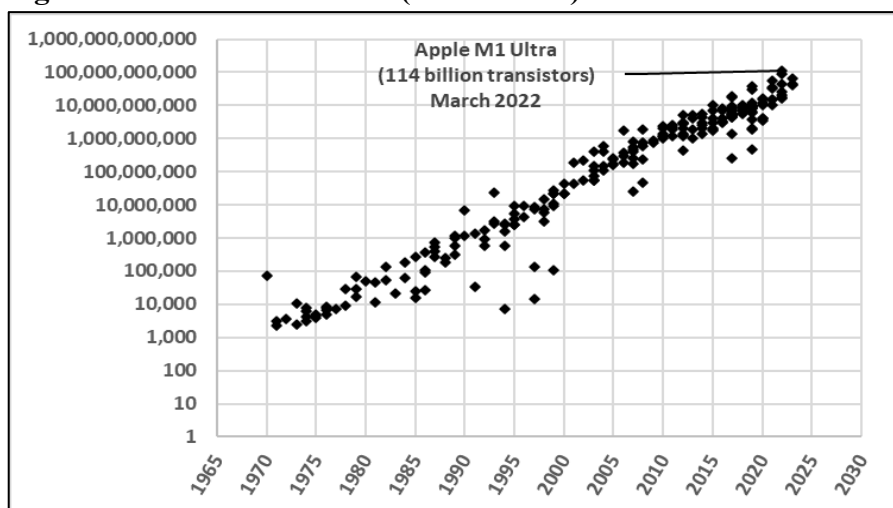


Moving on other like term trends: In our view, **when taking a multi-century view, there are two large trends at play: 1) an increase in total compute power (both efficiency (FLOPS per watt, etc.) and raw computer (total FLOPS) and 2) An increasing rate in per capita energy usage.**

While there are many ways to express the first graph, we look at a common one below, tracking the number of transistors over time, with one of the most recent being the new M1 chip from Apple Computer in March 2022. While there are certainly no guarantees this will continue, the progress has been amazing. It remains to be seen just how small these transistors can be made. That said, Jim Keller gives us hope with this quote from February 2020:

“There’s the question of ‘How small could a switching device be?’...So a modern transistor (has dimensions of) something like 1000 atoms by 1000 by 1000 atoms. And you get quantum effects down to around anywhere from 2 atoms to 10 atoms. So, you can imagine a transistor that is only 10 atoms by 10 atoms by 10 atoms in size. So that’s a million times smaller than today’s transistors [≈ 20 years of growth based on the trendline in the graph below]. And then you have the quantum computational people are working out ways to use quantum effects”...“I believe the next 10 to 20 years of shrinking is going to happen”.²⁰⁹

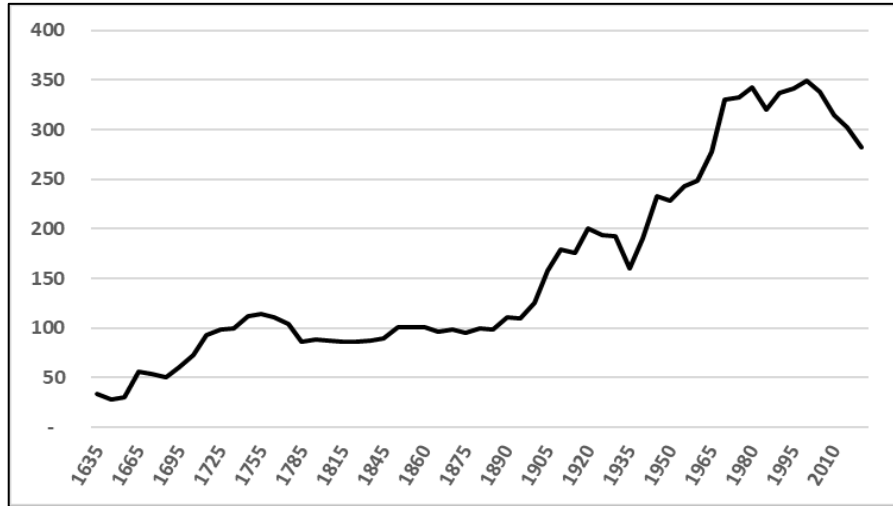
Figure 53: Transistor Count (1965 – 2023)²¹⁰



There are many ways to measure technology’s progress, and we’ve chosen a fairly standard one: Moore’s Law for the above graph. This measures the number of transistors (and importantly isn’t about transistor size nor linear performance).²¹¹

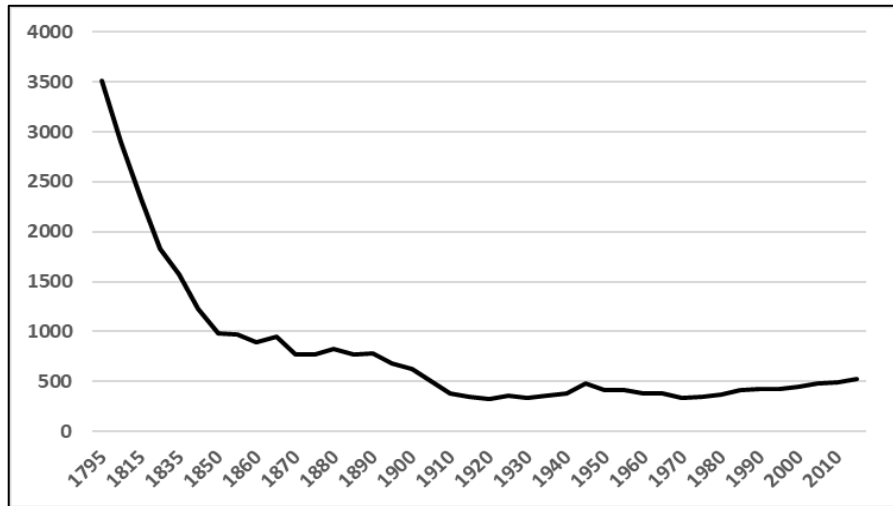
Unfortunately, the news is not quite as rosy when we look at energy usage per capita. Below we note the energy usage per capita in the United States (noting that it looks awfully similar to the number of nuclear power plants built in the US since the 1970s). Since 1635, per capita energy consumption has grown by approximately 0.5% per year. Total US energy consumption has grown by 3.2% per year over the same time frame.

Figure 54: United States Per Capita Energy Consumption, million BTU (1635-2022)²¹²



While the increasing GDP over this flattened energy use time frame (i.e., since 1970 or so) might imply this GDP per energy usage trend can continue at this same upward *rate* forever, we'd remain more skeptical.²¹³ We can see that population growth and energy usage were central factors in the increase in wealth society. Since the 1920s, real GDP has increased (after controlling for population growth and energy usage). We'll see if this continues. The population looks likely to level off at some point. It would be nice if we could increase our energy per capita numbers, but that is looking increasingly unlikely as well. Real GDP growth will of course continue (gains in compute per watt per \$, etc., will advance) but not as quickly as would otherwise have been possible if we also increased our per capita energy usage.

Figure 55: Real GDP ÷ Population ÷ Total Energy Usage (1795-2022)²¹⁴



Over the very long term, more energy will be required. Hopefully we can extract this energy in non environmentally harmful ways (though as usual, a cost benefit calculation must be done). While the trend in computer computations per KWh (Known as [Koomey's Law](#)) is a factor in the positive direction (i.e. ever increasing computational power per KWh), it would be optimal to have total energy increasing as well.

Getting society to a zero emissions future would be laudable, all else equal. However, it's important to not lose sight of the importance of economic growth. If going 100% renewable/zero emissions requires us to get off the [1.75% real GDP per capita growth we've seen since 1800](#), then it may not be worth it. Some sort of middle ground (with tradeoffs considered) may be necessary in the medium term (next 100 years or so).²¹⁵ Hopefully technological advance over the next century makes these tradeoffs less and less costly and we can eventually “have our cake and eat it too” (i.e. zero emission, ever rising per capita energy usage and advancement in computing power per unit of energy).²¹⁶

Footnotes and Sources

¹ Assumes a 1% annual management fee. Not included in these calculations is an approximately \$200 charge per account per year for fixed costs (minimum account fees, trading commissions, etc.). Split Rock Capital Management runs various separately managed accounts. While the strategy is the same, due to differing start dates, etc, the various accounts can have differing holdings and therefore differing performance numbers. While over the long term we expect these differences to even out, over the short run that can vary meaningfully. That said, on inception date, we started an initial portfolio (our *only* account at the time) which we have always, and will continue to use, as our tracking portfolio. To maintain consistency, and remove any selection bias, all historical performance numbers are from solely this account, regardless if the other accounts outperform or underperform this main tracking account in the past or going forward. Above performance numbers are from our original portfolio account. This was the only account setup as of our 12/15/2015 inception date, and the only account that has been continually open since inception.

² Includes dividends. Please note that these “S&P 500” numbers use [SP500TR](#). The performance numbers may vary slightly from the official S&P 500 performance numbers listed elsewhere on a year to year basis. However, over time, the differences should cancel out. For example, our SP500TR numbers for 2016 was 21.87% which was slightly above the official [21.83% for the S&P 500](#). However, in 2018 the differences largely evened out, with our SP500TR reporting a return of -4.41% while the official S&P 500 return was -4.38%. The differences in annual returns are largely canceled out over the entire 2-year time frame, and we expect differences between the two performance metrics to be even less of longer periods of time.

Also please note: Split Rock Capital Management runs various separately managed accounts. While the strategy is the same, due to differing start dates, etc., the various accounts can have differing holdings and therefore differing performance numbers. While over the long term we expect these differences to even out, over the short run that can vary meaningfully. That said, on inception date, we started an initial portfolio (our *only* account at the time) which we have always, and will continue to use, as our tracking portfolio. To maintain consistency, and remove any selection bias, all historical performance numbers are from solely this account, regardless if the other accounts outperform or underperform this main tracking account in the past or going forward.

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⁵ Partial year only; from inception date of 12/15/2015 to 12/31/2015.

⁶ Source: <https://fred.stlouisfed.org/series/GDP>

⁷ “While Powell thinks NGDP targeting is “interesting and works very well in models,” he is reluctant to adopt that monetary framework—primarily because “it seems difficult to implement from a practical standpoint.” His position echoes that of former Fed Chair Ben Bernanke, who in his 2015 memoir wrote: “Nominal GDP targeting is

complicated and would be very difficult to communicate to the public (as well as to Congress, which would have to be consulted).” Source: <https://www.cato.org/blog/case-nominal-gdp-targeting-reply-fed-chair-powell> ; <https://archive.is/00dvN>

⁸ While the above trend inflation is certainly worrisome, some pundits have gone too far in the other direction and called for hyperinflation. We don’t believe this is likely, and in defense of the Federal Reserve, the 5 year breakeven inflation rate stands at 2.4% while the 10 year breakeven is at 2.34. This is a far cry from hyperinflation and inflation does seem to be relatively anchored (albeit at an above trend level). Source:

<https://fred.stlouisfed.org/series/T5YIE> ; <https://fred.stlouisfed.org/series/T10YIE> ; <https://archive.is/m1WJw>

-We also note: while not a fan of the Taylor rule, as implemented, one potential improvement would be to use the Taylor rule but focused on inflation *forecasts* and not year over year inflation which may or may not also be expressed in forward inflation expectations. Monetary policy is 99% expectations so these rules should also focus on measures of expectations not necessarily focus on point in time figures

- There is a 0.3% difference in Chain-type Price Index vs the CPI. Since TIPS bonds use CPI, this can alter some of the calculations. There is also a risk premium and a liquidity premium. Adding these factors together means that breakevens in the 2.5% to 3% range imply 2% forward inflation. Source:

<https://www.clevelandfed.org/publications/economic-commentary/2020/ec-202006-cpi-pcepi-inflation-differential> ; <https://archive.is/D9VXm> ; <https://www.federalreserve.gov/econres/notes/feds-notes/tips-from-tips-update-and-discussions-20190521.htm> ; <https://archive.is/WbUdv>

⁹ Source: <https://fred.stlouisfed.org/series/GDP>

¹⁰ In theory, if current inflation trends continue, we might eventually reach the old 2008 trendline in Figure 1. However this is not cause for celebration. The main point of keeping NGDP on trend is so that markets have a predictable pattern of spending out in the future. Of course, if there is a deviation, markets *eventually adjust*. That is, nominal NGDP shocks do have *real* effects in the short and medium term. But in the long term, money is neutral, so the market will eventually adjust to the next trend deviated expectations. If you once again force the market to deviate *again*, then of course that will be another nominal shock that will have adverse *real* effects (even if you return to the trend from 2-3 cycles ago – after a certain point, the Fed has missed its chance to return to trend and its counterproductive to do so. In our opinion there is still time to return to the pre-2020 trend, but that is quickly running out. If we are say 20% above the 2020 trendline by 2028, there is no point in going back. The ship has sailed.)

¹¹ - Importantly, this red line is a market expectation of NGDP which should correlate to the market’s expectations for the Fed Funds Rate in the future ([which as of 3/24/23 stood at a peak of 4.85 which is the current level of 3/31/23](#)). If we are to move from the red line back to the green line/trendline, then these market expectations of the future peak Fed Funds Rate need to move higher (or stay higher for longer).

Sources: <https://www.metaculus.com/questions/13952/us-real-gdp-growth-annual/> ; <https://archive.is/1SGw0> ; <https://www.metaculus.com/questions/13973/us-annual-headline-cpi-inflation/> ; <https://archive.is/TeFm6>

¹² The Federal reserve should have begun raising rates when NGDP expectations started to rise above trend in Q4 2021. Instead they first raised rates in March 2022! It was obvious at the time that monetary policy was beginning to run hot, as we noted in a [Dec 4th, 2021 tweet](#). There is the potential there were other factors involved in not raising rates.

- Jerome Powell was reappointed on 11/22/2021

¹³ Source: <https://fred.stlouisfed.org/series/GDP>

¹⁴ https://en.wikipedia.org/wiki/Mr._Market ; <https://archive.is/JBMGm>

¹⁵ Source: 2h20m30s: <https://www.youtube.com/watch?v=GzVLeabssdE> “LIVE: Fed Chair Jerome Powell appears before the House Financial Services Committee”

¹⁶ Rohan Grey and George Selgin engaged in a lively and informative debate on the issue in the following twitter threads: <https://twitter.com/GeorgeSelgin/status/1617294792316035072> ; <https://archive.is/wzAVf> ;

<https://twitter.com/GeorgeSelgin/status/1617311206590537729> ; <https://archive.is/O2L3n> ;

<https://twitter.com/GeorgeSelgin/status/1617376817433960448> ; <https://archive.is/BjVDD>

¹⁷ Scott Sumner: “Monetary policy is about aggregate demand. Fiscal policy is about efficiency. The profession made a huge mistake in conflating the two policies.” Source: <https://www.themoneyillusion.com/fiscal-stimulus-is-costly> ; <https://archive.is/aVkmO>

¹⁸ Source: https://overcast.fm/+PVA_Muaok/35:47 “Macro Musings with David Beckworth: David Wilcox on the Debt Ceiling Crisis and the Crippling Costs of Default: February 20, 2023”

¹⁹ - Given most realistic assumptions in the rise of federal debt over the next few decades, Brian Riedl made a lot of sense in predicting that “Ultimately, I think we will probably have a series of little crisis’ that bring gradually reforms until ultimately we end up with a tax code that looks more like Europe: with high VAT (value-added tax) and high payroll taxes. That’ ultimately where this ends: with a 20% VAT and a 24% payroll tax (in the U.S. in the future).” Source: 43m40s at <https://overcast.fm/+PVA8dlJ80> “Macro Musings with David Beckworth - Brian Riedl on the Current and Future Outlook for US Public Finance and Budget Reform - March 27, 2023”

- Again we turn to Brian Riedl for some sane changes to Social Security and Medicare that would bring spending inline: “I would replace the whole benefit structure with a flat (Social Security) benefits of about 130% of the poverty line. And make it true insurance against poverty. Every retiree that pays into the system, gets a flat rate that keeps you out of poverty, 130% period. That can solve much of the funding gap. But that’s probably too ambitious for congress. Medicare is much more complicated. Nobody has a full solution to solve the Medicare gap. But two places I would start are: first raising Medicare B and D premiums for wealthier individuals. Again, B and D are not prefunded by payroll taxes. You just retire and you just pay 25% of your physician drugs costs, and tax payers pay 75%. The only who pay more than 25% are the richest 6% of seniors, and even then, for most of them it only goes up to 35% or 50%. I think if you are retired and are earning 100s of thousands of dollars a year even after retirement, and you have millions of dollars in liquid assets, you can pay much more of your Medicare costs. You don’t need a tax payer subsidy. And again, this is not the part of Medicare that is prefunded with payroll taxes. **This is closer to welfare (for the wealthy).** If you means test the B and D premiums, then It will be affordable. Also, I would like to move Medicare more towards the *premium support model*. Similar to where Medicare advantage is, where more seniors can shop around for private plans. The congressional budget office says that if you just allowed seniors to shop around for private plans, you could provide a system that is just as generous, at 7% of a cheaper cost for the government and 7% of a cheaper cost for the seniors, without costing anything in benefits. Just from efficiencies. Those two reforms would close about half of the Medicare gap. I think you probably may have to raise the payroll tax a little bit, and you have to do more on the Medicare side (its not a comprehensive plan).” Source: 46m25s at <https://overcast.fm/+PVA8dlJ80> “Macro Musings with David Beckworth - Brian Riedl on the Current and Future Outlook for US Public Finance and Budget Reform - March 27, 2023”

- Tyler Cowen expands on his ideal tax system (and we’d agree!): “The ideal tax system is a progressive consumption tax with a relatively light rate on capital income, though it can’t be zero because otherwise people will reclassify their labor income into capital income.” Source: 23m24s to 23m36s at https://www.youtube.com/watch?v=q8qjGuC_e_Q “Conversations with Tyler 2022 Retrospective (full) | Conversations with Tyler”

²⁰ Source: <https://fred.stlouisfed.org/series/GFDGDPA188S>

²¹ Source: <https://fedsoc.org/commentary/fedsoc-blog/the-fed-s-operating-losses-become-taxpayer-losses> ; <https://archive.is/JMzEP>

²² “First, even if QE leads to Fed losses in some periods, it will likely also boost Fed profits in other periods.[3] Thus, the losses in a given year may simply offset a portion of the profits in other years, leaving the overall effect on Fed income positive.” | “The Fed can’t default because it can always create reserves to pay its bills.” | “Happily, the Fed’s future profits are likely to be substantial, since more than \$2 trillion of its securities holdings are financed by currency, on which the Fed pays no interest.”

Source: <https://www.brookings.edu/blog/up-front/2022/06/01/what-if-the-federal-reserve-books-losses-because-of-its-quantitative-easing/> ; <https://archive.is/kKUTW>

²³ “In a development previously unheard of, the Federal Reserve has suffered operating losses of about \$42 billion since September 2022. That month, the massive interest-rate risk created by the Fed’s asset-liability maturity mismatch began generating cash-operating losses, and the losses now average \$7 billion a month. This is because the Fed’s trillions of dollars of long-term investments yield 2% but cost 4.6% to finance. The Fed will soon have negative equity capital, and as operating losses continue to mount, its equity-capital deficit will grow.

