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The Coming Commodity Super Cycle

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Abstract

A commodity super cycle is forming today. It will last 7–10 years. It will peak in this decade. Primary drivers are growing energy and material demand, supply tightness, under-investment in long-term oil, gas, and nuclear projects, malinvestments in low energy return on investment (EROI) power sources, unrealistic net zero goals, environmental opposition, and the US Federal debt.

The super cycle will be driven by supply-and-demand imbalance, but it will be supercharged by the malinvestment of capital to low-EROI green power sources like wind and solar. This malinvestment comes at the expense of high-EROI energy sources of oil and gas or nuclear. In addition, the US, and other countries, are prematurely turning off the only high-EROI green power source available, nuclear power. US monetary and fiscal policy will contribute to the super cycle by spurring inflation. Throughout history, the Organization of Petroleum Exporting Countries (OPEC) have adjusted nominal prices to maintain purchasing power against inflation.

Demand for oil continues to grow and is expected to hit 101.9 million barrels of oil per day in 2023. Key OPEC countries have admitted they are near pumping capacity and have warned non-OPEC countries to invest in long-term oil and gas projects. Cumulative underinvestment in oil and gas over the last 10 years could be $2 trillion. Record low discoveries in 2021 reflect this underinvestment.

US nuclear power capacity is down 5%. Six nuclear power plants totaling 4736 megawatts (MW) have been retired since 2017.

Environmental, social, and corporate governance (ESG) and antihydrocarbon non-governmental organizations (NGOs) have forced capital into low-EROI projects. Biofuels, solar, and wind projects return little energy. Biofuels return less 2 times the energy invested. The buffered EROI for wind is 8, and the buffered EROI for solar is 2. Gas and coal have EROIs of 30. Nuclear is 75.

Wind and solar are extraordinarily expensive power sources compared to a Haynesville gas well. Solar cost costs 16 times a single Haynesville well, wind costs 4 times a Haynesville well for the same power output. Green energy’s astronomical costs will bring “greenflation.”

Net zero goals are unrealistic and policies are incoherent: mandate electric vehicles by 2035 but ban copper, nickel, and cobalt mining in Minnesota; demand green energy but prematurely shut down CO_2 free nuclear power in New York. Well designed studies for a path to net zero by 2050 show the US will need 17 million acres of solar farms (with 9 billion photovoltaic cells), 1.5 million wind turbines, plus 5.2 fold increase in the power grid. The cost to 2030 alone is $2.5 trillion—before the majority of the build-out.

All energy transition mines in the US are either banned, stalled, or being litigated. World mineral deposits are past “peak minerals.” Ore grades for copper are below 1% around the planet. Social license for solar and wind machines is waning because of their enormous footprint and impact on rural stakeholders. Over 480 solar and wind power plants have been banned.

Energy prices are a major cost in making the material-intensive machines to capture wind and solar power. Rising energy prices and the rising cost of money are driving up the cost of green energy machines and making them uneconomic.

Monetary and fiscal policy will play a key role in the super cycle. Every energy transition scenario relies on federal money. US debt is now 120% of gross domestic product (GDP) and interest payments on the federal debt is consuming federal revenue. Growing federal debt by deficit spending on green projects will spawn inflation.

Near term, oil prices will settle in $85–140 range, but excursions over $200 should be expected. Longer term, $200 oil might become the price floor. Natural gas prices in the US will rise towards prices in Europe and Japan, circa $20/thousand cubic feet until Congress gets involved.

Introduction

Smil (2010, 2017) made clear that energy transitions throughout human history take 40 to 60 years. A new energy source never completely replaces the old one. It was 100 years after Drake’s oil well before oil displaced coal as the dominant energy source in 1960. Yet today, 3 times more coal is consumed than in 1960.

Most importantly, Dr. Smil showed that throughout human history, energy transitions are always to more dense forms of energy with more efficient machines. This trend is facilitated by surplus energy and economics. Surplus energy, and its attendant profits, are a natural guide that leads to the new energy system adaptation.