Source: <https://www.wsj.com/articles/for-the-first-time-the-fed-is-losing-money-mortgage-backed-securities-treasurys-interest-rate-risk-svb-ad92e96f> ; <https://archive.is/y1YoY>

²⁴ Source: 35m41s at <https://www.youtube.com/watch?v=m0frw7BKkVE> “Balaji’s Bet: Bitcoin hits \$1 million in 90 days”

²⁵ Source: <https://www.reuters.com/business/finance/new-svb-ceo-urges-top-venture-capital-clients-move-deposits-back-2023-03-14/> ; <https://archive.is/uGUQW>

²⁶ Other banks numbers are also listed here on the very informative table. Source:

<https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/svb-signature-racked-up->

[some-high-rates-of-uninsured-deposits-74747639#:~:text=Silicon%20Valley%20Bank%20ranked%20first,as%20of%20year%2Dend%202022 ; https://archive.is/VLsNg](#)

²⁷ In 2008 we saw many banks that had liquidity problems (some of which also had solvency problems). As Bill Dudley noted in 2008: “you can have a liquidity problem, without a bank being insolvent”. However this is a bit different than a debt ceiling issue, (which Dudley noted back in a December 2011 hearing when asked by Mchenry “You can also have a bank with no liquidity problems, that is fully insolvent” to which Dudley responded “Yes, well the thrift crisis is a good example of that”. Source: 36m10s at https://www.youtube.com/watch?v=09WBNI_APMI “What The Euro Crisis Means For Taxpayers And The U.S. Economy, Pt. II”

- Bill Dudley also opines on Too Big to Fail: “One alternative strategy for dealing with too big to fail is to reduce the size of large banks by imposing size limits. While I understand the motivation, it is important to recognize that imposing size limitations might not be a very efficient means of making the financial system more stable. First, it could sacrifice some socially beneficial economies of scale and scope, especially to the global clients of large financial institutions, depending on how the size limits were implemented. Second, the resulting benefits in terms of reducing systemic risk might be quite small. As demonstrated by the thrift crisis, if many firms are all vulnerable to the same shock, ensuring that these firms are small and numerous won't necessarily reduce the systemic risk they collectively pose to the financial system. Third, the costs incurred in breaking up such firms also need to be considered.” Source: <https://www.bis.org/review/r131108g.htm> ; <https://archive.is/OPW3c>

²⁸ - SVB was creative is trying to compete with too big to fail subsidy – SVB gave good terms to various VCs, startups etc. under the condition that they move all or a significant portion of their cash to deposits at SVB. These are the creative ways that the market works around regulatory structure – and many of these startups could not get loans at any other place, so they had to go to SVB, and then SVB further demanded they move *all* their companies cash to SVB.

-Its interesting to note that in 2008, many said the main problem for the endless drop in stock prices and the bad economy was the banks being forced to mark to market many assets, during a fire sale (capital requirements at these low market values only furthered the downward spiral of selling). In this case somewhat of the opposite occurred, where banks were holding assets at values significantly above what they could be sold for on the open market.

²⁹ Source: <https://www.federalreserve.gov/newsevents/pressreleases/monetary20230312b.htm> ; <https://archive.is/7H6TC>

³⁰ As we’ve seen in Europe

³¹ Source: https://en.wikipedia.org/wiki/Raimondo_Montecuccoli#Assessment ; <https://archive.is/xG8si>

³² Source: <https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020>

³³ “Mr. (James A.) Baker offered what he called ‘ironclad guarantees that NATO’s jurisdiction or forces would not move eastward,’ according to a declassified memorandum recording the discussion. ‘There would be no extension of NATO’s jurisdiction for forces of NATO one inch to the east.’ Mr. Baker told Mr. Gorbachev, coming back to the formula three times during the conversation.” Source: <https://www.nytimes.com/2022/01/09/us/politics/russia-ukraine-james-baker.html> ; <https://archive.is/YvbEq>

³⁴ An argument within pro NATO circles at the time was that NATO must “grow or die”. After the USSR equivalent of NATO, the Warsaw Pact, was no more, NATO had somewhat of an identity crisis, and growing was one way to delay the day or reckoning of this identity crisis (or so some thought).

³⁵ West Berlin had of course been a member of NATO since 1955, but in 1990 a unified Germany was admitted to NATO membership. “Twelve countries were part of the founding of NATO: Belgium, Canada, Denmark, France, Iceland, Italy, Luxembourg, the Netherlands, Norway, Portugal, the United Kingdom, and the United States” in 1949. Later, Greece and Turkey joined in 1952, as well as Spain in 1982. Source:

https://en.wikipedia.org/wiki/Enlargement_of_NATO#Adriatic_Charter ; <https://archive.is/rabzu>

in March 2004, President George Bush said: “The door to NATO will remain open until the whole of Europe is united in freedom and in peace.” Source: https://en.wikipedia.org/wiki/NATO_open_door_policy ;

<https://archive.is/cREt8>

³⁶ Source: https://en.wikipedia.org/wiki/2007_Munich_speech_of_Vladimir_Putin ; <https://archive.is/QejDV>

³⁷ https://en.wikipedia.org/wiki/Russo-Georgian_War#Relations_between_Georgia_and_the_West ;

<https://archive.is/Fdaoz>

³⁸ Source: https://en.wikipedia.org/wiki/Russo-Georgian_War ; <https://archive.is/Fdaoz>

³⁹ Source: https://en.wikipedia.org/wiki/Annexation_of_Crimea_by_the_Russian_Federation ;

<https://archive.is/LNAyt>

⁴⁰ Source: https://en.wikipedia.org/wiki/Russo-Ukrainian_War#Russian_accusations_and_demands ; <https://archive.is/093Cq>

⁴¹ Source: https://en.wikipedia.org/wiki/International_relations_theory ; <https://archive.is/9ROTh>

⁴² Alternatively, Robert Kagan demarcates international relations into four main categories: “Well there a couple of different (geopolitical) camps. But they’re not easily defined by political party. And that’s where people think it’s a nice simple “Republican vs. Democrat” thing. The truth is, that if you use the term 1) ‘neoconservative’, which I don’t like, but if you define that as ‘believing that American power is central. That America should be promoting democratic principles when it can. That the United States should play a predominant role in the world’, then I would say that describes half the top leadership, if not more, of the Obama administration. And Obama himself, depending on which speech you focus on, has said almost exactly that. He’s said at the West Point speech a couple years ago. And I know people in the administration who have that very strong view. What people call ‘neoconservative’, I call a mainstream view, bipartisan view that has been dominate in this country and in Washington DC for quite some time. Everyone from Dean Acheson to John F. Kennedy to Ronald Reagan. Now another school is what you would call 2) ‘liberal internationalists’. Who want everything to be about institutions. They want to rely more on institutions: they want to strengthen the United Nations; they want the United States to support international institutions and international law. And are *more* worried about the United States running afoul of those institutions than they are about America exerting power. Now sometimes these people overlap. There were some actions that liberal internationalists favor because they think it supports a world order. So that gets complicated. Then there is the so called 3) ‘realists’. And I don’t know what that means anymore. Either because the realists tend to argue that the United States needs to be more restrained. But realism is supposed to be about the exercise of power and what works. But in general, realists, especially responding to George W. Bush, have called for a more restrained approach. And then on the final extreme you have what you might call genuine 4) ‘isolationists’ of the Ron Paul variety. But I must say, depending on the issue, depending on who’s in power, and which party is in power: it’s amazing how much flux there is. One of my favorite examples is George Will, who I think it taking a strong minimalist approach to American foreign policy. He says we shouldn’t be off on crusades. But I remember when George Will supported the invasion of Panama, under George H.W. Bush, arguing that its right for the United States to be supporting democracy. So, you know, people are all over the map. And things are not as neat as some reviewers in New York City think they are.” Source: 48m40s to 51m42s at <https://www.youtube.com/watch?v=Vkr3S4TKBsU> “Robert Kagan, Author, "The World America Made"”

⁴³ Robert Kagan expands on the Liberal World Order. “It was a very concrete series steps (taken by Truman, Dean Acheson, and Roosevelt). Taking Germany, that had been an aggressive dictatorship and transforming it into a pacific, vibrant democracy (after World War 2). Doing the same in Japan. Those were very concrete things and they led to other concrete steps: A unification of Europe, a setting aside of European nationalism, a growth in the European economy, etc. (and again, similarly in Asia). *And that is the (Liberal World) Order that I’m talking about: largely democratic, peaceful and prosperous world*” || “The European Union (EU) came about, as any European will tell you, because the United States essentially settled the ‘European Problem’ by bringing peace and security to both Germany and France (who had both engaged in 3 major wars). United Germany and France in a common effort and laid the foundation for the European community and ultimately the European Union. And NATO was a critical security pact that held all that together and made all these other things possible. (We’ve become an indispensable nation – that’s the phrase that Bill Clinton used.)” || “If you go back and read Truman and Acheson, they believe that the great error that Americans had made in the 1920s and 1930s, was refusing to take responsibility for maintaining a general peace and a general order...that benefited them but that also benefited others” || “The reason (why it is necessary for the U.S. to be focused all over the world, to protect what we have here in the U.S.) is because we are the only ones who can do it (as we discovered). It isn’t because we are especially virtuous (we are only somewhat virtuous), it isn’t because we are intelligent (because goodness knows we are not – we make mistakes), its because we are the only ones that *can* do what we’ve done. And if you just look at the world before we started playing this role, it was a cycle of endless conflict. And so the United States has the capacity to do it...and because it has the capacity to do it, it has to do it in its own interest. That’s the thing that Americans lose sight of: we aren’t doing this as a favor to anybody. *What we discovered in the 20th century was that there was no order, and wars erupted, and we were inevitably dragged into them. We couldn’t stay out of them, even if we wanted to. And goodness knows we tried to stay out (of both World War 1 and World War 2). And therefore, what the founders of the (Liberal World) Order understood, was that we didn’t have the option of staying out, so therefore we had to create a system that would prevent those wars in the first place.*” || “This geographic advantage which you describe (large oceans separating us from the rest of the world and friendly neighbors to the North and the south), it leads us

in two different directions: 1) it leads us to think that ‘everything is so far away, it doesn’t matter what happens out there’ and 2) we are so secure, that we can afford to be out there. And what you see if constant vacillation between those two options. We get involved in World War 1 and then we decide we wished that we hadn’t. Then we get involved in World War 2 and our first instinct is ‘now we can all come home, but now we decide that we can’t’. Then even during the Cold war, you have the Korean war and the disillusionment under Eisenhower. Then you have Jack Kennedy and Vietnam. And then you have Jimmy Carter. And then you have Ronald Reagan. So, America is constantly vacillating between these two poles.” || “What we’ve seen now, and should’ve known, is that none of those things are true. Authoritarianism is a very stable form of government. It may even be *more* stable than democracy. And we are seeing countries like China, who are doing very well economically, but showing no sign of moving toward democracy, in fact they’ve moved in the opposite direction since Xi Jinping has amassed all power to himself. So, we’ve got to stop diluting ourselves that (democracy) is a natural phenomenon. It is a struggle. That’s my key point: Democracy is a constant struggle that never ends...because you are dealing with aspects of human nature that are at war with each other.” || “One of the reasons (that the Cold War didn’t turn into a hot war) was because the Soviet Union found itself so isolated in this successful Liberal World Order, that it really didn’t have any really good options. And they tried to reform, and they collapsed.” || “After all, Americans look back now and say containment (of USSR during Cold War) was good strategy. But that strategy of containment got us into Vietnam. There is no foreign policy that is going to be without failure. Foreign policy is a very difficult activity. Its going to have its fair share of failures, and if people are looking for a foreign policy where there is no downsides, where there are no risks, where there are no failure, where there is no immorality, where this is no cost...then they are kidding themselves. So we focus on the mistakes we made in Iraq and Vietnam, but we never focus on the mistakes made by *not* doing anything (SRM: some would cite the Korean War and prosperous present day South Korea as being an example of containment working). The men and woman who created the world order after World War 2, they remember what we had *not* done (in the 1920s and 1930s). We had not stepped in deal with the jungle growing back in Europe and in Asia prior to World War 2” || “And this is why I use the ‘Jungle’ metaphor: because that is the natural occurrence. The unnatural occurrence (i.e., Democracy and Liberal World Order) is holding that at bay. If you don’t hold it (authoritarianism, violent nationalism, etc.) at bay, then it grows back. If you plant a garden, you haven’t finished your job. You have to keep cutting the weeds back, otherwise...*the jungle grows back.*” || “Foreign Policy is something that is very hard to succeed at. Most of the time you get it wrong. In earlier book I used the analogy of hitting in a baseball game: If you miss 70% of the time and don’t get a hit, then you’re going to the Hall of Fame. And I think we, as a people, don’t have a sufficiently tragic sense of what wielding power and what conducting foreign policy is all about. And so, we are incredibly impatient. If you are in Washington then you see the political ramifications of errors and mistakes (that I think are, unavoidable). The political ramifications are that: it (unfortunately) leads people to say, ‘we just got to get out of this business entirely’. And trying to keep Americans engaged in the world, despite the failures, despite the difficulties...is a constant struggle” || (Going forward) “Most importantly, we must focus on Chinese military activities in East Asia. We have to be able to deter China from acting militarily.” Source: <https://www.youtube.com/watch?v=EEZGykCsYQk> “TIA&TW - Robert Kagan (The Jungle Grows Back)”

- Kagan: “So in a way, I think that it’s too ambitious that you’re going to eliminate these (geopolitical) problems. And I certainly don’t think that letting them play out works, because when you let them play out...well, we saw the consequences of letting them play out. We should be appropriately modest in our assessment of what we can do. And yet, I believe that modest accomplishment, yields incredible benefits. In a way I was critical of Obama when he said “I don’t want to just put a lid on a problem.” (He was talking about Syria for instance). But my feeling is that we are always just putting lids on problems. We put a lid on the European problem (after WW2) and we put a lid on the Asian problem. You think Japan and China won’t go back to conflict in a nanosecond if we (the United States) aren’t somehow involved?” Source: 50m50s at <https://www.youtube.com/watch?v=e8QiCK6ZnA> “Book Launch: The Jungle Grows Back: America and Our Imperiled World”

- Kagan: “But the United States has played a role in the world that no other nation in the history of the world has played. The United States took on responsibility after World War 2, for maintaining a certain kind of world order. And they did it in their interest. It wasn’t a favor to anyone. When people like Dean Acheson and George Marshall and Harry Truman, and during the war, FDR, set out this vision of America taking responsibility for maintaining some kind of order...It’s because they’d lived through the consequences of *not* doing that. They weren’t idealistically trying to create somekind of heaven on earth. They were quite pessimistically trying to prevent sliding back into the horrors that they had all witnessed in the course of their lifetimes in the first half of the 20th century.”

Source: 27m10s at <https://www.youtube.com/watch?v=sRCwYy5qrt4> “The Jungle Grows Back: A Case for American Leadership”.

- Kagan: “so, if China thinks we are trying to contain them militarily *and* were trying to contain them economically, that to me is the worst of all possible worlds. And what I really fear we are doing right now is we are going to squeeze them economically but we’re not actually as frightening as we need to be militarily.” 37m36s at <https://www.youtube.com/watch?v=e8QiCK6ZnA> “Book Launch: The Jungle Grows Back: America and Our Imperiled World”

⁴⁴ - Source: https://en.wikipedia.org/wiki/Liberal_international_order ; <https://archive.is/kDISN>

- “At the end of World War II, the U.S. and European powers created two financial institutions as part of the Bretton Woods Agreement: the World Bank and the International Monetary Fund (IMF). It was informally agreed that the U.S. would choose the head of the World Bank, and Europe would choose the head of the IMF.” || “To date, this arrangement has remained in place. All 12 World Bank presidents have been American, while all 11 IMF managing directors have been European. But as time goes on, the U.S.’s financial stake in the World Bank has decreased and the reasons for which the country was to lead the institution have diminished with it. As such, there have been growing calls in recent years to select the most qualified candidate—regardless of nationality.” Source:

<https://finance.yahoo.com/news/why-world-bank-president-always-102112739.html> ; <https://archive.is/6TofB>

⁴⁵ “I’d consider myself a realist, alright? But in philosophical terms I’m what’s called a pessimist” – Rush Cohle, True Detective, Season 1, Episode 1

⁴⁶ Source: <https://www.theatlantic.com/magazine/archive/2012/01/why-john-j-mearsheimer-is-right-about-some-things/308839/> ; <https://archive.is/VYmol>

⁴⁷ - Robert Kagan when questioned on if there should be limits to the U.S.’s foreign intervention: “Think about Vietnam. In 1964 and 1965, the general consensus among everybody, from the New York Times editorial page, to democrats and republicans, to administrations of both parties, all thought that it was absolutely vital to prevent South Vietnam from falling to communism. And now we look back on that, because we’re so smart, and we know that was a stupid decision. No one knew it was a stupid decision at the time. So, when president Obama says ‘let’s have a doctrine of not doing stupid stuff’, I’m all for that. The problem is we don’t know what’s stupid until it turns out to be stupid sometimes. And so, we are left with this problem of not knowing. And we’re left with two kinds of dangers: 1) not doing enough, which we tried in the 1920s and 1930s and 2) doing too much, which we tried maybe in the 1990s and 2000s. But the answer is, we need to find the right moment, the right balance, the right understanding, and there’s no magic formula for it.” 57m50s at <https://www.youtube.com/watch?v=sRCwYy5qrt4> “The Jungle Grows Back: A Case for American Leadership”

⁴⁸ Source: <https://www.youtube.com/watch?v=g5SDUUhkx0A> “Historian Robert Kagan: U.S. passivity ‘encouraged’ Putin”

⁴⁹ For example: some geopolitical pundits have floated the (not so crazy) idea that the geography of a country (and its borders in particular) might lead to certain types of leaders being more likely to be elected (or grab power). Germany and Russia both have vulnerable land borders with not many natural barriers for defense (like mountain ranges, difficult to cross deserts, oceans, rivers, etc.) This makes these countries, in particular, more vulnerable to attack. Many pundits claim that this leads to a more militarized society that must exist in order to defend these vulnerable borders. As result of these military necessities, these countries tend to have leaders that are more authoritarian and less democratic (i.e. all else equal: ex-military leaders/presidents who were generals prior to presidency, tend to be more authoritative). Russia’s borders with the rest of Europe to the rest of Moscow, are largely flat lands with no natural borders, make defense difficult and making Russia prone to invasion through its history ([Mongol invasion of Russia in 13th century](#), etc.). This likely had at least some effect on its current day rulers and their style of government.

-“If God had built mountains in eastern Ukraine, then the great expanse of flatland that is the European Plain would not have been such inviting territory for the invaders who have attacked Russia from there repeatedly through history. As things stand, Putin, like Russian leaders before him, likely feels he has no choice but to at least try to control the flatlands to Russia’s west. So it is with landscapes around the world their physical features imprison political leaders, constraining their choices and room for maneuver. *These rules of geography are especially clear in Russia, where power is hard to defend, and where for centuries leaders have compensated by pushing outward.*” || “Just as strategically important and just as significant to the calculations of Russia’s leaders throughout history has been the country’s historical lack of its own warm-water port with direct access to the oceans. Many of the country’s ports on the Arctic freeze for several months each year. Vladivostok, the largest Russian port on the Pacific Ocean, is enclosed by the Sea of Japan, which is dominated by the Japanese.” || “On the other hand, Russia’s vastness has

also protected it; by the time an army approaches Moscow, it already has unsustainably long supply lines, which become increasingly difficult to protect as they extend across Russian territory. Napoleon made this mistake in 1812, and Hitler repeated it in 1941.” Source: <https://www.theatlantic.com/international/archive/2015/10/russia-geography-ukraine-syria/413248/>; <https://archive.is/DXPxr> “Russia and the Curse of Geography: Want to understand why Putin does what he does? Look at a map.” By Tim Marshall.

-In addition to the above, most/all of Russia’s current ports involve traversing chokepoints held by NATO (Denmark, Japan, Turkey, etc.) restricting Russian ship’s access to the world’s oceans (potentially preventing not only trade but military maneuverability in the event of a conflict)

⁵⁰ Mearsheimer also expands on America’s geopolitical history, noting back in 2013: ““We (the U.S.) tell ourselves all these false tales about our history. Where we are portrayed as noble people who do nothing but good on the world stage...That’s not the way its operated over time. Let’s go back to 1783: In the beginning the United States was comprised of 13 measly colonies strung out along the Atlantic seaboard. What happened over the next 70 or so years is that the United States marched from the Atlantic seaboard to the Pacific Ocean. We murdered huge numbers of Native Americans. We stole their land. We went to war with Mexico and stole from them what is the Southwest of the United States. We invaded Canada in 1812 for the express purpose of incorporating Canada into the United States. The British and the Canadians worried throughout the 19 century that we were going to pay them a return visit...Because they knew we had a voracious appetite. Much of the Caribbean would, today, be American were it not for the slavery issue. The southern states were desperate to expand into the Caribbean to make all sorts of territory in that part of the world (and make it part of the United States). What prevented it was that the northern states did not want any more slave holding states in the Union. Sugar was the main industry in the Caribbean, and sugar was a labor-intensive industry. That meant there were huge numbers of slaves in the Caribbean. And the northern states did not want more slave holding states. Not only did we have our gun sites on the Pacific Ocean...we also had our gun sites to the north (on Canada) and we had our gun sites south. **There is no country in modern history that has the record of expansion that comes close to that of the United States.** Its no accident that when Adolf Hitler went into the Soviet Union on June 22, 1941, the next few months he talked frequently about doing (in the Soviet Union) what the United States did in North America. That’s how the United States was created. Very powerful state. Very aggressive state. The 2nd thing we (the U.S.) had to do to establish hegemony In this (Western) hemisphere...is we had to get the European power out. You all remember the Monroe Doctrine? In 1823, he (President James Monroe) basically told the European great powers that ‘this is our hemisphere. Were eventually going to throw you out. We aren’t powerful (now) to do it, but you’re leaving. It’s just a matter of when. And once you leave, you are not welcome back here (in the Western Hemisphere)’” Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=19m28s> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?”

- (52m02s) Rubio: Secretary Nuland I agree with all of the assessments uh that have been made about Vladimir Putin that he seeks you know to establish great power parity with the United States and therefore tries to show force and power around the world. I also think he's driven to some extent maybe a great extent by the ego and the drive to bring Ukraine and to at least the Russian sphere of influence, if not into the Russian federation, as and cement his legacy as the uniter of a greater Russia. I think there's a third factor here that I'm curious whether you agree with: and that is that he also thinks that the west and that by no means I'm a fan of Vladimir Putin and I'm confident that they're not fans of mine but they're thinking, as irrational as we may think it, is that we want to turn Ukraine the west in general the U.S. and specific into a base of operation to threaten their security in order to undermine you know their internal cohesion and the like and therefore he's using this as an opportunity to try to impose neutrality ,at a minimum, imposed neutrality on Ukraine and if that is in fact at least the primary motivator in the short term of this threat of military action uh then i would imagine that he's already been publicly messaging what his asks are: the first is that 1) we would pull back NATO forces from anywhere near their western border 2) the second is to completely rule out the admission probably not just of Ukraine but Georgia as a member of NATO and 3) the third is to stop arming Ukraine. Are those three conditions that he's publicly messaged already...would the United States agree to any of those three? **Victoria Nuland: “All of those would be unacceptable”** || (1h12m24s) Tim Kaine: “and there's no NATO in the Indo-pacific we have allies in the Indo-Pacific but we don't have a NATO with a charter with a self-defense article. I think China would determine if the west response to a military invasion (of Ukraine) went as far as sanctions but no further that the United States and other nations would be extremely unlikely to use military force to counter a military invasion of Taiwan. And i think Taiwan would likely conclude the same thing. So I'm very concerned about that and i wonder is that a fair concern uh that i have about how the Chinese and the Taiwanese would view the west's unwillingness to provide more significant military support to stop an invasion

by Russia is my concern a fair one? Nuland: “in this setting I would simply say that this is a moment of testing and I believe that both autocrats around the world and our friends around the world will watch extremely carefully what we do and it would have implications for generations and they could go well beyond Europe.” || (1h29m32s) Rubio: “let me ask you a question if the Biden administration imposed sanctions on Nord Stream AG if it halted the certification of the pipeline so that the Nordstrom 2 pipeline did not go online would that make invasion of Ukraine more

likely or less likely? Nuland: “senator it's the German government that has paused the certification of the pipeline itself right now that certification is not going forward. You know that we believe this pipeline is a bad deal for Europe and a bad pipeline but i do not believe that anything we would have done with regard to Nordstrom 2 would have changed Putin's calculus with regard to the build up we have around Ukraine today I believe he has an ambition..(cut off) Rubio: “So let me ask you another way if Nordstrom 2 goes online and is operational does that make an invasion of Ukraine more likely or less likely? If Nord stream 2 goes online, I don't think it's coincidental that the predicted date for an invasion is almost exactly when certification (of Nord stream 2) is predicted to be over, I don't think that's accidental. So, my question is this: if Nord Stream 2 goes online does that make invasion of Ukraine more likely or less likely? Source: (December 7, 2021 *a few months before Ukraine Invasion:*

<https://www.youtube.com/watch?v=d6ew79co6RE> “Victoria Nuland Testifies on U.S.-Russia Relations I LIVE” 5151515151 Mearsheimer expands even further by listing out 5 assumptions of great power politics and how these assumptions effect the world order: 1) There is no higher authority that sits *above* states. The system is anarchic (“We states dial ‘911’ there’s no one at the other end”. There’s no higher authority to appeal to) 2) Every state has *some* offensive capability 3) States can never be sure about the intentions of other states. In particular, they can’t be sure of the *future* intentions of states. He notes that even 100 years later we are still debating Germany intentions in July 1914 (“We didn’t know their *intentions*, but we knew their (military) *capabilities*. Capabilities you can be more sure of.”). During the Cold War there was never agreement among American policy makers on what the Soviet Unions intentions were. Mearsheimer even uses the example of marriage and divorce, where a couple can never be sure of the *future* (negative) intentions of their spouse, even if they are sure of their spouses’ positive intentions at the time of marriage (“you can never be certain of the benign intentions for the *duration* of the marriage, at the *time* of marriage”) 4) the main goal of a nation state is to *survive* 5) states are rational actors. Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (5m to 13m)

-Mearsheimer goes on to look at the implications of these 5 assumptions. In particular he says “if a state is interested in maximizing its odds of survival, it should: 1) aim to be a regional hegemon 2) make sure you have no peer competitor (which is another way of saying that you are the only regional hegemon on the planet)”. The U.S. crushed any of the four potential peer competitors in the 20th century (Imperial Germany, Imperial Japan, Nazi Germany and the U.S.S.R.)

- “You don’t think the Chinese are going to have a Monroe Doctrine? You think its ok for us to be terribly upset when Soviets send missiles to Cube, but they (China) shouldn’t be upset when we run aircraft carriers up and down their coast? (Because the US says it’s a ‘benign hegemon or some other nonsense like that’)” || “Why shouldn’t they (China) want a Monroe Doctrine? If I, John Mearsheimer, were the national security advisor in Beijing, and they asked me whether we (China) should work hard and have our own Monroe Doctrine and push the Americans out beyond the first island chain and the second island chain, I’d do everything I could to push Americans out. I’d do everything I could to push the Americans out. I’d want to dominate Asia the way the United States dominates the western hemisphere. Does that mean the Chinese are evil? Is it because they have a different culture than we do? Absolutely not! My argument is that the structure of the international system leaves you little choice but to dominate your region of the world. ”

Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (27m to 28m)

-Some have questioned whether the Monroe Doctrine is relevant anymore in the more recent history. If in doubt, here as an excerpt from Foreign Affairs magazine from 2010: “In late 2009, U.S. Secretary of State Hillary Clinton seemed to dash hopes that the United States would drop its hegemonic attitude when she warned Latin American and Caribbean governments that might be tempted to ‘flirt with Iran’ to ‘take a look at what the consequences might be.’ Even Latin Americans wary of Iran were rankled. Obama's welcome call for a new approach to Cuba produced little change.” Source: <https://www.foreignaffairs.com/articles/central-america-caribbean/2010-07-01/obama-and-americas> (Volume 89, Number 4, Page 116 in print edition).

- “The balancing coalition will look like this...It will include: Japan, South Korea, Taiwan, Singapore, Australia, Indonesia, India, Russia (Note: lecture made in 2013!) and the United States. The interesting question is what happens with countries like: Pakistan, Myanmar, Laos and Cambodia. Those are the four that likely to be the other (China’s) side. But we will have all the powerful countries, in Asia, on our side. They’ll be part of the balancing coalition. And the main reason is that those countries live next door to China and Chinas much more of threat to them than the United States is. It’s the same reason that everybody balanced against the Soviet Union, and didn’t balance against the United States: because the Soviet Union, being a neighbor with countries in Europe and Southeast Asia, was a much greater threat than the United States was.”

Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (31m12s to 32m08s)

- Mearsheimer goes on to say that because offensive and defensive capabilities/exercises look the same, and because you can never be sure of the intentions of another country, than an arms race will develop between China and the U.S. Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (32m20s)

- “No social science gets it right more than 75% of the time” || “My theory is not perfect and it may be wrong”

Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (35m45s)

- “Another reason they (British) didn’t pick a fight with us (the U.S. North during the US Civil War) was that they were not free to roam. Most people don’t know this, but the British foolishly facilitated the unification of Germany under Bismarck, because they thought France was the bigger threat, and to a lesser extent Russia. And they thought that creating a united Germany in the center of Europe could help them with Russia and more importantly, help them with France. And the British were focused on very important ways on the (European) continent (and therefor couldn’t check the U.S. rise in power during 1800s and early 1900s). They weren’t free to roam.” Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (43m24s)

- “I think in almost all cases, **politics trumps economics.**” Source:

<https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?” (57m15s) || (SRCM: An open question/corollary to this is: ‘Does politics and geopolitical conflict trump climate change initiatives?’). The economist explains below some of the conflicts and tradeoffs with air pollutants and similar issues might apply to global CO2. Will countries put climate change initiatives ahead of their own geopolitical interests? Would countries put themselves at risk of losing a war if the choice came down to: 1) green friendly energy that presents security and defense risks or 2) using fossil fuels to win a war. It’s far from certain (in our mind) that these countries will chose climate change initiatives).

<https://www.economist.com/asia/2023/02/13/india-and-pakistan-are-choking-on-each-others-pollution> ;

<https://archive.is/gph07> “India and Pakistan are choking on each other’s pollution: Fixing the problem will require countries that hate each other to co-operate”

- “Missile defense is not possible against someone who has even a somewhat capable ballistic missile capability. I can’t believe how missile defense gets brought into this serious (geopolitical) issue. Nuclear weapons on the other hand (are a serious issue).” (1h13m0s)

- “And by the way I felt the same way about communism (that it was much *less* important than nationalism, which is the driving force – not political ideologies or religions). I thought that during the cold war that we obsessed about communism, and we thought there was this monolithic force out there called “communism” and anyone who had this “communist” label was against us. Remember what happened in South East Asia, when China and Vietnam went to war. Cambodia and Vietnam went to war. Remember the Sino-soviet split. Remember Tito and Yugoslavia. If we were sophisticated, and of course we’re never sophisticated, we would’ve played off on all these differences among these communist states.” Source: 1h6m44s to 1h7m17s at

<https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=300s> “Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?”

- Mearsheimer explains that why he doesn’t believe in Democratic Peace Theory (i.e. the idea that democracies do not fight each other or are less likely to fight each other). Even if a country is a democracy is now, you can’t be sure it won’t backslide out of democracy in the near future. (1h16m40s)

- “He’s laying out *preventative war argument* (that you want to cut China off at the knees *now*, before they grow, and why not launch a preventative war now). By the way, this is the reason why I think Germany started World War I – because they were trying to cut the Russians off at the knees in August 1914. We can’t do it with China. We

can't figure out (today) how to cut China down to size, without starting a nuclear war." Source: <https://www.youtube.com/watch?v=0DMn4PmiDeQ&t=5m> "Harper Lecture with John J. Mearsheimer: Can China Rise Peacefully?" (1h18m0s)

- "Britain's refusal to give a neutrality pledge in return for limits on the High Seas Fleet demonstrates that beneath the Anglo-German friction lay clashing concepts of security. To Britain, security rested on a balance of power—a divided Europe with British power backing the weaker coalition. *To Germany, bordered east and west by nations fearful of her power, security lay in unifying Europe under her leadership, as Bismarck had done. British and German concepts of security were irreconcilable.*"

- "Every European-centered history of World War I devotes pages to the trenches in Europe; Parvus knew that a true world war would be decided on the Bosphorus. When World War I began in the Balkans and Ottoman control of the two straits near Gallipoli made it difficult for British and French cities to feed themselves, he was proved right." Source: Page 182 in Kindle Book: "Oceans of Grain: How American Wheat Remade the World" by Scott Reynolds Nelson.

- "The prelude to World War I provides striking examples. The approximate equality of alliance partners made them closely interdependent. The interdependence of allies, plus the keenness of competition between the two camps, meant that while any country could commit its associates, no one country on either side could exercise control. If Austria-Hungary marched, Germany had to follow; the dissolution of the Austro-Hungarian Empire would have left Germany alone in the middle of Europe. If France marched, Russia had to follow; a German victory over France would be a defeat for Russia. And so it was all around the vicious circle. *Because the defeat or the defection of a major ally would have shaken the balance, each state was constrained to adjust its strategy and the use of its forces to the aims and fears of its partners.*" || "The game of power politics, if really played hard, presses the players into two rival camps, though so complicated is the business of making and maintaining alliances that the game may be played hard enough to produce that result only under the pressure of war. Thus the six or seven great powers of the interwar period did not move into a two-bloc formation until more than two years after World War II began. The forming of two blocs, moreover, did not make the multipolar system into a bipolar one any more than the forming of opposing coalitions for the purpose of fighting an election turns a multiparty into a two-party system." Source: Page 167 in Kindle book "Theory of International Politics" by Kenneth Waltz

- Kenneth Waltz also has a great table on page 162 of the above book. He notes that progression of changing of the guard as far as Great World Powers – and how this impacts the multipolarity of the geopolitical situation. In 1700 there were 7 great powers in the world: Turkey, Sweden, Netherlands, Spain, Austria-Hungry, France and England. By 1800 there were 5: Austria-Hungry, France, Great Britain, Prussia, and Russia. By 1875, the list was the same except there were now 6 great powers with the addition of Italy. By 1910, two more great powers were added (Japan and the United States) bringing the total to 8 great powers in the years proceeding World War I. By 1935, the Great powers totaled 7 and were: France, Great Britain, Germany, Russia (Soviet Union), Italy, Japan and the United States. And of course, by the end of World War II, the world entered bipolarity with the only two great powers in 1945 being the United States and the Soviet Union. Kaltz goes on to explain the various vulnerabilities that can exist to peace under various power structures (i.e. relative stability of a bipolar world, and odds of conflict under a geopolitical environment with 3 great powers vs. one with 4 great powers, etc.): "Systems of three (great powers) have distinctive and unfortunate characteristics. Two of the powers can easily gang up on the third, divide the spoils, and drive the system back to bipolarity. In multipolar systems four is then the lowest acceptable number, for it permits external alignment and promises considerable stability. Five is thought of as another threshold number, being the lowest number that promises stability while providing a role for a balancer..." Source: Page 163 in Kindle book "Theory of International Politics" by Kenneth Waltz.

- Regarding the stability in a bipolar world: "within a bipolar world, four factors conjoined encourage the limitation of violence in the relations of states. 1) the absence of peripheries, 2) the range and intensity of competition 3) the persistence of pressure and crisis 4) the preponderant power of each of the two competitors" Source: p. 7/886 in "The Stability of a Bipolar World" by Kenneth N. Waltz (1964)

- *Was World War I inevitable?* "Historians never like to say that things are inevitable, and certain there are people who could have chosen a different path, in the short term and in the long term...But fundamentally

there were irreconcilable differences in the system of empires in the world in 1914. It didn't have to be this war, but it probably had to be a war." || "I think there are people who would lay all of the blame (for World War I) on the Germans. They would point to a generation of arms buildup, alliances and promises that Germany made to their allies in the Balkans and to the Austro-Hungarians. And so yes, there is an awful lot of responsibility there (on the Germans). (Alternatively) there has been a trend lately to say 'It's no ones fault'. That all of the various (world) powers sleep walked into the war inadvertently. I think that let's everyone a little too much off the hook. I think for the in-between: I would put the blame (for World War I) on the system of empires itself. But, in that system, the actor that carries the most responsibility is definitely imperial Germany." Source: 3m9s in <https://youtu.be/SK4kMPmgKW0> "Christopher Capozzola: World War I, Ideology, Propaganda, and Politics | Lex Fridman Podcast #320"

⁵² Source: <https://youtu.be/X4qh75f1FDA?t=86> "Is Cuba Ukraine? Really an existential threat to USA? – John Mearsheimer on Ukraine, USA and Russia"

- Mearsheimer also mentions that the 1917 Zimmerman Telegram (an intercepted communication of a proposed alliance between Germany and Mexico if the US entered World War I) furthers the point that the U.S. will not tolerate foreign powers allying with any countries in the Western Hemisphere that is shared with the United States (whether that be the Soviet Union allying with Cuba during the Cold War or Germany allying with Mexico during World War I)

- Some have stated that countries expand to gain security and cite the United States as an example. It expanded until it reached a natural barrier (the Pacific Ocean). This has given the United States significant security benefits, especially when combined with the fact that there are no adversarial peer competitors as neighbors (Canada and Mexico) – nor any peer competitors in the western hemisphere.