The coming collision between an unnatural energy transition and traditional energy sources (oil, gas, nuclear) will transform a typical energy boom into a commodity super cycle.

The traditional energy industry has been in a downturn since the collapse of oil prices in late 2014. Capital has been slow to return because investors got burned when companies went bankrupt. Many operators focused on growing their production profile at the expense of returning cash to investors. Investors are reluctant to return. In other words, it was a typical “down cycle” in the industry.

Today, we are at the end of the “down cycle.” Oil and gas markets are very tight. In 2021, energy prices spiked in Europe. In the United Kingdom, fertilizer plants were closed and two dozen utilities went out of business. In 2022, a shooting war began in Ukraine. North Atlantic Treaty Organization (NATO) allies are fighting a proxy war with Russia. Russia has used its energy as a weapon. European NATO allies are starved for energy. Saudi Aribia has openly admitted it is near its pumping capacity. Normally, these events would translate into a traditional energy “boom” with a frenzy of drilling and capital flowing into energy project. This is not happening.

Instead, an unnatural energy transition unlike anything Smil (2010, 2017) has described is being advocated. Environmental, social, and corporate governance (ESG) has captivated Wall Street. Politicians, non-governmental organizations (NGOs), and Wall Street fund managers, with rare exceptions, talk of an energy transition that will be completed in 27 years and for which, by most accounts, only biofuels, wind, and solar will be used, irrespective of their inefficiency. Nuclear power gets limited support. This energy transition will require an unnatural move to less dense energy sources using less efficient machines that require more materials per terawatt-hour than oil, gas, or nuclear power (Figure 1)

America is trying to electrify its economy by moving to the lowest density, lowest energy return on investment (EROI) electricity sources, wind, solar, biofuels, which cost the most and require the most energy. The obsession with the energy transition to the exclusion of all other concerns is disturbing because history shows that energy transitions fail. The seven energy transitions predicted since President Carter’s time have all failed to materialize (Figure 2). It is probably because they are not energetically favored. The only way an energy transition to less-efficient sources can happen is if government subsidizes low-EROI sources like wind and solar (Goehring and Rozencwajg, 2020a). Oil and natural gas are being vilified today, but this vilification is actually detrimental to a green energy transition (Sharma, 2021).

The cause of the coming super cycle is that global petroleum supplies are at their limit even as demand continues to grow. But today, in the name of ESG and “saving the planet,” people and policies are doing exactly the wrong thing at exactly the wrong time: we are turning off oil, gas, and nuclear energy faster than low-EROI green machines can possibly be built to fill the coming energy demand. Utility operators are waking up to the fact that by 2030, wind and solar will only replace 50% of the power lost from retiring fossil fuel power plants (PJM, 2023).

Mines for energy transition minerals are being blocked by the very administration that espouses that all cars should be electric vehicles (EV) by 2035. And in the meantime, billions are being lavished on green energy projects through federal largess and ESG investing that is causing increase demand for materials. This has the knock-on effect of depriving much needed capital for high energy density, high-EROI sources like oil, gas, and nuclear.

This paper is not proposing that green policies will create the commodity super cycle. This paper posits that a bullish commodity cycle has been brewing since 2014. Supply, demand, and underinvestment are the underlying drivers. However, current green policies and ESG directed funding will make the coming bullish commodity cycle much worse “just another boom” in the oil business.

An important factor that stands outside of the conflict between tradition energy and the energy transition is inflation. The national debt drives inflation and inflation drives commodity prices (DeMis, 1996). The US debt is now 120% of gross domestic product (GDP). The government’s only means of paying for green projects is by printing money.

These complex factors are creating a perfect storm of energy and material shortages that begat spiking prices and commodity scarcity that limits economic activity — a commodity super cycle.

This paper proposes spiking prices, so an estimate of future prices is provided for completeness using an historical context (DeMis, 1996, 2000, 2021).