⁵³ Source: <https://www.metaculus.com/questions/13171/nuclear-detonation-in-ukraine-by-2024/> ; <https://archive.is/6T9hA>

⁵⁴ Source: <https://www.metaculus.com/questions/4779/at-least-1-nuclear-detonation-in-war-by-2050/> ; <https://archive.is/iQJej> ; <https://www.metaculus.com/questions/3517/will-there-be-a-global-thermonuclear-war-by-2070/> ; <https://archive.is/q1ry7>

⁵⁵ Sources: <https://www.metaculus.com/questions/10737/ukraine-controls-sevastapol-on-jan-1-2024/> ; <https://archive.is/ksKqB> ; <https://www.metaculus.com/questions/10738/ukraine-controls-dnrlnr-on-jan-1-2024/> ; <https://archive.is/MboRl>

⁵⁶ Source: <https://www.metaculus.com/questions/10745/russian-control-of-new-territory-2024-01-01/> ; <https://archive.is/fZnjt>

⁵⁷ More interesting markets:

Largest yield (offensive) nuclear weapon detonation by 2050 stands at 332 kt. Source:

<https://www.metaculus.com/questions/8372/the-largest-yield-nuclear-weapon-by-2050/> ; <https://archive.is/y30Aj>

⁵⁸ Source:

https://commons.wikimedia.org/wiki/File:Geographic_Boundaries_of_the_First_and_Second_Island_Chains.png

⁵⁹ Russia also has potential restricted port access to the world's oceans as noted in footnote 49

⁶⁰ "Control of Taiwan would do more than enhance Chinese ocean surveillance capabilities, however. It would also give China an advantage in submarine warfare. With Taiwan in friendly hands, the United States can defend against Chinese attack submarines by placing underwater sensors in key locations to pick up the sounds the submarines emit. The United States likely deploys such upward-facing hydrophones—for listening at shorter distances—along the bottom of narrow chokepoints at the entrances to the Philippine Sea, including in the gaps between the Philippines, the Ryukyu Islands, and Taiwan. At such close ranges, these instruments can briefly detect even the quietest submarines, allowing U.S. air and surface assets to trail them. During a crisis, that could prevent Chinese submarines from getting a "free shot" at U.S. ships in the early stages of a war, when forward-deployed U.S. naval assets would be at their most vulnerable. If China were to gain control of Taiwan, however, it would be able to base submarines and supporting air and coastal defenses on the island. Chinese submarines would then be able to slip from their pens in Taiwan's eastern deep-water ports directly into the Philippine Sea, bypassing the chokepoints where U.S. hydrophones would be listening" Source: <https://www.foreignaffairs.com/articles/china/2022-06-16/consequences-conquest-taiwan-indo-pacific>

⁶¹ Shirvan continues: "However one looks at it, China is powerless against the United States for at least the next decade. Looking beyond, to 2030 and beyond, 5th generation jets and hypersonic missiles could change the equation. That's when things get dangerous." || "By 2050, it is expected that China is expected to have reformed its military into a world class fighting force, on par with the United States, by 2050. By then, the PLA Navy and the

US Navy will have nearly the same gross tonnage in ships and almost the same number of aircraft carriers.” Source: 7m30s to 12m30s at <https://www.youtube.com/watch?v=f52FCWb5FEM> “America predicts war with China in 2025”

⁶² Source: <https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020>

⁶³ We note the tweet from @EconomPic that: despite massive gains in China’s GDP, Chinese equities have *underperformed* t-bills since 1992. During this time frame, China’s GDP increased about 30 times, vs an increase of “only” 3.3 times for the United States over that same time frame (1992-2021). Rapid GDP growth does not necessarily equate to equity gains. Source: <https://twitter.com/EconomPic/status/1572641480711499779> ; <https://archive.is/Cq8FI>

⁶⁴ Source: <https://population.un.org/wpp/Graphs/DemographicProfiles/Line/156>

⁶⁵ Source: <https://www.metaculus.com/questions/5755/china-to-usa-gdp-ratio-in-2050/> ; <https://archive.is/LPOSF>

⁶⁶ Source: <https://www.metaculus.com/questions/11112/us-response-if-china-invades-taiwan-2035/> ; <https://archive.is/H79aY>

⁶⁷ Source: <https://www.metaculus.com/questions/11401/china-controls-taiwan-after-invasion/> ; <https://archive.is/LZ39o>

⁶⁸ Source: <https://www.metaculus.com/questions/11127/china-to-retaliate-if-us-intervenues-in-taiwan/> ; <https://archive.is/DNfRt>

⁶⁹ Metaculus has the odds of a nuclear weapon being used as an act of war by 2050 standing at 32%. Source:

<https://www.metaculus.com/questions/4779/at-least-1-nuclear-detonation-in-war-by-2050/> ; <https://archive.is/iQJej>

- Related to this, Matthew Kroenig makes some thought provoking, if worrying, predictions and conclusions in his book “The Logic of American Nuclear Strategy: Why Strategic Superiority Matters”. We list some of these below:

- “Scholars argue that nuclear capabilities above and beyond a second-strike capability do not matter, but policymakers often behave as if they do.” | “This book takes a different approach. Rather than dismiss it as illogical, this it explains the logic of American nuclear strategy. It argues that military nuclear advantages above and beyond a secure, second-strike capability can contribute to a state’s national security goals. This is primarily because a robust nuclear force reduces a state’s expected cost of nuclear war, increasing its resolve in high-stakes crises, providing it with coercive bargaining leverage, and enhancing nuclear deterrence.” | “As we will see later in this book, a state’s relative vulnerability to nuclear war is closely linked to the balance of nuclear capabilities between states, and “nuclear superiority” will, therefore, be used interchangeably with the terms “favorable nuclear balance of power” and, following past scholarship, “military nuclear advantages.”

- “The central theoretical argument of this book, which I label the *superiority-brinkmanship synthesis theory*, brings these strands of scholarship together to argue, quite simply, that military nuclear advantages increase a state’s willingness to run risks in international conflicts. In more colloquial terms, the logic of the argument is simple: in a game of chicken we might expect the smaller car to swerve first even if a crash would be disastrous for both. If you try to run away from it, if you are scared to go to the brink, *you are lost*” Source: pages 1-3 in “The Logic of American Nuclear Strategy: Why Strategic Superiority Matters” by Matthew Kroenig

- Of course this ramping up of a potential nuclear arms race then brings up the nuclear winter question. We turn to Edward Teller, known as the “father of the hydrogen bomb”, who notes: “Turco et al. estimate that 225 million tons of smoke particles would be emitted in their *5,000 megaton baseline war.*” | “In conclusion, there is no obvious reason why large quantities of smoke particles should have long residence time in the atmosphere. The calculations associated with the nuclear winter do not include major cleansing effects of water vapor, which are themselves smoke induced, or the influence of the oceans and winds during the time needed for spreading the smoke worldwide.” Pages 136-138 in “Better a Shield Than a Sword: Perspectives on the Defense and Technology” by Edward Teller

⁷⁰ Source: <https://worldpopulationreview.com/country-rankings/military-spending-by-country> ; <https://archive.is/UGnml>

⁷¹ Source: https://ourworldindata.org/explorers/climate-change?time=-6167..2022&facet=none&hideControls=true&Metric=CO%E2%82%82+concentrations&Long-run+series%3F=true&country=~OWID_WRL

⁷² Source: <https://ourworldindata.org/grapher/temperature-anomaly>

⁷³ Sources: <https://earth.org/data-visualization/a-brief-history-of-co2/> ;

<https://commons.wikimedia.org/w/index.php?curid=1240577> ; http://gergs.net/all_palaeotemps-2/

⁷⁴ As we’ll explain shortly, carbon dioxide is hardly the only chemical that effects the climate

⁷⁵ 1) Carbon Dioxide (Only) emissions vs 2) “Carbon Dioxide Equivalents”/(Total) ”Greenhouse Gas Emissions” (1990 – 2019) :

https://ourworldindata.org/grapher/annual-co2-emissions-per-country?time=1838..latest&facet=none&country=~OWID_WRL ;

https://ourworldindata.org/grapher/total-ghg-emissions?tab=chart&country=~OWID_WRL

⁷⁶ Sources: https://ourworldindata.org/grapher/annual-co2-emissions-per-country?time=1838..latest&facet=none&country=~OWID_WRL ;

https://ourworldindata.org/grapher/total-ghg-emissions?tab=chart&country=~OWID_WRL

⁷⁷ Source: https://ourworldindata.org/grapher/annual-co2-emissions-per-country?time=1838..latest&facet=none&country=~OWID_WRL

⁷⁸ We note the Metaculus prediction market here, which predicts global CO₂ will peak in March 2034. Source:

<https://www.metaculus.com/questions/11933/global-CO2-emissions-peak-year> ; <https://archive.is/ftLAN>

⁷⁹ Source: <https://plana.earth/academy/what-are-scope-1-2-3-emissions> ; <https://archive.is/WgEwk>

⁸⁰ Source: <https://ourworldindata.org/grapher/global-fossil-fuel-consumption>

⁸¹ Source: <https://ourworldindata.org/grapher/fossil-fuel-primary-energy?tab=chart®ion=NorthAmerica&country=IND~ZAF~JPN~USA~GBR~CHN~AUT~Europe~European+Union+%2827%29>

⁸² Source: <https://ourworldindata.org/grapher/modern-renewable-energy-consumption>

⁸³ Chart Source:

https://ourworldindata.org/explorers/energy?facet=none&country=USA~Europe~CHN~IND~OWID_WRL~JPN&Total+or+Breakdown=Select+a+source&Energy+or+Electricity=Primary+energy&Metric=Share+of+total&Select+a+source=Foshttps://ourworldindata.org/explorers/energy?facet=none&country=USA~Europe~CHN~IND~OWID_WRL~JPN&Total+or+Breakdown=Select+a+source&Energy+or+Electricity=Primary+energy&Metric=Share+of+total&Select+a+source=Fossil+fuels ; Other potential sources of similar data:

<https://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS?end=2015&start=1960&view=chart&year=2015> ,

<https://www.macrotrends.net/countries/USA/united-states/fossil-fuel-consumption>

⁸⁴ We note the Metaculus prediction market here which predicts fossil fuels will drop to 50% of global energy usage by November 2046. Source: <https://www.metaculus.com/questions/8651/date-fossil-fuels-50-of-global-energy/> ;

<https://archive.is/URJu5>

⁸⁵ Source: <https://ourworldindata.org/grapher/global-primary-energy> ; <https://archive.is/x2LuR>

⁸⁶ Using a 0.66% annual growth rate, the world energy consumption reaches the same amount of solar energy that hits the earth around the year 3600. We reach the sun’s total energy output by around year 6800 using that 0.66%/year growth rate in energy usage. (Using a 1.88% growth rate moves these to around year 2500 and 3600 respectively).

⁸⁷ Chart Source: <https://ourworldindata.org/grapher/solar-pv-prices>

⁸⁸ Chart Source: https://ourworldindata.org/grapher/primary-energy-consumption-from-solar?tab=chart&country=IND~CHN~USA~Europe~OWID_WRL~JPN

⁸⁹ Chart Source: https://ourworldindata.org/grapher/solar-share-energy?tab=chart&country=CHN~IND~JPN~USA~OWID_WRL~Europe

⁹⁰ For reference, Bill Gates: “Even if nuclear succeeds, we’ll still be 60% or 70% renewables, so its just a question of whether we have (nuclear) as a baseload capability” || “But yes, I think the world is underinvested in those (nuclear power) capabilities, because I think they could make a hug difference”. Source: 42m23s at https://www.youtube.com/watch?v=038_DssSv0 “Preparing for Global Challenges: In Conversation with Bill Gates”

- We note the Metaculus prediction market here, which predicts a bit less than 7% of primary energy in the United States will be derived from solar power in 2031. Source: <https://www.metaculus.com/questions/8466/primary-energy-from-solar-in-us-2031/> ; <https://archive.is/7CRLz>

- We note the Metaculus prediction market here, which predicts that, *globally*, solar power will deliver approximately 6,122 TWh (6.1 petawatt-hours PWh) by 2030. Source:

<https://www.metaculus.com/questions/9190/twh-of-electricity-from-solar-in-2030/> ; <https://archive.is/rzUMn>

⁹¹ Source: 11m51s at <https://www.youtube.com/watch?v=laGtd-b0vMY> “Carbon capture: the hopes, challenges and controversies | FT Film”

⁹² Source: <https://www.statista.com/statistics/506774/weighted-average-installed-cost-for-onshore-wind-power-worldwide/>

⁹³ Various amortization times for sources of energy have been estimated. This source puts wind “energy amortization time for construction, operations and disposal” at 5 to 8 months. For hydro its 9-13 months, and for solar is 1 to 2 years (and “never” for natural gas, nuclear and coal). They go on to state: “Over the life cycle of a V117-4.2 MW wind power plant, it will return 50 times more energy back to society than it consumed. That means that when 1 kWh is invested in a wind energy solution, you get 50 kWh in return. For coal, however, if you invest 1kWh you typically get below 0.4 kWh in return.” Source:

<https://www.vestas.com/en/sustainability/environment/energy-payback> ; <https://archive.is/6dgIs>

⁹⁴ Metaculus has the world electricity from wind power at 4,850 TWh by 2030. Source:

<https://www.metaculus.com/questions/9220/twh-of-electricity-from-wind-in-2030/> ; <https://archive.is/yT5NB>

⁹⁵ Source: [https://ourworldindata.org/grapher/wind-share-](https://ourworldindata.org/grapher/wind-share-energy?tab=chart&country=OWID_WRL~CHN~USA~IND~Europe~JPN)

[energy?tab=chart&country=OWID_WRL~CHN~USA~IND~Europe~JPN](https://ourworldindata.org/grapher/wind-share-energy?tab=chart&country=OWID_WRL~CHN~USA~IND~Europe~JPN)

⁹⁶ The Enron scandal can provide a useful corollary of what can happen when regulations are not lined up with market forces; Sensible regulations are key: “Truthfully, Governor, California hasn’t deregulated,” Greenspan said. “The state simply replaced one form of regulation with another. It’s become a system of central planning run amok.” Summers joined in. “You have a fixed price set by the state for selling electricity to the public. But you have a variable, floating price when you buy electricity.” “That’s not sustainable,” Greenspan said. “The problem is your regulatory system. And there are a very limited number of solutions. But the first step is that prices for consumers are going to have to go up.” Davis showed no emotion. “I really feel the problem is the energy producers,” he said. “They’re manipulating the markets and forcing up prices.” “They may be,” Greenspan said. “But that’s beside the point. That’s not causing the problem; that’s making it worse. The real problem is a supply-and-demand imbalance.” Davis objected. There was plenty evidence, he said, that energy producers were withholding power from the market. *Greenspan and Summers didn’t argue the point, stressing that it made economic sense for power to be withheld. The utilities weren’t making good on their bills already. With the utilities now careening toward bankruptcy, it would be folly for power companies to keep pumping electricity into the state without limits. It would just increase their exposure to the likely bankruptcies.* || “Governor,” Summers said, “this is classic supply and demand. The only way to fix this is ultimately by allowing retail prices to go wherever they have to go.” Davis’s face hardened. He didn’t like being lectured from the ivory tower. “Fine,” he said. “You two live in your world of economics, supply and demand and pricing.” He leaned in. “Let me tell you about my world,” he said. “About California politics. About referendums, where anybody with enough signatures can take a ballot initiative to the voters and overrule anything that we’re doing.” Greenspan and Summers listened as Davis laid out his political dilemma. The words made it obvious that the power problems in California would become much worse. Economics and politics were in conflict. And for now, politics would rule.”- Source: Kindle location 7820 in “Conspiracy of Fools: A True Story” by Kurt Eichenwald

⁹⁷ Chart Source: IEA, Evolution of Li-ion battery price, 1995-2019, IEA, Paris <https://www.iea.org/data-and-statistics/charts/evolution-of-li-ion-battery-price-1995-2019> IEA. Licence: CC BY 4.0

⁹⁸ IEA (2022), Grid-Scale Storage, IEA, Paris <https://www.iea.org/reports/grid-scale-storage> License: CC BY 4.0. As also noted on this page: “While innovation on lithium-ion batteries continues, further cost reductions depend on critical mineral prices” || “While the past decade has witnessed substantial reductions in the price of lithium-ion batteries, it is now becoming evident that further cost reductions rely not just on technological innovation, but also on the rate of increase of battery mineral prices. The leading source of lithium demand is the lithium-ion battery industry.” || “Ranging from mined spodumene to high-purity lithium carbonate and hydroxide, the price of every component of the lithium value chain has been surging since the start of 2021. Moreover, the impacts of Russia’s invasion of Ukraine are also apparent in the battery metals market. Both cathode (nickel and cobalt) and anode (graphite) materials are affected by this.” Source: <https://www.iea.org/reports/grid-scale-storage>

- Also see: <https://ourworldindata.org/battery-price-decline> ; <https://archive.is/1P5tr>

⁹⁹ For reference hydro pumped storage has not grown as quick (as most of the good geographical sources of this have already been exploited). In 2013, the Time adjusted Capacity for pumped storage was 22.4 GW (with a usage factor of 9.8%). By 2020, the Time adjusted capacity for pumped storage was 23.04 GW (with a usage factor of 11.1%). For Solar: in 2013, the Time adjusted Capacity for solar was 0.126 GW (with a usage factor of 0.7%). By 2020, the Time adjusted capacity for solar was 6.4 GW (with a usage factor of 5%). Source: table 6.07.C <https://www.eia.gov/electricity/monthly/>

¹⁰⁰ Our rough calculations show that something like 14 Tesla powerwalls would be needed to make a normal size suburban house in the Northeast (Massachusetts) be anything close to self-reliant and avoid using the grid at all. - Also see warnings in footnote directly above/prior (underlined) about material costs as warned by IEA.

¹⁰¹ We see this in the price trend of tesla power walls: In 2015, the Tesla Powerwall 1 was approximately \$468/kWh. However by 2021, the Tesla Powerwall+ had an *increased* price of \$629/kWh. The trend is in the wrong direction at least in this specific instance (and for now). Source:

https://en.wikipedia.org/wiki/Tesla_Powerwall#Powerwall_models ; <https://archive.is/YPYYX>

¹⁰² This report by has (Next-generation 3 Lithium Sulphur / Air) Li-ion battery energy density reaching a bit over 1,000 Wh/kg by the 2040s. Source: <https://www.spglobal.com/esg/s1/topic/the-future-of-battery-technology.html> ; <https://archive.is/2pI82>

¹⁰³ For Battery Cost, uses “Consumer Electronics” from 2008 through 2010 and “Automotive” prices thereafter. Source: Chart Source: IEA, Evolution of Li-ion battery price, 1995-2019, IEA, Paris <https://www.iea.org/data-and-statistics/charts/evolution-of-li-ion-battery-price-1995-2019> IEA. Licence: CC BY 4.0

- Battery Density Sources: <https://onlinelibrary.wiley.com/doi/full/10.1002/aenm.202103050> ;

<https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries> ; <https://archive.is/SYXQp> ; https://www.energy.gov/sites/default/files/2022-04/FOTW_1234_web.xlsx

- This report by has (Next-generation 3 Lithium Sulphur / Air) Li-ion battery energy density reaching a bit over 1,000 Wh/kg by the 2040s. Source: <https://www.spglobal.com/esg/s1/topic/the-future-of-battery-technology.html> ; <https://archive.is/2pI82>

¹⁰⁴ Source: 8m45s to 11m46s at <https://www.youtube.com/watch?v=d1EB1zsxW0k> “Energy Investments Dialogue | Bill Gates | Global Energy Forum”

¹⁰⁵ Sources: <https://insideclimatenews.org/news/20022019/100-percent-renewable-energy-battery-storage-need-worst-case-polar-vortex-wind-solar/> ; <https://archive.is/UDLDQ> ; https://www.greencarreports.com/news/1121465_polar-vortex-tests-viability-of-renewable-power ; <https://archive.is/v726C>

¹⁰⁶ Another estimate using about 1.4 Billion world wide electric cars, estimates that we’d need 4500 TWh of batteries jut for those cars. Source: 21m05s in video <https://youtu.be/MBVmnKuBoc> | “Assoc Prof Simon Michaux - The quantity of metals required to manufacture just one generation of...”

In this same video (32m16s), it is estimated that approximately 550 TWh of batteries will be needed across the *globe* if we derive most or energy from solar and wind (corresponds to a needed 4 week buffet to account for variability in solar and wind energy production throughout the year

- Another rule of thumb (at least in California) that is commonly cited, is to install batteries equal to about 1% of the installed renewable energy sources (likely higher in other less sunny regions of the world). California uses about 200 TWh of energy capacity per year or about 23,000MW on average. If we assumed 100% renewables, using the 1% rule, we’d need about 230MW of batteries installed. <https://thundersaidenergy.com/2022/04/29/battle-of-the-batteries-evs-vs-grid-scale-storage/> ; <https://archive.is/ZpAOX>

¹⁰⁷ Source: <https://iopscience.iop.org/article/10.1088/1748-9326/ac4dc8> ; <https://archive.is/Sq6JH>

¹⁰⁸ - Using this rate, we arrive at \$28 Trillion for 56 TWh of storage capacity (of course this is not realistic as batteries won’t make up 100% of the energy storage in Germany). Elon musk has stated that the globe will need approximately 300 TWh of cumulatively net installed battery capacity for a fully renewable electric system (following article lays out a path to accomplish this by 2050 by producing 20 TWh *per year* by 2050). Source: <https://source.benchmarkminerals.com/article/how-can-the-world-meet-elon-musks-300-twh-battery-capacity-target> ; <https://archive.is/KDTBC>

- Unfortunately, Tesla Megapack pricing is not always heading in the right (i.e. lower cost over time) direction, and at today’s rates, these prices are likely at least an order of magnitude too high (depending on your assumption of how much battery storage is needed for a 100% renewable grid – much less 100% total energy system):

“Earlier this year, Tesla updated Megapack pricing., which changes depending on how many Megapacks you order, but for a single-pack project, Tesla was charging \$1,537,910. Now with the updated bigger Megapack, Tesla has increased the price to \$2,414,070 for a project with a single Megapack. On a per kWh basis, Tesla went from \$591 to \$622 with the bigger Megapack that has more energy capacity. The price goes down considerably for a bigger project. For example, a 10-Megapack project costs \$19,235,700. With 38.5 MWh of capacity, the price per kWh goes down to \$500. *The price goes down to \$475 per kWh for even larger 100+ Megapack projects*, which are actually becoming quite common.” Source: <https://electrek.co/2022/09/14/tesla-megapack-update-specs-price/> ; <https://archive.is/PDCd7>

- “Britain boasts of being ahead of other countries in renewables, offshore wind in particular. But it is a long way behind in energy storage. Britain has a total of 39.3 GWh of energy storage, mostly pumped storage. Given that we consumed 346,000 GWh of electricity in 2020 this amounts to just 60 minutes’ worth of supply.” | “The US

Department of Energy in 2020 estimated the lifetime cost of energy from a pumped storage system at around \$131 per MWh. That was around twice the wholesale price of electricity in Britain at the time.” || “At 2021 prices, and assuming that the plant is designed to discharge its stored energy over a ten-hour period, it comes out as: 1) Compressed air \$104 per MWh 2) Pumped storage \$131 per MWh 3) Hydrogen \$203 per MWh 4) Lithium ion batteries \$336 per MWh” || “The study also attempted to forecast the costs in 2030 – after, hopefully, technology has improved. This is a mug’s game, as we know, but it is interesting that the researchers expect only hydrogen and lithium ion batteries to fall appreciably in cost – to around \$152 per MWh and \$244 per MWh respectively. Even then they would still be more expensive than the pumped storage systems we already have... There is, in other words, little on the horizon to suggest that costs of storing energy are going to come down dramatically any time soon.” || “*Even in the best-case scenario – generating electricity via onshore wind and then storing it in the form of compressed air – we would be paying \$154 for our stored, renewable energy (\$50 for generating the energy and \$104 for storing it). That is nearly double what we were paying for gas-generated electricity in the summer of 2021, even taking carbon levies into account.*” || “Britain has been linked to the French national grid since 1986, and other connections have been added since so that, as of 2021, *Britain can, at any one time, exchange 3 GW of power with France, 1 GW each with Belgium and the Netherlands and 500 MW with Ireland. To put these figures into context, Britain’s electricity consumption averaged 38.1 GW in 2021. Between 2018 and 2021, a 1.4 GW cable was laid between Britain and Norway, a metre below the seabed. At 450 miles it is the longest such link in the world. The rationale behind that £1.5 billion project was that Norway has the potential to supply surplus hydroelectric power – while Norway hopefully might be able to consume surplus UK wind energy at times. We do, then, already have an embryonic international electricity grid. But Britain, France, Belgium, the Netherlands and Norway are all within one time zone of each other, providing limited opportunities to exchange solar energy.*” || “But transporting electricity long distances doesn’t come cheap. The cost of the Morocco–UK cable, together with the wind and solar farm, has been estimated by the company at £16 billion. That, notionally, would work out a little cheaper than building a large nuclear power station – the latest estimate for Hinkley C power station in Somerset (which is designed to produce 3.3 GW of power) is £23 billion.” || “A Morocco to UK cable would be four times as long, so you would expect to lose around four times as much energy along the way – leaving you with only around 80 GWh of your 100 GWh. The bigger the grid, the more electricity you try to transmit across the world, the more these losses will matter. Could we lay transatlantic cables to take advantage of solar energy once the sun goes down in Europe and North America? That would be a minimum of 3,500 miles and 15,000 feet deep in places – and be half as far again as a Morocco–UK link. The transmission technology will have to improve if we are to avoid losing a third of our energy on the transatlantic journey.” Source: Kindle location 999 in book: “Not Zero” by Ross Clark. “As already noted, just 4.2 percent of Britain’s total energy needs are currently provided by wind and solar (in 2022) and we don’t even have the beginnings of an energy storage facility which would allow intermittent wind and solar to become viable as the mainstay of our national grid. We are almost totally reliant on gas to fill the gaps.” Source: Kindle location 3902 in book: “Not Zero” by Ross Clark.

¹⁰⁹ Others have noted, that the US could get to 80% renewable energy usage with 5.4 TWh of installed batteries. This would work out to \$2.7 trillion in megapacks (vs \$25 Trillion US GDP). Source: <https://www.pv-magazine.com/2022/01/24/us-zero-carbon-future-would-require-6twh-of-energy-storage/> ; <https://archive.is/At5kZ>

¹¹⁰ Source: <https://www.energy-storage.news/us-installs-5gwh-of-battery-storage-in-h1-2022-but-overall-clean-power-deployments-fall/> ; <https://archive.is/Uq8lN>

¹¹¹ See: <https://www.forbes.com/sites/jeffmcmahon/2019/07/01/new-solar--battery-price-crushes-fossil-fuels-buries-nuclear/?sh=3f5fabf15971> ; <https://archive.is/9kL10>

¹¹² Its likely that if you plotted the % renewables vs batteries needed, you’d see some sort of exponential relationship (certainly not linear). That is to say, doubling the percentage renewables on your electric grid would result in *more* than a doubling of needed battery capacity. Its likes there is some point of diminishing returns, and that most of the benefit of renewables can be achieved while long spending huge amounts and incremental additions of batteries. Somesort of 80/20 rule in renewables would dictate that 80% of the battery cost is spent getting your renewables the final 20% of the way toward a fully renewable grid. These are certainly not close to accurate numbers, but simply illustrating the high level nonlinear growth concept of costs vs renewables saturation.

¹¹³ Source: 15m26s and 16m20s at <https://www.youtube.com/watch?v=AdJH3tKjvzM> “Answers to Hot Topics Around Simon P. Michaux's Report”. Also note at 21m15s that supply two weeks worth of US energy usage in battery storage would cost anywhere from \$100 Trillion to \$200 Trillion (assumes battery cost of \$400/KWh)

¹¹⁴ “One of the main disadvantages is the energy inefficiency of CAES plants. The process of compressing and decompressing air involves large energy losses, which means electricity-to-electricity efficiency is typically around

40-52%, compared to 70-85% for pumped-hydro energy storage facilities and 70%-90% for chemical batteries.” || “The technology is, however, cleaner than the use of batteries because it does not involve the release of toxic chemicals into the environment during decommissioning. Also, the lifespan of CAES plants can be quite long, with both plants mentioned above having been in operation longer than 30 years; a lithium ion battery typically has a lifespan of 2-3 years or 300-500 charges. Another advantage of CAES systems is the duration of achievable energy storage. Energy can be stored for over 25 days, which is pretty impressive and among the highest of currently operational energy storage technologies. It’s second place only to pumped hydro energy storage.” Also note the great chart about halfway down the page comparing types of storage. Source: <https://schaperintl.com/is-the-juice-worth-the-squeeze-compressed-air-energy-storage-for-grid-scale-power/#:~:text=The%20process%20of%20compressing%20and,%25%2D90%25%20for%20chemical%20batteries> ; <https://archive.is/UrLrq>

¹¹⁵ For reference: https://en.wikipedia.org/wiki/Carbon_capture_and_storage ; <https://archive.is/8gg9h>

¹¹⁶ Note: Natural Gas Processing is the only of the 5 classified as “High CO2 Concentration”. The other four are classified as “Low CO2 Concentration”. Source: IEA (2021), Is carbon capture too expensive?, IEA, Paris

<https://www.iea.org/commentaries/is-carbon-capture-too-expensive> ; <https://archive.is/Z3OII>

- Battery Density Sources: <https://onlinelibrary.wiley.com/doi/full/10.1002/aenm.202103050> ;

<https://www.energy.gov/eere/vehicles/articles/fotw-1234-april-18-2022-volumetric-energy-density-lithium-ion-batteries> ; <https://archive.is/SYXQp> ; https://www.energy.gov/sites/default/files/2022-04/FOTW_1234_web.xlsx

¹¹⁷ Source: 5m13s to 7m0s at <https://www.youtube.com/watch?v=rhNxDP8e7p8> “Bill Gates: The innovations we need to avoid a climate disaster | TED Countdown”

¹¹⁸ Source: <https://www.c2es.org/content/international-emissions/> ; <https://archive.is/HBp5L>

¹¹⁹ Source: https://en.wikipedia.org/wiki/Direct_air_capture ; <https://archive.is/ofolH>

¹²⁰ Source: <https://www.metaculus.com/questions/4614/date-carbon-capture-costs-50-per-ton/> ; <https://archive.is/CsC1L>

- Also note this comment at the above webpage: “Reasoning about how things might look in 2030, I assumed a 10% reduction in price for every doubling, going from around 5,000 tons to 1,000,000 would reduce a \$200/ton figure to roughly \$100/ton for a 10% learning rate. Assuming a 20% learning rate reduces it to \$50/ton. However, I don't think we're going to be seeing these learning rates yet! A lot of companies are making exciting claims about sub-\$50/ton technologies, but I think these targets may be scuppered by the fact that storage also costs money: the storage technology used by Climeworks currently costs around \$25/ton! With all this in mind, my 80% confidence interval for direct air capture reaching <\$50/ton (after capturing 1 million tons) is roughly 2040–2060.”

- For reference, this prediction market has Carbon capture and storage (CCS) or carbon capture, utilization, and storage (CCUS) at 167 million tonnes per annum (Mtpa) by 2030 (with IEA estimate at 5,635 Mtpa of CSS by 2050.

Source: <https://www.metaculus.com/questions/7081/carbon-capture-and-storage-potential-in-2030/> ;

<https://archive.is/7rKid>

¹²¹ Source: <https://www.eia.gov/totalenergy/data/annual/showtext.php?t=ptb0901> ; <https://archive.is/bULLL>

¹²² Source: https://en.wikipedia.org/wiki/List_of_commercial_nuclear_reactors#United_States ;

<https://archive.is/ASMWe>

¹²³ Further exasperating the problem is the fact by the early 2030s, many of the older nuclear power plants will begin to be retired. Its certainly possible that we see a drastic *decrease* in the number of operating nuclear power plants in the 2030s and 2040s.

- That said, we note that China has 245 GW of Nuclear power in the pipeline, vs 63GW for India vs 49 for Russia and 19 for the U.S. Source: <https://twitter.com/quakes99/status/1632560352784437248> ; <https://archive.is/wvpLM>

¹²⁴ Source: https://en.wikipedia.org/wiki/Three_Mile_Island_accident#Health_effects_and_epidemiology ;

<https://archive.is/PK0Hc>

¹²⁵ Source: https://en.wikipedia.org/wiki/Chernobyl_disaster#Acute_radiation_effects_and_immediate_aftermath ;

<https://archive.is/shXaF>

- Edward Teller himself said in 1982: “Perhaps as many as 1,000 premature deaths among the many millions exposed (after Chernobyl) in the Soviet Union may occur during the next seventy years.” p. 167 in “Better a Shield Than a Sword: Perspectives on the Defense and Technology” by Edward Teller

¹²⁶ Source: <https://ourworldindata.org/grapher/death-rates-from-energy-production-per-twh>

¹²⁷ Source:

https://en.wikipedia.org/wiki/Experience_curve_effects#Wright's_law_and_the_discovery_of_the_learning_curve_effect ; <https://archive.is/60VZ3>

¹²⁸ While inflation is the preferred metric to comparing costs across time, there are other issues that might warrant using a higher growth rate. Because of factors such as [Baumols Cost Disease](#), using some other growth rate might be prudent. If for example you used say 6.5% NGDP growth rate since the mid 1960s, then the converting the original say \$400 Million cost in 1965 dollars to 2021 dollars results in a current day estimated cost of about \$12 Billion

¹²⁹ Source: https://en.wikipedia.org/wiki/Vogtle_Electric_Generating_Plant; <https://archive.is/0c8w3>

¹³⁰ Note: Solar Capacity generally ranges from 33% in the summer to 15% in winter months. Wind is in the high 20% in the summer, and occasionally in the lower 40% in the winter. Source: Tables 6.7.A and 6.7.B at <https://www.eia.gov/electricity/monthly/>

¹³¹ Source: https://en.wikipedia.org/wiki/Levelized_cost_of_electricity#Usage_and_limitations; <https://archive.is/P7Zxh>; <https://www.cfact.org/2021/03/21/it-takes-big-energy-to-back-up-wind-and-solar/>; <https://archive.is/942x5>

¹³² Source: https://en.wikipedia.org/wiki/Nuclear_reactor#By_coolant; <https://archive.is/5hu9c>

¹³³ As Kirk Sorensen notes, there are also negative consequences if you lose pressure and the water “flashes to steam. If you don’t get emergency coolant to the reactor, it can overheat and melt”. Source: <https://www.youtube.com/watch?v=N2vzotsvkvw> “Thorium: Kirk Sorensen at TEDxYYC”

¹³⁴ Source: <https://www.sciencedirect.com/science/article/pii/B9780081023372000110>; <https://archive.is/Arndv>

¹³⁵ Source: 8m to 9m14s at <https://www.youtube.com/watch?v=dXSa6ssjYsw> “TC No 27 Kirk Sorensen@Protospace + ORNL Documentary”

¹³⁶ Source: 34m05s at <https://youtu.be/bbyr7jZOIII> “The Thorium Molten-Salt Reactor: Why Didn't This Happen (and why is now the right time?)”

¹³⁷ Source: 8m35s to 10m30s at <https://www.youtube.com/watch?v=dXSa6ssjYsw> “TC No 27 Kirk Sorensen@Protospace + ORNL Documentary”

¹³⁸ Source: 11m10s at <https://www.youtube.com/watch?v=dXSa6ssjYsw> “TC No 27 Kirk Sorensen@Protospace + ORNL Documentary”

¹³⁹ Source: 4m53s at <https://www.youtube.com/watch?v=2S9gCbEew5s> “Nuclear Fuel: Liquid vs Solid - "Th" Thorium Documentary”

¹⁴⁰ Thorium reactor research was largely stopped in 1973 in favor of fast breeder reactors (*possible* reason why: partially because of a political jobs program, partially because of perceived energy independence using existing nuclear technologies at the time). Source: <https://youtu.be/bbyr7jZOIII?t=1281> “The Thorium Molten-Salt Reactor: Why Didn't This Happen (and why is now the right time?)”

¹⁴¹ Source: 4m50s at <https://www.youtube.com/watch?v=N2vzotsvkvw> “Thorium: Kirk Sorensen at TEDxYYC”

¹⁴² Source: <https://world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-process-heat-for-industry.aspx>; <https://archive.ph/u8jwL>

¹⁴³ Desalination is another potential benefit of thorium reactors (or many other types of cheap power). Solar power is also a prime candidate for further increasing desalination output. Source:

<https://en.wikipedia.org/wiki/Desalination#Costs>; <https://archive.is/tLG9P>

¹⁴⁴ Source: 5m11s to 6m2s at <https://www.youtube.com/watch?v=N2vzotsvkvw> “Thorium: Kirk Sorensen at TEDxYYC”

¹⁴⁵ Source: 9m8s at <https://youtu.be/tyqYP6f66Mw?t=548> “THE THORIUM PROBLEM - Manufacturing & energy sector hobbled by thorium”

¹⁴⁶ Source: 6m2s at <https://www.youtube.com/watch?v=N2vzotsvkvw> “Thorium: Kirk Sorensen at TEDxYYC”

¹⁴⁷ Source: 14m to 15m38s at <https://www.youtube.com/watch?v=N2vzotsvkvw> “Thorium: Kirk Sorensen at TEDxYYC”

¹⁴⁸ Source: 14m28s to 15m52s at <https://www.youtube.com/watch?v=dXSa6ssjYsw> “TC No 27 Kirk Sorensen@Protospace”

¹⁴⁹ “A single ton of Thorium can generate as much energy as 200 tons of uranium”. Source: <https://www.popularmechanics.com/science/energy/a6162/the-truth-about-thorium-and-nuclear-power/>; <https://archive.is/yr4qW>

¹⁵⁰ “Commercially, the U235 isotope is enriched to 3 to 5% (from the natural state of 0.7%) and is then further processed to create nuclear fuel.” Source: <https://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html>; <https://archive.is/G6M8e>

¹⁵¹ Source: <https://www.forbes.com/sites/energysource/2012/02/16/the-thing-about-thorium-why-the-better-nuclear-fuel-may-not-get-a-chance/?sh=3f7d0bb1d803>; <https://archive.is/E7tTZ>

¹⁵² Source: <https://www.forbes.com/sites/energysource/2012/02/16/the-thing-about-thorium-why-the-better-nuclear-fuel-may-not-get-a-chance/?sh=3f7d0bb1d803> ; <https://archive.is/E7tTZ>

¹⁵³ “Thus, a uranium breeder reactor, once running, can be refueled with natural or even depleted uranium, and a thorium breeder reactor can be refueled with thorium; however, an initial stock of fissile material is required”

Source: https://en.wikipedia.org/wiki/Nuclear_reactor#By_use ; <https://archive.is/5hu9c>

¹⁵⁴ Source: 10m8s at <https://youtu.be/tyqYP6f66Mw?t=548> “THE THORIUM PROBLEM - Manufacturing & energy sector hobbled by thorium”

- “They also demonstrated that existing long-term (240,000 years or more) nuclear waste can be “burned up” in the thorium reactor to become a much more manageable short-term (less than 500 years) nuclear waste. An Accelerator-Driven System (ADS), as the process is called, comprises an assembly of key technologies developed at CERN: an accelerated proton beam focuses on a metal target, usually lead, in a process called spallation. This spawns neutrons that in turn convert thorium into fissile uranium-233, producing heat by way of nuclear fission. The heavy uranium-233 nuclei divides into smaller nucleus such as zirconium (think Shopping Channel jewellery) or xenon (used in camera flash bulbs), with only minimal radioactive waste produced.” Source:

[https://www.weforum.org/agenda/2018/11/destroying-nuclear-waste-to-create-clean-energy-it-can-be-done/#:~:text=They%20also%20demonstrated%20that%20existing,than%20500%20years\)%20nuclear%20waste](https://www.weforum.org/agenda/2018/11/destroying-nuclear-waste-to-create-clean-energy-it-can-be-done/#:~:text=They%20also%20demonstrated%20that%20existing,than%20500%20years)%20nuclear%20waste) ; <https://archive.is/vXF14>

¹⁵⁵ Sources: <https://en.wikipedia.org/wiki/Uranium-238> ; <https://en.wikipedia.org/wiki/Plutonium-239> ; <https://en.wikipedia.org/wiki/Plutonium-238>

¹⁵⁶ Source: <http://www.ncpathinktank.org/pdfs/ib149.pdf> “The Potential of Thorium for Safer, Cleaner and Cheaper Energy” by the National Center for Policy Analysis (September 2014).