This paper does not question the need for an energy transition, or the need to arrest anthropogenic global warming. This is not a prescriptive paper on how to fix the climate problem. This paper is focused on the unintended but completely foreseeable energy crisis that is forming today because of supply-demand imbalance, underinvestment, malinvestment, monetary and fiscal policy colliding with an obsession with green energy and ESG to the point of energy myopia. The result of this crisis will be that an all-of-the above energy policy will be adopted.

Demand

The most accurate predictions for global oil demand through Covid-induced drop have come from OPEC (Figure 3). Demand is still rebounding after Covid. Oil demand is expected to rise to 101.7 million barrels of oil per day in 2023 (Blackmore, 2023). Energy Information Administration (EIA) projects US dry gas production will be 100.34 billion cubic feet of gas per day in 2023 (Reuters, 2023).

China abolished its Zero Covid policy of strict lockdowns in December 2022 (Feng, 2022). China's oil demand is projected to recover and grow by 2 million barrels a day by end 2023 (Oil and Gas Journal, 2023). In addition, Europe now needs to replace 2 million barrels of oil per day of Russian crude that it has banned (Reuters, 2022).

Continued growth in population, and in global economies, means increasing energy demand. Since 2000, Organization for Economic Cooperation and Development (OECD) countries have seen their per capita energy demand fall by 10%. The drop is because OECD countries have moved their energy-intensive industries to non–OECD countries (Cembalest, 2021) (Figure 4). Over the same time, non–OECD countries' per capita energy demand grew by 65% (Goehring and Rozencwajg, 2022a).

Despite strong demand growth, non–OECD energy demand is still only 70% of OECD demand. Non–OECD per capita GDP is expected to double over the next 20 years, meaning continued growth of energy demand (Goehring and Rozencwajg, 2022a). Oddly, International Energy Agency (IEA) projects non–OECD per capita energy demand *will fall by 20%* as these countries modernize. This projection is incongruous with history. If the historic per-capita energy consumption were cut in half and projected out to 2040, the doubling of non–OECD GDPs by 2040 would result in energy demand *growing by 30%, not falling by 20%* as posited by IEA (ibid).

IEA Goof on Demand

The IEA's May 17, 2021, "Net Zero by 2050" (IEA, 2021a) reported was a prescriptive scenario that suggested companies should end looking for new oil and gas fields, and that demand would fall consistently after Covid passed. The IEA goof is still being repeated by some who think consumption will fall (Figure 3), and oil companies need not worry about future exploration. An IEA spokesman has since confessed to IEA ethnocentrism saying, “It is difficult to imagine a business-as-usual approach in today’s circumstances” (Lee, 2021). IEA actions have hurt people, companies, economies, and possibly started a war by misrepresenting the world’s coming energy demand.

The IEA was formed after the 1973 oil embargo and its single purpose is to prevent energy shortfalls. It failed miserably in Europe in 2020 and 2021. Natural gas prices in Europe rose 3 fold by 2021 (Figure 5), and dozens of utilities went bankrupt in the United Kingdom because of the energy crisis in 2021 (Cyrus, 2021). The UK lacked for natural gas and other fossil fuels.

Europe’s energy crisis was in full swing before the Ukraine War. One could reasonably argue that Vladimir Putin saw Europe’s energy crisis and concluded that Europe was far too addicted to his Russian oil and gas to do much if he invaded Ukraine (author’s speculation).

Supply Tightness

Oil inventories in the US and the OECD are at historic lows (Figures 6 and 7). American oil demand cannot be supplemented by more releases from the strategic petroleum reserve because the supplies are at historic lows (Figure 8).

OPEC output has been declining (Figure 9). Key OPEC countries reported last summer their production is nearly maxed out. Saudi Arabia has about 1 million barrels of spare capacity (Paraskova, 2022) and the UAE has about 400,000 barrels per day of spare capacity (Reuters, 2022). A study commissioned by OPEC predicts that spare capacity will fall to 400,000 barrels per day by 2024 (Faucon and Said, 2022). To put today’s current spare capacity in an historical context, Yergin (1991) estimated that in 1973, just before the oil prices tripled, the surplus oil capacity was 500,000 barrels per day, or 1% of global consumption. Spare capacity today 1.5% of global consumption.