¹⁵⁷ “Thorium has consistently been referenced as a more proliferation-resistant fuel. Ironically, articles state that this is because U-233 is more dangerous to handle than U-235, resulting in more difficulty whilst crafting a nuclear weapon. [1] U-233 is more risky because U-233 produced from the thorium decay cycle is tainted with U-232 and not easily separated from it. This is not ideal for weapons creation because U-232 releases dangerous decay products that emit gamma radiation, which can penetrate skin and damage cells. As a result, remote handling of the equipment is required. This is not an issue if thorium is in a reactor, as U-232 is eventually burned during the production of energy. However, it is hazardous when crafting a military bomb with U-233, as trace U-232 can damage underlying electronics. Furthermore, thorium is a chemically more stable fuel than uranium. [3] As a result, thorium as a nuclear fuel is deemed more proliferation-resistant than U-235. However, there have been early nuclear tests performed utilizing thorium, so there is still an underlying potential for danger.” Source:

<http://large.stanford.edu/courses/2018/ph241/dai1/> ; <https://archive.is/M0vbQ>

¹⁵⁸ Source: https://en.wikipedia.org/wiki/Liquid_fluoride_thorium_reactor#Disadvantages ; <https://archive.is/7GR1s>

¹⁵⁹ The Nine Mile Point Nuclear reactor with 1375 MW capacity was built for about \$8.5 billion in today’s dollars. Using average of 350W per person and 7B people (2.8TW total), that equates to something like \$17 trillion to convert entire electrical capacity to nuclear (or about \$60 trillion for all globe’s primary energy consumption – assuming (unrealistically at present) that we can convert all to nuclear). Comparing this to more recent estimates from Tesla: In its March 2023 investor day slide titled “[A Sustainable Energy Economy is Within Reach & We Should Accelerate It](#)”, Tesla states that 240 TWh of storage are needed. Using Tesla’s own 4MWh megapack, that works out to about 60 million Tesla megapacks needed! At \$1.9 Million per megapack that works out to about \$114 Trillion! If electric cars are widespread and we generously mark car batteries as ‘free’, that knocks off about 60TWh of battery needed. That still leaves us with a total cost of \$86 trillion in megapack battery storage needed. If we take further extremely generous assumptions, In 2011, automotive batteries were about 28% the price of utility batteries (partially because of increased electric vehicle volume relative to grid battery storage and the learning curve effects that come with this volume), which brings our \$86 trillion to \$114 trillion to something like \$24-\$31 Trillion. In 2017, automotive batteries were about 15% the price of utility batteries, which brings our \$86 trillion to \$114 Trillion to something like \$13-17 Trillion. However, this assumes many things, and if we are giving volume credit/learning curve effects to grid scale batteries, we should give at least some learning curve effect to the many modular nuclear reactors we are comparing the battery system to. Sources:

<https://www.youtube.com/watch?v=H11zEzVUV7w&t=1753s> “2023 Investor Day” ;

<https://www.tesla.com/megapack/design> ; <https://archive.is/3TfcG> ;

https://en.wikipedia.org/wiki/Nine_Mile_Point_Nuclear_Generating_Station

¹⁶⁰ Source: <https://www.iaea.org/newscenter/news/what-is-nuclear-fusion> ; <https://archive.is/TsEsF>

¹⁶¹ In theory, an antimatter weapon would convert **100%** of mass to energy. “ Using the convention that 1 kiloton TNT equivalent = 4.184×10¹² joules (or one trillion calories of energy), one half gram of antimatter reacting with one half gram of ordinary matter (one gram total) results in 21.5 kilotons-equivalent of energy (the same as the atomic bomb dropped on Nagasaki in 1945).” Source: https://en.wikipedia.org/wiki/Antimatter_weapon ; <https://archive.is/ya8fq> | | “The energy per unit mass (9×10¹⁶ J/kg) [of antimatter] is about 10 orders of magnitude greater than chemical energies,[83] and about 3 orders of magnitude greater than the nuclear potential energy that can be liberated, today, using nuclear fission (about 200 MeV per fission reaction[84] or 8×10¹³ J/kg), and about 2 orders of magnitude greater than the best possible results expected from fusion (about 6.3×10¹⁴ J/kg for the proton–proton chain). The reaction of 1 kg of antimatter with 1 kg of matter would produce 1.8×10¹⁷ J (180 petajoules) of energy (by the mass–energy equivalence formula, E=mc²), or the rough equivalent of 43 megatons of TNT – slightly less than the yield of the 27,000 kg Tsar Bomba, the largest thermonuclear weapon ever detonated.” Source: <https://en.wikipedia.org/wiki/Antimatter#Fuel> ; <https://archive.is/qemF9>

- We expand more on specific energy and energy density of various materials in the table below, selected from the Wikipedia link listed in the source below:

Storage type	Specific energy (MJ/kg)	Energy density (MJ/L)
<i>Arbitrary Antimatter</i>	89,875,517,874	depends on density
<i>Deuterium–tritium fusion</i>	338,000,000	
<i>Uranium-235 fissile isotope</i>	144,000,000	1,500,000,000
Natural uranium (0.7% U-235) in FB reactor	86,000,000	
Reactor-grade uranium (3.5% U-235) in LW reactor	3,456,000	
Pu-238	2,200,000	
Natural uranium (0.7% U235) in light-water reactor	443,000	
Lithium + Fluorine	23.75	
<i>Gasoline + Oxygen → Derived from Gasoline</i>	13.3	
battery, Lithium–air	6.12	
TNT	4.61	6.92
<i>battery, Lithium-ion nanowire</i>	2.54	
Thermal Energy Capacity of Molten Salt	1	
battery, Sodium–Sulfur	0.72	1.23
battery, Lithium–Manganese	1.01	2.09
battery, Lithium-ion	0.72	3.6
battery, Lithium–Sulfur	1.8	1.26
Flywheel	0.5	
<i>Capacitor</i>	0.002	
<i>Spring power (clock spring)</i>	0.0003	0.0006

Source: https://en.wikipedia.org/wiki/Energy_density_Extended_Reference_Table ; <https://archive.is/UYM0z>

¹⁶² Source: <https://www.science.org/content/article/fusion-breakthrough-nif-uh-not-really> ; <https://archive.is/9lr3S>

¹⁶³ Source: https://en.wikipedia.org/wiki/Fusion_energy_gain_factor#Scientific_breakeven_at_NIF ; https://en.wikipedia.org/wiki/Fusion_energy_gain_factor#Breakeven ; <https://archive.is/sZJ9P> ; https://en.wikipedia.org/wiki/DEMONstration_Power_Plant ; <https://archive.is/Vfhyi>

¹⁶⁴ Source: <https://www.science.org/content/article/historic-explosion-long-sought-fusion-breakthrough> ; <https://archive.is/sgTou>

¹⁶⁵ https://en.wikipedia.org/wiki/Fusion_energy_gain_factor#Engineering_breakeven ; <https://archive.is/sZJ9P>

¹⁶⁶ In the following link, Q_{wp} (“wall Plug in”) refers to the engineering breakeven, with median votes have us passing this milestone in 2037. Source; <https://www.metaculus.com/questions/14109/date-fusion-reactor-achieves-q-5/> ; <https://archive.is/WpG8j>

¹⁶⁷ Source: https://en.wikipedia.org/wiki/Fusion_energy_gain_factor#Commercial_breakeven ; <https://archive.is/sZJ9P>

¹⁶⁸ “Q” would be 10 in this case because the injected thermal input is only 50MW (with Gross Thermal Ouptu being 500MW). Sources: <https://en.wikipedia.org/wiki/ITER> ; <https://archive.is/7bYth> ; https://en.wikipedia.org/wiki/DEMONstration_Power_Plant ; <https://archive.is/Vfhyi>

¹⁶⁹ Source: https://en.wikipedia.org/wiki/DEMONstration_Power_Plant ; <https://archive.is/Vfhyi>

¹⁷⁰ <https://www.metaculus.com/questions/9464/nuclear-fusion-power-01-of-global-energy/> ; <https://archive.is/bjkOw>

¹⁷¹ <https://www.metaculus.com/questions/9465/nuclear-fusion-power-10-of-global-energy/> ; <https://archive.is/R4sgX>

¹⁷² As David Friedman notes, the main difference between the two is: “With straight cap and trade, the equivalent revenue from the carbon tax is going to last years’ emitters rather than the government, and that obviously had advantages and disadvantages: If the government wants money then (cap and trade) isn’t such a great scheme... But if the government wants to bribe the people (who might be injured by the cap and trade law) into supporting it, then it looks like quite a great scheme because, with cap and trade, it isn’t even clear if the emitters are worse off. That depends on the equilibrium: One the one hand the emitters aren’t able to emit as much, but on the other hand, you’ve raised the marginal cost of producing, which is going to rise the price and under some circumstances that means the power companies make more money (with the higher price of electricity) than they lose in the restriction in what they can produce/emit. But that would be a complicated question.” Source: <https://youtu.be/s-yJ3K9fNos?t=868> (14m28s to 15m15s) “David Friedman "Global Warming, Population, and the Problem with Externality Arguments”

¹⁷³ In addition, not every industry has historically been covered by these carbon schemes.

¹⁷⁴ The recently passed Inflation Reduction Act makes an attempt at this. “The charge starts at \$900 per metric ton of methane, increasing to \$1,500 within two years. It will be based on the prior year's emissions, and the charge starts in 2025 based on 2024 data” || “(this \$900/ton for methane) equates to \$36 and \$60 per metric ton of carbon dioxide *equivalent*” Source:

<https://www.hklaw.com/en/insights/publications/2022/08/methane-emissions-new-developments-in-the-inflation-reduction-act> ; <https://archive.is/aFJPj> ; <https://crsreports.congress.gov/product/pdf/R/R47206>

¹⁷⁵ Source: https://carbonpricingdashboard.worldbank.org/map_data

¹⁷⁶ Sources: “A 2030 price floor of \$75 a ton for advanced economies, \$50 for high-income emerging market economies such as China, and \$25 for lower-income emerging markets such as India would keep warming below 2°C”: <https://www.imf.org/en/Publications/fandd/issues/2021/09/five-things-to-know-about-carbon-pricing-parry> ; <https://archive.is/xAs7P> ; <https://www.imf.org/en/Blogs/Articles/2022/07/21/blog-more-countries-are-pricing-carbon-but-emissions-are-still-too-cheap#:~:text=Despite%20the%20proliferation%20of%20carbon,today%20to%20%2475%20by%202030> ; <https://archive.is/1orzX>

¹⁷⁷ Source: (See graph in “Figure 1”) [https://about.bnef.com/blog/carbon-offset-prices-could-increase-fifty-fold-by-2050/#:~:text=New%20York%20and%20London%2C%20January,research%20company%20BloombergNEF%20\(BNEF\)](https://about.bnef.com/blog/carbon-offset-prices-could-increase-fifty-fold-by-2050/#:~:text=New%20York%20and%20London%2C%20January,research%20company%20BloombergNEF%20(BNEF)) ; <https://archive.is/Ev86q>

¹⁷⁸ Source: <https://icapcarbonaction.com/en/ets/eu-emissions-trading-system-eu-ets> ; <https://archive.is/ZpTmK>

¹⁷⁹ Source: <https://www.imf.org/en/Blogs/Articles/2022/07/21/blog-more-countries-are-pricing-carbon-but-emissions-are-still-too-cheap#:~:text=Despite%20the%20proliferation%20of%20carbon,today%20to%20%2475%20by%202030> ; <https://archive.is/1orzX>

¹⁸⁰ Source: (Uses only “Total” bar in the stacked column) https://carbonpricingdashboard.worldbank.org/map_data

¹⁸¹ Source: <https://documents1.worldbank.org/curated/en/191801559846379845/pdf/State-and-Trends-of-Carbon-Pricing-2019.pdf> (Page 17). Other older relevant data at:

https://www.worldbank.org/content/dam/Worldbank/document/Climate/background-note_ets.pdf

; https://en.wikipedia.org/wiki/Carbon_price#Scope_and_coverage

¹⁸² Source: <https://ourworldindata.org/grapher/production-vs-consumption-co2-emissions>

¹⁸³ Source: https://en.wikipedia.org/wiki/Carbon_accounting#Origins ; <https://archive.is/7kZt3>

¹⁸⁴ Sources: <https://fred.stlouisfed.org/series/DCOILBRENTTEU> ; <https://fred.stlouisfed.org/series/GASREGW>

¹⁸⁵ Source: <https://www.iea.org/data-and-statistics/data-product/monthly-reliance-on-russian-oil-for-oecd-countries>

¹⁸⁶ Source: <https://www.consilium.europa.eu/en/infographics/eu-gas-supply/#:~:text=In%20August%202022%2C%20Russia's%20share,the%20US%2C%20Qatar%20and%20Nigeria> ; <https://archive.is/1fPuY>

¹⁸⁷ Sources:

https://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=PRICES_CPI&ShowOnWeb=true&Lang=en

¹⁸⁸ Sources: https://www.eia.gov/petroleum/gasdiesel/gaspump_hist.php

¹⁸⁹ Sources: <https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MGIRIUS2&f=A> ;

https://www.eia.gov/dnav/pet/PET_PNP_UNC_DCU_NUS_A.htm

¹⁹⁰ Source: <https://www.eia.gov/tools/faqs/faq.php?id=29&t=6> ; <https://archive.is/EJtb3>

¹⁹¹ Source: <https://www.economist.com/united-states/2023/02/09/joe-biden-is-not-quitting-fossil-fuels> ; <https://archive.is/jcSHk>

¹⁹² “The IRA raises royalty rates charged to the drillers, but it prohibits the BLM (ferally run ‘Bureau of Land Management’) from leasing public land for renewables unless it also offers leases for oil and gas development”... (that)” trade-off was “Joe Manchin’s cost of entry”. The senator for West Virginia was the IRA’s decisive vote, and is in favour of continued drilling.” Source: <https://www.economist.com/united-states/2023/02/09/joe-biden-is-not-quitting-fossil-fuels> ; <https://archive.is/jcSHk>

¹⁹³ Sources: https://ourworldindata.org/grapher/oil-production-by-country?country=QAT~OMN~SAU~NOR~IRQ~USA~ARE~OWID_WRL~CHN

¹⁹⁴ Source: <https://knoema.com/infographics/vyronoe/cost-of-oil-production-by-country> ; <https://archive.is/TCZS4>

¹⁹⁵ “Saudi Arabia only officially played the role of swing producer for a short period in the early 1980s, when it failed to stem the oversupply of global oil markets and slide in prices.” || “Saudi Arabia had often acted as an informal swing producer, but this was the first time the role had been formalized. Saudi Arabia’s role as a swing producer formally terminated in 1984 when it opted instead for a quota of 4.35 million bpd, though in practice it went on performing the swing producer role until September 1985.” || “Nazer’s successor as oil minister, Ali Naimi, was even blunter: ‘Saudi Arabia tried in the past to play the role of the swing producer by reducing production to maintain a specific price, but the result was unfavorable to the kingdom,’ he said in an interview in March 1998. ‘Despite the fact that its production fell from more than 10 million bpd in 1980 to less than 3 million bpd in 1985, prices collapsed. As a result, the kingdom not only lost in terms of prices but also lost its market share at that time.’ ‘We have abandoned once and for all the role of swing producer,’ Naimi said (‘Saudi oil minister spells out kingdom’s views on current oil market’, Middle East Economic Survey, March 1998).” || “The problem is that the role of swing producer is not one that Saudi Arabia’s policymakers have voluntarily accepted, but one which has been thrust upon them.” || “audi Arabia is the only country that has production centralized in one company (Saudi Aramco) and exports enough to have a major influence on global prices (7-8 million bpd). Saudi Arabia is also a low cost producer which has the operational flexibility to adjust its production up or down by several million barrels per day. Saudi Arabia is therefore the only country that can to some extent choose a production target or a price target, though importantly not both. For structural reasons, Saudi Arabia is always the swing producer in the crude oil market, whether it welcomes the role or not.” || “Between 2014 and the first half of 2016, the kingdom operated in punitive mode, focusing on defending market share and allowing prices to fall. In the second half of 2016, however, the kingdom switched back to swing mode, and is now adjusting production to achieve a desired reduction in stock levels and firming prices.” Source: <https://www.reuters.com/article/us-saudi-oil-kemp/saudi-arabia-cannot-escape-destiny-as-swing-producer-kemp-idUSKBN15G4OO> ; <https://archive.is/GAOTA>

¹⁹⁶ Source: <https://www.reuters.com/business/energy/how-much-extra-oil-could-opec-pump-cool-prices-2022-03-11/> ; <https://archive.is/P3Dw5>

¹⁹⁷ Source: https://www.eia.gov/international/analysis/special-topics/Global_Surplus_Crude_Oil_Production_Capacity

¹⁹⁸ Source: https://en.wikipedia.org/wiki/List_of_countries_by_proven_oil_reserves#Countries ; <https://archive.is/x7kiU>

¹⁹⁹ Source: https://en.wikipedia.org/wiki/Peak_oil ; https://ourworldindata.org/grapher/oil-production-by-country?country=~OWID_WRL ; <http://pascal.virtual.gac.edu/~huber/hubbert/>

²⁰⁰ Source: <https://ourworldindata.org/grapher/global-primary-energy>

²⁰¹ Source: <https://ourworldindata.org/grapher/oil-proved-reserves?tab=chart&country=SAU~IRQ~USA~VEN~CAN~IRN~NOR~CHN>

²⁰² “If you mined every ounce of Lithium that are in the known reserves, that would probably be about 5% of what is needed to green the economy *once*. Forgetting about the fact that every 30 years, it would then need to be replaced” | | “They’ve been looking for Lithium now for decades, and they have a pretty good idea of where the best reserves are. And they are totally inadequate for the task. The lesson we draw from that is we have to change the task. We have to redesign our way around Lithium. We have to find a way to make light weight batteries using something other than Lithium. Potassium and sodium and good candidates. And there are hundreds of times more sodium and potassium around than lithium.” (though we note that Tyler Cowen intelligently follows up with “The finite supply argument has been made for sometime, and it hasn’t yet turned out to be binding. And wouldn’t it be strange if all of sudden it were now binding?”) Source: 0m40s to 3m30s at <https://www.youtube.com/watch?v=BvQC3QIly> “Jeremy Grantham on Investing in Green Tech (full) | Conversations with Tyler”

²⁰³ - Extra notes based on lettered endnotes:

(a) Important to note we are not saying the world run out of these reserves in X years. As we saw with oil, discovery of reserves over time (technological advancement, etc.) can commonly lead to global reserves increasing over time.

(b) Iron ore reserves are a guess at best. Iron is very abundant and there are wide error bars in this estimate. New battery technology using lithium iron phosphate (LFP) batteries instead of cobalt might reduce stresses on some of the raw materials here. Iron phosphate is However, iron phosphate is often produced as a byproduct of iron ore mining and phosphate rock mining, which have annual production rates of around 2.5 billion metric tons and 240 million metric tons, respectively. Estimates for iron ore reserves are around 175 billion metric tons, while phosphate rock reserves are estimated at around 68 billion metric tons. Regarding *current* batteries: Cobalt can be recycled from old batteries which will put less relative strain on new production as electric vehicle batteries become a larger share of the market.

(c) "About 10 metric tons of natural uranium go into producing a metric ton of LEU, which can then be used to generate about 400 million kilowatt-hours of electricity, so present-day reactors require about 70,000 metric tons of natural uranium a year." || "According to the NEA, identified uranium resources total 5.5 million metric tons, and an additional 10.5 million metric tons remain undiscovered—a roughly 230-year supply at today's consumption rate in total" || "First, the extraction of uranium from seawater would make available 4.5 billion metric tons of uranium—a 60,000-year supply at present rates. Second, fuel-recycling fast-breeder reactors, which generate more fuel than they consume, would use less than 1 percent of the uranium needed for current LWRs. Breeder reactors could match today's nuclear output for 30,000 years using only the NEA-estimated supplies." Also note comment section (only on archive.is version of link)." <https://archive.is/pVLjH>

- Also refer to quote from Kirk Sorensen earlier in our letter about the relative abundance of U-235 vs U-238

(d) The preceding reserve figures refer to the amount of thorium in high-concentration deposits inventoried so far and estimated to be extractable at current market prices; millions of times more total exist in Earth's 3×10¹⁹ tonne crust, around 120 trillion tons of thorium, and lesser but vast quantities of thorium exist at intermediate concentrations. Proved reserves are "a poor indicator of the total future supply of a mineral resource" Source: https://en.wikipedia.org/wiki/Occurrence_of_thorium. Assuming 28 Billion kWh per tonne of thorium, we arrive at the total 6.3 million tonnes of thorium reserves being able to supply about 1,000 years' worth of the worlds primary energy usage (which currently is about 171 trillion kwh per year). If we used the 120 trillion tonnes that are potentially in the earth's crust, that equates to 19 billion times more than the earth's current annual energy usage (illustrative purposes only).

(e) This \$530 trillion in (selected) raw material reserves is about 450% of world GDP (\$96 trillion). There are certainly many more reserves of other materials as well reserves of the above materials that are not yet listed, but may be listed in the future as discovery technology, etc. improves.

(f) This assumes all world oceans used for Fusion fuel - and based on current annual world energy consumption of 500 quad (fanciful, we know! Used only for illustration purposes!)

(g) From here to the end of the table, we'll be doing watts, etc. I.E., moving from *energy* (barrel of oil, watt hours, etc.) to *power* (watts, etc.). Source: https://en.wikipedia.org/wiki/Kardashev_scale#Type_I ; <https://archive.is/iV3VL>

(h) Source: https://en.wikipedia.org/wiki/Kardashev_scale#Type_II ; <https://archive.is/iV3VL>

(i) Source: https://en.wikipedia.org/wiki/Kardashev_scale#Type_III ; <https://archive.is/iV3VL> ;

https://en.wikipedia.org/wiki/Names_of_large_numbers#Extensions_of_the_standard_dictionary_numbers

(j) <http://bostonastronomy.net/Power.html> ; <https://archive.is/sEFKb>

- Next we list some of the historical figures for selected raw materials:

<u>Commodity</u>	<u>1980 production</u>	<u>1980 reserves</u>
Oil	23 billion barrels/year	683 billion
Coal	4.1 billion tonnes	1.1 trillion tonnes
Natural Gas	1.5 trillion bcm	80 trillion cubic meters (bcm)
Cobalt	26,000 tonnes /yr (107k in 2010)	7.3 million tonnes
Lithium	28,000 mt/yr (2010)	
Nickle	0.8 million mt	49 million mt
Iron	506 million mt/yr	100 billion mt
Lead	2.8 million tonnes/yr	50 million tonnes
Copper	8.5 million tonnes/yr	300 million tonnes
Tin	200,00 mt	9.1 million mt
Uranium	70,000 tonnes	2.5 million tonnes

-Finally, below are the sources:

Lithium: <https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-lithium.pdf>

Oil: https://en.wikipedia.org/wiki/List_of_countries_by_proven_oil_reserves#Countries

Coal: https://en.wikipedia.org/wiki/List_of_countries_by_coal_reserves

https://en.wikipedia.org/wiki/List_of_countries_by_coal_production

Natural Gas: https://en.wikipedia.org/wiki/List_of_countries_by_natural_gas_proven_reserves#cite_note-13 ;

<https://ourworldindata.org/grapher/natural-gas-prices> ; https://en.wikipedia.org/wiki/Natural_gas_prices ;

<https://www.worldometers.info/gas/> ; <https://www.eia.gov/dnav/ng/hist/n9103us3m.htm>

Cobalt: <https://en.wikipedia.org/wiki/Cobalt#Production> ; <https://www.statista.com/statistics/1058647/global-cobalt-reserves/>

Nickle: https://en.wikipedia.org/wiki/Nickel#World_production ; <https://www.statista.com/statistics/273634/nickel-reserves-worldwide-by-country/> ;

<https://www.statista.com/statistics/603621/global-distribution-of-nickel-mine-production-by-select-country/>

Iron: https://en.wikipedia.org/wiki/List_of_countries_by_iron_ore_production ;

https://en.wikipedia.org/wiki/Iron_ore#Production_and_consumption

Copper: https://en.wikipedia.org/wiki/Peak_copper ;

https://en.wikipedia.org/wiki/List_of_countries_by_copper_production

Tin: https://en.wikipedia.org/wiki/List_of_countries_by_tin_production ;

<https://en.wikipedia.org/wiki/Tin#Production>

Silicon: <https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-silicon.pdf> ;

https://en.wikipedia.org/wiki/List_of_countries_by_silicon_production

Uranium: <https://archive.is/pVLjH> ; https://en.wikipedia.org/wiki/List_of_countries_by_uranium_reserves ;

https://en.wikipedia.org/wiki/List_of_countries_by_uranium_production ; <https://elements.visualcapitalist.com/70-years-of-global-uranium-production-by-country/>

Thorium: https://en.wikipedia.org/wiki/List_of_countries_by_thorium_resources ;

<https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-thorium.pdf> ;

https://en.wikipedia.org/wiki/Occurrence_of_thorium

Deuterium: <https://physics.stackexchange.com/questions/164282/how-much-potential-fusion-energy-is-in-earths-ocean> ;

<https://archive.is/KPtIO>

Other relevant sources: 41m33s at <https://youtu.be/MBVmnKuBoc> “Assoc Prof Simon Michaux - The quantity of metals required to manufacture just one generation of...”

²⁰⁴ S&P Global Commodity Insights has ‘Global CO₂ emissions from energy combustion’ peaking at about 36 gigatons by the late 2020s and then (only) declining to 32 or 33 gigatons by 2050. At that (linear) rate of decline, it would stand at approximately 20 to 25 gigatons of global CO₂ emissions per year by 2100. Source: “War and subsidies have turbocharged the green transition: They may have knocked as much as ten years off the timeline” ;

<https://www.economist.com/finance-and-economics/2023/02/13/war-and-subsidies-have-turbocharged-the-green-transition> ; <https://archive.is/7LHkp>

- Metaculus has only 44% of countries meeting their carbon neutral pledges for 2050. Source:

<https://www.metaculus.com/questions/5546/success-rate-for-national-carbon-neutrality/> ; <https://archive.is/XCAHQ>

- Metaculus has China reaching carbon neutral by 2062. Source: <https://www.metaculus.com/questions/10712/date-of-chinese-carbon-neutrality/> ; <https://archive.is/UbSBp>

- Metaculus has an 85% chance of greater than 2 °C warming by 2100. Source:

<https://www.metaculus.com/questions/585/2c-global-warming-by-2100/> ; <https://archive.is/QsrqC>

²⁰⁵ - We note the Metaculus prediction market here, which predicts global CO₂ concentrations in 2100 will be 588ppm, which corresponds to something like the RCP4.5 scenario. Source:

<https://www.metaculus.com/questions/7801/co2-in-atmosphere-in-2100/> ; <https://archive.is/L3s4s>

- We note the Metaculus prediction market here, which predicts global temperatures in 2100 will be 2.33° above 1880 baseline temperature. This corresponds, again, to something like the RCP4.5 scenario. We also note that this predicted 2100 temperature was over 3 °C, in 2019.

Source: <https://www.metaculus.com/questions/605/how-much-global-warming-by-2100/> ; <https://archive.is/y9vsvu>

²⁰⁶ Source: <https://www.pik-potsdam.de/~mmalte/rcps/> ;

https://en.wikipedia.org/wiki/Representative_Concentration_Pathway ; <https://ourworldindata.org/explorers/ipcc-scenarios>

²⁰⁷ Source: <https://earthscience.stackexchange.com/questions/8557/how-do-current-pollution-levels-in-los-angeles-compare-to-the-1970s> ; <https://archive.is/BaEQQ>

²⁰⁸ Source: Parrish, David D; Warneke, C.; de Gouw, J.; Holloway, J.; Peischl, J.; Ryerson, T.; Atlas, E., et al. (2012). Multiyear trends in volatile organic compounds in Los Angeles, California: Five decades of decreasing emissions. Journal of Geophysical Research: Atmospheres, 117(D21), n/a-n/a. Report #: ARTN D00V17.

<http://dx.doi.org/10.1029/2012jd017899> Retrieved from <https://escholarship.org/uc/item/3cr1n0sk>

- also see: <https://earthscience.stackexchange.com/questions/8557/how-do-current-pollution-levels-in-los-angeles-compare-to-the-1970s> ; <https://archive.is/BaEQQ>

²⁰⁹ Source: 3m42s at <https://www.youtube.com/watch?v=c01BIUDI1K4> “Moore's Law is Not Dead (Jim Keller) | AI Podcast Clips”

- Further trends (single-thread performance (specINT x 10³), frequency (MHz), typical power (watts), number of logical cores, etc.), are noted on the graph here: <https://github.com/karlrupp/microprocessor-trend-data> ;

<https://archive.is/RUxQc>

- AI and Chat-GPT have been in the news lately. Its truly an amazing technology and we encourage everyone to try it out. As a quick background of the progress that has been made, we list out the progression of some metrics in the last few years:

Model	Year	Training Compute (FLOPS)	Training Tokens	Parameters
GPT	2018	20,000,000,000,000,000	4.5GB of text	120,000,000
GPT-2	2019	1,400,000,000,000,000,000	10 Billion	1,500,000,000
GPT-3	2020	200,000,000,000,000,000,000	300 Billion	175,000,000,000
GPT-4	2023	4,000,000,000,000,000,000,000,000	??	≈1,000,000,000,000

- We note the 1 trillion parameters for GPT-4 is about 1% of the 100 trillion synapses in a human brain (synapses being the place where the 100 billion neurons in the human brain connect and communicate with each other)

- “GPT4 should have 20X GPT3 compute. GPT4 should have 10X parameters. GPT 5 should have 10X-20X of GPT4 compute in 2025. GPT5 will have 200-400X compute of GPT3 and 100X parameters of GPT3.” || “GPT-5 should be expected at the end of 2024 or in 2025. 100 trillion parameter model won't be GPT-4 and is far off. They are getting much more performance out of smaller models. Maybe they will never need such a big model.” || “According to the paper Scaling Laws for Neural Language Models (2020), model performance as measured by cross-entropy loss can be calculated from three factors: 1) the number of parameters in the model, 2) the amount of compute used during training, and 3) the amount of training data. There is a power-law relationship between these three factors and the loss. For every 10x increase in compute, the paper approximately recommends increasing the number of parameters by 5x, the number of training tokens by 2x, and the number of serial training steps by 1.2x.”

Sources: <https://www.nextbigfuture.com/2023/02/what-to-expect-for-openai-gpt-4-and-gpt-5.html> ;

<https://archive.is/6BtGS> ; https://en.wikipedia.org/wiki/Generative_pre-trained_transformer ;

<https://archive.is/wWhL> ; <https://www.metaculus.com/questions/14327/gpt-4-number-of-parameters/> ;

<https://archive.is/H6Pw2>

- “Notice GPT-2 1.5B is trained with 40GB of Internet text, which is roughly 10 Billion tokens (conversely assuming the average token size is 4 characters)” Source: <https://lambdalabs.com/blog/demystifying-gpt-3> ;

<https://archive.is/XV0VI>

- “Regarding parameter counts growth, the industry is already reaching the limits for current hardware with dense models—a 1 trillion parameter model costs ~\$300 million to train” || “Another order of magnitude scaling would take us to 10 trillion parameters. The training costs using hourly rates would scale to ~\$30 billion. Even with 1 million A100s across 125,000 HGX / DGX systems, training this model would take over two years. Accelerator systems and networking alone would exceed the power generated by a nuclear reactor” || “While 1 trillion to 10 trillion is the practical limit for today's hardware, new hardware is coming” || “Training efficiency is the key metric to watch. Training efficiency is the amount of compute and training time used to achieve superior model quality versus the prior state of the art.” Source: <https://www.semianalysis.com/p/the-ai-brick-wall-a-practical-limit> ;

<https://archive.is/QHxHe>

- “More importantly, inference costs far exceed training costs when deploying a model at any reasonable scale. In fact, the costs to inference ChatGPT exceed the training costs on a weekly basis” || “Estimating ChatGPT costs is a tricky proposition due to several unknown variables. We built a cost model indicating that ChatGPT costs \$694,444 per day to operate in compute hardware costs. OpenAI requires ~3,617 HGX A100 servers (28,936 GPUs) to serve Chat GPT. We estimate the cost per query to be 0.36 cents.” Source: <https://www.semianalysis.com/p/the-inference-cost-of-search-disruption> ; <https://archive.is/GA5CM>

-Metaculus predicts AI will beat Metaculus users at forecasting by 2035. Source:

<https://www.metaculus.com/questions/7024/ai-to-beat-humans-on-metaculus/> ; <https://archive.is/1oVSK>

- For fun, we'll ask chatGPT-3.5 a fanciful question in relation to Jim Keller's prediction in the quote above (with SRCM underlining added to the responses). We'll then ask chatGPT-4 Our question is: "*How much compute would be available if the entire earth were turned into a computer?*". To which Chat-GPT3.5 responded with: "It's difficult to provide a precise answer to this question as it involves several hypothetical assumptions and variables. However, we can make some rough estimates based on the current state of computing technology. According to a report published by OpenAI in 2018, the current compute power of the most powerful supercomputer in the world, the Summit supercomputer located in the US, is approximately 200 petaflops (200,000 trillion floating-point operations per second). If we assume that the entire Earth could be turned into a computer with similar or greater computing power density, we can estimate the total compute power available. The mass of the Earth is approximately 5.97×10^{24} kg. Assuming that we can use all this mass to build computing hardware, and assuming an energy efficiency similar to that of current supercomputers, we can estimate the theoretical maximum compute power to be in the range of 10^{32} to 10^{36} floating-point operations per second (FLOPS).

It's important to note that this is a highly speculative estimate, as it assumes that we could achieve perfect energy efficiency, cooling, and manufacturing technology to build such a massive computer, which is currently beyond our technological capabilities. Additionally, such a hypothetical scenario raises important ethical, environmental, and practical questions about the feasibility and desirability of transforming the entire Earth into a computer."

-GPT-4 Response to the same question was: "To estimate the amount of compute available if the entire Earth were turned into a computer, we need to make several assumptions and simplifications. Landauer's Principle: Landauer's principle states that there is a minimum amount of energy required to perform one irreversible computation. It is given by the formula: $E = kT \ln(2)$, where k is the Boltzmann constant (1.380649×10^{-23} J/K), T is the temperature in Kelvin, and $\ln(2)$ is the natural logarithm of 2. At room temperature (about 300 K), this yields a minimum energy of 2.9×10^{-21} Joules per bit operation. Earth's mass: The Earth's mass is approximately 5.972×10^{24} kg. Mass-energy equivalence: Using Einstein's famous equation, $E=mc^2$, we can convert Earth's mass to energy. The speed of light (c) is 2.998×10^8 m/s. Therefore, the total energy content of the Earth's mass is approximately 5.4×10^{41} Joules. Conversion efficiency: We need to assume an efficiency factor for converting mass into energy and then into computational power. For simplicity, let's assume 100% efficiency, even though this is unrealistic. Compute power: With the above assumptions, we can calculate the total number of bit operations that could be performed using the energy content of the Earth. We have a total energy of 5.4×10^{41} Joules, and each bit operation requires 2.9×10^{-21} Joules. Dividing the total energy by the energy per operation, we get approximately 1.86×10^{62} bit operations. Please note that this is a highly speculative and theoretical estimation that makes several unrealistic assumptions. Converting the Earth into a computer would not be feasible or practical, but this calculation offers an interesting thought experiment to illustrate the scale of potential computation.

(SRCM: Interesting responses and capabilities to say the least!). Sources: <https://chat.openai.com/chat?model=text-davinci-002-render-sha> ; <https://chat.openai.com/chat?model=gpt-4>

- That was too much fun and can't resist one more question/output! Below we ask for a brief history of the famous equation of exchange ($MV=PQ$). It gave an impressive answer though forgot to mention Newcomb (note our 2nd prompt asking about this omission and its impressive revised answer!). Again, underlines added by SRCM, not Chat-GPT. Prompt given by SRCM: "*give me a history of the equation of exchange?*". GPT-4 response: "The equation of exchange is a fundamental concept in macroeconomics that links the money supply, the velocity of money, the price level, and real output in an economy. The equation is often represented as: $MV = PT$ Where:

M = money supply

V = velocity of money (the average frequency a unit of money is spent in a given time period)

P = price level

T = real output (or the number of transactions)

The history of the equation of exchange can be traced back to several key figures and their contributions: David Hume (1711-1776): Scottish philosopher and economist David Hume is often credited with planting the seeds of the equation of exchange with his "quantity theory of money." Hume emphasized the relationship between the money supply and the price level, arguing that an increase in the money supply would lead to a proportional increase in prices.

John Stuart Mill (1806-1873): Mill built upon Hume's ideas and introduced the concept of the "equation of money and goods," which established a relationship between money, prices, and the volume of transactions. Mill's work laid the foundation for the modern equation of exchange.

Irving Fisher (1867-1947): American economist Irving Fisher is responsible for the most well-known version of the equation of exchange, which he derived from Mill's work. Fisher formalized the equation as $MV = PT$, which is still widely used today. He also introduced the concept of the velocity of money, which allowed for a more detailed analysis of the relationship between money supply, prices, and output.

John Maynard Keynes (1883-1946): Although not directly involved in the development of the equation of exchange, Keynes's theories on aggregate demand influenced how economists thought about the relationships within the equation. Keynes's work highlighted the importance of factors such as interest rates, expectations, and government spending, which affect the velocity of money and the level of output in an economy.

Milton Friedman (1912-2006): Friedman, a prominent advocate of monetarism, expanded on Fisher's equation of exchange by introducing the concept of the "natural rate of unemployment" and emphasizing the long-run relationship between money supply growth and inflation. Friedman argued that in the long run, changes in the money supply would primarily affect the price level, with only temporary effects on output and employment. The equation of exchange remains an essential tool in macroeconomic analysis, informing monetary policy decisions and helping economists understand the interplay between money supply, velocity, price levels, and output. While there have been many refinements to the equation over time, its core principles continue to guide economic thinking and policy.

SRCM followup prompt: *"what about the contribution of Simon Newcomb?"*

GPT-4 followup response: "Simon Newcomb (1835-1909) was a Canadian-American astronomer, mathematician, and economist who made significant contributions to the development of the equation of exchange. Although he is not as well-known as some other figures mentioned earlier, Newcomb's work played an important role in shaping the modern understanding of the relationship between money, prices, and economic activity. Newcomb's contributions to the equation of exchange are primarily found in his 1885 book "Principles of Political Economy." He built upon the ideas of Hume, Mill, and others by presenting a refined version of the equation of exchange, which he referred to as the "equation of the circulating medium." Newcomb's equation can be represented as:

$M = kPT$ Where:

M = money supply

k = a constant representing the proportion of money held in reserve (or not spent)

P = price level

T = real output (or the number of transactions)

Newcomb recognized the importance of considering the velocity of money and the proportion of money held in reserve when examining the relationship between money supply, prices, and output. He argued that an increase in the money supply would not necessarily lead to a proportional increase in prices if the proportion of money held in reserve also increased. This insight laid the groundwork for Irving Fisher's later development of the velocity of money concept (V) and the modern equation of exchange ($MV = PT$).

In addition to his work on the equation of exchange, Newcomb made important contributions to economic theory more broadly. He was among the first economists to emphasize the role of expectations in determining prices and interest rates, and his work on the "law of demand" helped to lay the foundation for modern demand theory."

Source: <https://chat.openai.com/chat?model=gpt-4> (retrieved on 3/31/23)

²¹⁰ Source: This is something like 30% to 35% annual growth from 1970 to 2022.

https://en.wikipedia.org/wiki/Transistor_count#Transistor_count ; <https://archive.is/k3QfK>

²¹¹ Source: <https://news.ycombinator.com/item?id=26911205> ; <https://archive.is/4By3Y>

²¹² Source: <https://www.eia.gov/totalenergy/data/monthly/> (Table D1 and Table 1.1)

²¹³ Metaculus has global energy consumption by 2100 standing at 988,000 TWh (or about a 2.3% annual growth from the [159,000 TWh used globally in 2021](https://www.metaculus.com/questions/6629/global-energy-consumption-2100/)). Source: <https://www.metaculus.com/questions/6629/global-energy-consumption-2100/> ; <https://archive.is/H7NC7>

²¹⁴ Source: <https://www.eia.gov/totalenergy/data/monthly/> (Table D1 and Table 1.1)

²¹⁵ - David Friedman notes that for every 1 foot rise in sea level, you lose on average about 100 feet of coastline land (water moves 100M inland on average for the South East United States. So you might loose 100m of coastline by the end of the century (if there's a 1m sea level rise). "The only place that is at risk is the Nile delta." || "If the IPCC is right, then by the end of the century, Minnesota will be as warm as Iowa is now, and that's not very scary" || "It may make sense to do something about the other air pollutant effects, as they are more likely real. And part of the reason I'm skeptical about this is because I was alive in the last round of fear, which was population. Back in the 1960s and 1970s, the population scare filled the exact same niche as climate change does now. (The Population Bomb explosion) was the looming catastrophe, that we had to do something drastic to prevent or terrible things

would happen (so we were told). And it didn't happen. Africa, which was supposed to be destroyed by population growth, is still pretty poor, but its *less* poor today than it was back then...and population went *up* by a lot in Africa (during that time frame)." Source: <https://www.youtube.com/watch?v=euL39f1kins> "Economist Dr. David Friedman is questioning whether global warming is a net negative."

- "The answer is clear. He finds that the net cost (to slow global warming) of waiting fifty years instead of taking the optimal actions now is \$4.1 trillion dollars. Spread out over the rest of the century, that comes to about \$48 billion/year, or about .06% of current world GNP. Which position is that closer to, that there is a need to panic and take drastic action or that there is not?" Source: <https://davidfriedman.blogspot.com/2014/03/acts-vs-words-case-of-nordhaus.html> ; <https://archive.is/OQe2u>

- "Bert Bolin, former chairman of the IPCC, notes that if Kyoto (signed in 1997 – aimed at cutting rich world emissions to 5.2% below 1990 baseline emissions) were fully implemented, twenty-five years later the global temperature would be cut "by less than 0.1 degree C, which would not be detectable." Lomborg estimates that the world climate will increase by 1.92°C by 2094 if nothing is done. *If Kyoto is fully followed, it will take six more years to reach the same temperature.* In other words, Kyoto will neither stop nor seriously slow climate change. We would need many times Kyoto to stabilize greenhouse gas concentrations in the atmosphere. Thus, it would cost several times Kyoto, more than 10 percent of our GDP, to stop the buildup of CO2 while, at the outside, climate change would cost only about 1 percent of U.S. income and could be beneficial." Source:

<https://www.econlib.org/library/Enc/GlobalWarmingABalanceSheet.html> ; <https://archive.is/ZAjHf>

- "Long, however, found increases of 12%, 13%, and 14% (rice, wheat, and soybeans) from an increase to 550 ppm from the ambient concentration, which implies an increase of about 17.5% for a doubling.4 Kimball 2016, a survey of FACE (Free-air CO2 Enrichment) studies of which Long is one, found that "Yields of C3 grain crops were increased on average about 19%" by increasing CO2 from 353 ppm to 550, which implies a 23% increase for a doubling." | "They found that a 1 ppm increase in CO2 equates to a 0.4%, 0.6%, 1% yield increase for corn, soybeans, and wheat, respectively" | "As I wrote in a book published fifteen years ago '... with a few exceptions, I have limited my discussion of the future to the next thirty years or so. That is roughly the point at which both AI and nanotech begin to matter. It is also long enough to permit technologies that have not yet attracted my attention to start to play an important role. Beyond that my crystal ball, badly blurred at best, becomes useless; the further future dissolves into mist. (Friedman 2008)'... Rennert sums costs over the next three centuries, with about two-thirds of the total coming after 2100. Their solution to the problem of predicting technological change over that period is, with the exception of their estimates of CO2 production and energy costs, to ignore it, implicitly assume technological stasis. That is the wrong solution, but any projection of technological change that far into the future would be science fiction not science. What they claim to do cannot be done." Source:

<http://www.davidfriedman.com/Ideas%20I/Climate/Critique%20of%20Rennert%20et%20al.pdf> "Critique of Rennert et al"

-Its important to look at the most fundamental source of the data, the Intergovernmental Panel on Climate Change Report. The AR5 report from 2014 lists the following for scenarios by the year 2100:

- At 430 to 480 ppm CO₂ eq: below 1.5°C as "More unlikely than likely"
- At 430 to 480 ppm CO₂ eq: below 2°C as "likely"
- At 480 to 530 ppm CO₂ eq: below 1.5°C as "unlikely"
- At 480 to 530 ppm CO₂ eq: below 2°C as either "more likely than not" or "about as likely as not"
- At 480 to 530 ppm CO₂ eq: below 3°C as "likely"
- At 530 to 650 ppm CO₂ eq: below 1.5°C as "unlikely"
- At 530 to 650 ppm CO₂ eq: below 2°C as "more unlikely than likely"
- At 530 to 650 ppm CO₂ eq: below 3°C as "likely"
- At 650 to 720 ppm CO₂ eq: below 2°C as "unlikely"
- At 650 to 720 ppm CO₂ eq: below 3°C as "more likely than not"
- At 650 to 720 ppm CO₂ eq: below 4°C as "likely"
- At 720 to 1000 ppm CO₂ eq: below 2°C as "unlikely"
- **At 720 to 1000 ppm CO₂ eq: below 3°C as "more unlikely than likely"**
- At 720 to 1000 ppm CO₂ eq: below 4°C as "likely"
- Over 1000 ppm CO₂ eq: below 3°C as "unlikely"
- Over 1000 ppm CO₂ eq: below 4°C as "more unlikely than likely" (Page 22)

“These incomplete estimates of global annual economic losses **for temperature increases of ~2.5°C above pre-industrial levels are between 0.2 and 2.0% of income (medium evidence, medium agreement)**” || “As a result, mitigation cost and climate damage estimates at any given temperature level cannot be compared to evaluate the costs and benefits of mitigation. Very little is known about the economic cost of warming above 3°C relative to the current temperature level.”

(Page 79) Source: https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

-Use both of the bolded above, a 3 degree rise at 720 to 1000ppm would cost only a bit more than the 2% of GDP that it would cost under a 2.5°C warming scenario. These costs in the year 2100 should be compared to today's cost to mitigate effects many decades from now – incorporating the time value of money, technological progress/cost reduction, etc. (SRCM Commentary)

-Direct from the Fourth National Climate Assessment (NCA2018) by US Global Change Research Program (USGCRP) there is an estimated Direct Damage to the U.S. Economy under various climate change scenarios. Under even the worst scenario (RCP8.5), at 5°F (not Celsius!) change, there is slightly more than 4% hit to G.D.P. In between 8°F and 9°F rise, there is a slightly less than 8% hit to G.D.P. Source: (Chapter 29, page 1360)

https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf “Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States.pdf”. Graph was reproduced, with original source: <https://www.science.org/doi/10.1126/science.aal4369> “Estimating economic damage from climate change in the United States” (2017) by Solomon Hsiang, et al.

²¹⁶ While we certainly don't agree with everything he says, David Friedman makes some interesting points below: “The problem with both the (over) population problem and the climate change problem, not only do we not know the net externality in each case, we don't even know its sign. We do not know, and can not know (probably), whether (on net) having someone else having more children makes us better off or worse off. Or whether on net, putting an extra bit of carbon dioxide into the air makes us better off or worse off. And that makes it very difficult to apply any of these rules (carbon tax, carbon pricing/cap and trade, etc.) for regulating it.” (17m20s to 17m53s) || “But we're talking about 3/10ths of a degree every decade (3 per century). That's a very slow change. Over 100 years, with or without global warming, farmers will have changed their crops multiple times over. Because people develop new types of crops, etc., especially now a days with genetic engineering. Tastes change, etc. Such that its implausible to think that even without global warming, the farmer wont change what he is growing.” || “Over 100 years, most buildings get replaced. Over that long a period of time, the fact that things are changing with regards to climate and with regards to sea level, is going to go along with a whole bunch of other reasons why people move, people find new construction techniques...costs of some things go up and some costs go down, meaning certain designs of houses make more sense” || “It therefore seems to me that the costs to build new housing due to global warming are sunk costs, but they aren't enormous costs” || “and if I had to guess, the net externality of global warming is positive, not negative...but that's very much a guess.” || “I think the only *predictable* negative externality is sea level rise. Sea level rises reduces by a little bit, the amount of usable land. But it's not clear that that's a *big* net negative effect. The Dutch after all, 300 or 400 years ago, managed to farm land below high tide. I've seen online that someone tried to work out online that costs of diking and it was a small number like .1% or something like that. So it's a cost, but it's a small cost” || “The human use of land is currently limited by cold, not by heat (i.e. the equator is populated, the poles are not). So that suggest that if you rise the temperature by 1 degree everywhere that (leaving aside sea level rise) the amount of usable land by humans goes up” (so a bit more of Canada is now usable). || “So what you're doing is adding quite large amounts of usable land as temperatures go up. (my rough) estimates where that the effect of increased (amt) availability of land (land gained) from warming is about 100 times more than the land lost due to flooding (from rising sea levels).” || “Global warming is predictably larger in cold places in cold times, than it is in warm places at warm times. And the reason for this goes back to the point about water vapor. Water vapor is a strong greenhouse gas (stronger per atom than CO2). The warmer the climate is at a place on average, the more water vapor is in the air. The more of one greenhouse gas is in the air, the *less* the effect of adding another greenhouse gas to it. So that means that, on average, in warm areas with high water vapor in the air, the amount that the temperatures go up will be small. And in cold areas, with little water vapor in the air, the temperature rise will be large. On the whole, warmth is a nice thing when its cold and not a nice thing when its hot. So that one respect in which global warming was in effect, designed for our benefit so to speak. It happens more in the places we like it and less in the places we don't like it.” || “global warming also means that the (crop) growing season is longer, meaning the amount of agricultural output for a given piece of land is bigger. (both in total land area increase as well as increased CO2 leading to higher crop yields due to increased photosynthesis)” || “The general problem is that we have externalities that have both positive and negative signs. These externalities

are large and uncertain. And therefore, it is hard to tell whether the net effective is either positive or negative. And its partly due to the fact that we're dealing with large periods of time. We don't know what the world will look like in 50- 100 years" || "There is a curious asymmetry to their approach. They took account of low probability high cost consequences of permitting global warming. But, so far as I could tell, they made no similar attempt to take account of low probability, high cost consequences of preventing global warming. That might make sense if we could be reasonably confident that, absent the effects of human action, climate would never change. But we have no grounds for such confidence, since climate has been changing, sometimes quite radically, since long before human beings were able to influence it. We are currently in an interglacial, a relatively warm period within an ice age that began more than two million years ago. We do not know what causes interglacials to start—or end. Long term estimates of global temperature suggest that it has been trending slowly down for a very long time, possibly since the beginning of the current interglacial, a trend reversed by current warming. *It is at least possible that global warming is all that is preventing the interglacial from ending.* The result, judging by past glaciations, would be a drop in sea level of more than three hundred feet, leaving every port in the world high and dry. *Also half a mile or so of ice over the present locations of London and Chicago.* I do not think the prevention of global warming would be likely to set off that catastrophe. It is, however, possible, and there may be other unlikely but possible catastrophes that have not occurred to me. Nordhaus, looking for negative effects of global warming, included the unlikely ones. He did not, so far as I can tell from that book, a later one, or correspondence with him—when writing this chapter I wanted to make sure that I had not misread his work—include any estimate of unlikely effects in the other direction. Which I take as evidence of the problem of using externality arguments to produce policy conclusions. When balancing costs and benefits, it is only too easy to put an unconscious thumb on the scale." (35m10a to 49m0s) Source: <https://youtu.be/s-yJ3K9fNos?t=868> "David Friedman "Global Warming, Population, and the Problem with Externality Arguments"

- Metaculus has sea level rising by 0.578 meters by 2100. Source: <https://www.metaculus.com/questions/7800/sea-level-rise-by-2100/> ; <https://archive.is/TiIGo>

- David Friedman expands further on this: "How accurately could somebody in 1900 have predicted what would matter to human life in 2000? What reason do we have to think we can do better?" || "It is hard to see any other reason to expect global warming to make us, on net, worse off. The earth and its climate were not, after all, designed for our convenience, so there is no good reason to believe that their current state is optimal for us. It is true that our species evolved to survive under then existing climatic conditions but, over the period for which humans have existed, climate has varied by considerably more than the changes being predicted for global warming. And, for the past many thousands of years, humans have lived and prospered over a range of climates much larger than the range that we expect the climate at any particular location to change by. If we have no good reason to believe that humans will be substantially worse off after global warming than before, we have no good reason to believe that it is worth bearing sizable costs to prevent global warming." Source (written back in 2011):

<http://davidfriedman.blogspot.nl/2011/09/what-is-wrong-with-global-warming.html> ; <https://archive.is/P3luF>

- David Friedman on climate change: "I wouldn't worry a lot about promises for the next 50 years. The Chinese are rapidly building coal power facilities, meanwhile they are promising that at some future date they going to cut down their CO2." || "The IPCC emissions estimates has emissions roughly doubling by the end of the century. And doubling CO2 concentration increases the yield of most crops by about 30%. It turns out that there are two different versions of photosynthesis used by crops, and C3 is the main one (and it increases by about 30%). C4 is the more efficient, and less common photosynthesis path. And it also increases by something a bit less than 30%. There are two important crops that are C4 and those are maize and sugar cane. All the other major crops are C3. So that means what they are describing is that, what they are describing (doubling of CO2 concentration) will increase crop yields, all else held constant, by something like 20% to 30%." || "If you work out the physics of green house effect warming, the effect is larger in cold times and cold places than in hot times and in hot places. That's why the poles are warming a good deal. And that has to do with the interaction of water vapor. Water Vapor is also a green house gas. The more of one green gas there is, the less effect of adding another will have. And the warmer it is, the more water vapor is in the air. And I should say, I got that from a book by a Nobel prize winning physicist who pointed out that fact." || "And the sea level rise is a pretty wimpy problem if you actually look at it. The IPCC high emissions estimate (Which is probably too high), that yields a rise in sea levels of about a meter by the end of the century. That's about half the distance between high tide and low tide. It depends on where you are but on an old study on the Southeast of the United States, they found that for every foot the sea level rose, the coast moved in by something like 100 feet. So, you're talking about, at least for places like the southeast United States, shifting coasts maybe something like 100 meters by the end of the century. That's a tiny effect. Now there are a few places that

will be worse off. As far I can tell, the only place that is at severe risk of a sea level rise is the Nile River delta. Its very low riding, and you actually shove that in quite a lot and displace a lot of people.” || “The way I like to put it is: if the IPCC is right, then Minnesota, by 2100, will be as warm as Iowa is now. And that’s not very scary. So, in my view it does not make sense to do a bunch of things to avoid climate change. *It may make sense to do things to avoid the other air pollution effects; those are probably more nearly real.* Part of the reason (I’m skeptical) is because I was around in the last round (of global worry/fear), and that was population. Back in the 1960s and 1970s, overpopulation (fears) filled almost the exact same niche that climate change fills now. That was the looming catastrophe that we had to prevent, or else terrible things will happen. *And it didn’t happen.* And we didn’t do those things, and nothing happened. Africa, which was supposed to be destroyed by population growth, is still pretty poor now, but it is *less* poor now that it was then, and population *went up* by a lot in Africa.” || “But diking is not a perfect solution, because there are rivers. And a dike pulls the ocean back, but you also have to worry about some sort of diking along the rivers, which are going to be higher as a result of this.” Source:

<https://www.youtube.com/watch?v=euL39fIkins> “Economist Dr. David Friedman is questioning whether global warming is a net negative.”

-David Friedman on climate change costs (acting now or waiting): “What he (William Nordhaus) does not mention is that his \$4.1 trillion is a cost summed over the entire globe and the rest of the century. Put in annual terms, that comes to about \$48 billion a year, a less impressive number. Current world GNP is about \$85 trillion/year. So, the annual net cost of waiting, on Nordhaus's own numbers, is about one twentieth of one percent of world GNP. Not precisely a catastrophe. I suggest a simple experiment. Let Nordhaus write a piece explicitly arguing that the net cost of waiting is about .06% of world GNP and see whether it is more popular with the supporters or the critics of his position.” Source: <https://davidfriedman.blogspot.com/2014/03/contra-nordhaus.html> ; <https://archive.is/HFKdp>.

Not directly related to above quote, but related based on topic (written back in 2012):

<http://davidfriedman.blogspot.nl/2012/03/nordhaus-on-global-warming.html> ; <https://archive.is/1A8wZ>

-Freeman Dyson also opines: “You ought to enjoy being in the minority” || “I mean latterly speaking its true...man made climate change is certainly real. There’s no doubt it’s real. And the question is ‘how much, and whether it (climate change) is good or bad?’. And those are quite separate questions (from whether its real or not). I would say on the whole it (climate change) is good. And (the climate change) is not as large as most people imagine.” Source: 20m50s to 21m52s at <https://www.youtube.com/watch?v=BQHhDxRuTkI> “Carbon Dioxide is Making The World Greener (w/ Freeman Dyson, Institute for Advanced Studies)”.

- On the other side of the debate we quote Andrew Dressler: “I think what he (Alex Epstein) is referring to is the fact that its logarithmic. For every doubling of Carbon dioxide emitted, each ton emitted gives you less and less warming. It’s not an S curve, its logarithmic” (10m20s) || “I have to say, it would be hard for to get 5 degrees of warming by the end of the century. You’d have to burn every hydrocarbon. Instead, we are track for about 3 degrees of warming by 2100. But if we listen to people who say we should burn *more* fossil fuels, then we will go above that 3 degrees of warming (the 3 degrees of warming assume we go to net zero *later* in the century – 2050 or 2060).” (24m50s) || China is building more coal plants, but the utilization is going down (Coal plant utilization in China dropped from 57 in% in 2010 to 45% in 2020) “China is on track to meet its 2030 emissions goal” (1h23m25s) || “*at 70% wind and/or solar, then things begin to change. Adding more renewables doesn’t give you any more value.* You can’t retire anymore coal plants (or fossil fuel plants). Because you need the coal plants to counter the intermittency (of wind and solar). Nobody says ‘let’s run a grid that is 100% wind and solar with no backup. It is theoretically possible, but you’d have to overbuild so much extra power, that it would be cost prohibitive. *So, the cheapest grid is something that is 70% wind and solar, and 30% some kind of special power. Now you don’t want (that 30%) to be coal. (That 30%) could be Nuclear, it be geothermal, it could be natural gas with carbon capture...something that is used to counterbalance (the intermittency).* Even nuclear, which is very expensive, makes sense if it is generating say 15% of your power. Even at \$6,000/kilowatt, which is about what nuclear costs now, it still makes sense to dispatch nuclear. You can ramp nuclear up and down.” (1h29m15s) (SRCM: important to remember that even if 70% of electric grid is made up of renewables, only 30% of so of emissions come from electricity (see figure 28). So going from 0% renewables on the grid, to 70% renewables on the gride would reduce *total* emissions by about 20%) || “I have hope for small modular nuclear reactors and geothermal” (1h34m30s). Source: <https://youtu.be/T9HItSLJNEs> “The Moral Case for Renewable Energy with Andrew Dessler”.

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