Saudi Aramco’s CEO, Amin Nasser, explicitly warned on CNBC News that without additional global investment in oil there will be a shortfall in supply, “…you need additional investment elsewhere globally to meet demand” (Turak, 2023). Aramco’s position cannot be dismissed as provincial or ignoring the coming energy transition. “Saudi Arabia and many of its partners in OPEC … have repeatedly called for *simultaneous investment in hydrocarbons and in the energy transition* to avoid a future supply squeeze” (emphasis added; ibid).

A good sign of a coming energy shortage is when the leaders of the world’s oil cartel start telling their competition that they need to invest in more oil and gas. Put another way: when was the last time the De Beers diamond cartel said the world needed more diamond mines?

The shale revolution was possible because of cheap money, oceans of private equity, low inflation, and a minimal concern for shareholder’s return on capital. Marathon Oil's CEO admitted to attendees at CERAWeek in 2019 that the industry “destroyed a lot of trust in the investment community over the last decade.” US shale drillers are cutting back on spending to deliver *returns* for shareholders (DiChirstopher, 2019).

The fantastic growth in US production came at the ruin of many private equity (PE) investors. By 2016, 70 companies went into bankruptcy when the music stopped (Resnick-Ault and Nair, 2020). Many people now seem to think “shale production” are magic words that will increase

US production by their mere utterance. Some politicians are asking, "How soon can shale production ramp up to bring lower prices at the pump?"

Shale production cannot grow forever. The four biggest US shale gas plays are shown in Figure 10. The Barnette and Fayetteville have passed their peak. Marcellus production is predicted to "roll over" in early 2025, and the Haynesville production might also "roll over" as soon as 2024 (Goehring and Rozencwajg, 2022a). The Marcellus is capacity-stranded because additional pipelines have been canceled or indefinitely postponed.

Natural Gas for Europe and US Blocked

President Biden pledged US will provide Europe the natural gas it needs after the Ukraine War. The administration has done less than nothing to facilitate natural gas pipelines to bring natural gas to the Atlantic coast for export to Europe. He canceled the ability to transport liquified natural gas (LNG) by rail, which killed the New Fortress LNG facility in Wyalusing, Pennsylvania (Coates and Stefano, 2022).

Marcellus gas is the best resource to make good on Biden's pledge to supply Europe. But the Marcellus is land-locked by opposition to any pipeline. The Constitution Pipeline was blocked by Earthjustice to preserve "clean water and our climate" (Nasmith, 2020). Earthjustice contended that "The project also would have increased demand for fracked gas, locking in more climate pollution."

This statement is green propaganda because the pipeline would have brought natural gas to the Northeast for winter heating, displacing the more-polluting oil that is used to heat homes. Over 30 studies, including by the Environmental Protection Agency (EPA) and the US Geological Survey (USGS), have found no evidence of ground water pollution attributable to fracking anywhere (Whitehead, 2017).

The Mountain Valley pipeline is being actively opposed by the Natural Resources Defense Council (Greenfield, 2021). It could deliver 2 BCFG per day from the Marcellus and other shale gas plays to Virginia for export. It is still not completed.

Nuclear Power Supply Dropping

Nuclear power has the best safety record of any energy source (Energy for Humanity, 2023) and requires the least amount of material (Figure 1). Nuclear power is a critical source of carbon-free electricity. The UK has made nuclear power an important leg of its energy transition, Europe now considers nuclear power sustainable energy, and the US Department of Energy (DOE) allocated $6 billion to keep nuclear plants running (DOE, 2021). Albeit the US and Germany have been prematurely turning off this clean energy supply.

US nuclear power capacity has dropped from 102 to 95.7 GW since 2018 (IEA, 2022). Six nuclear power plants with a capacity of 4736 megawatts (MW) have been retired since 2017. Three more reactors with a combined 3009 MW of capacity are scheduled to be retired in the coming year (ibid). Nuclear power supply is declining at the very time the US needs it to serve as the 24/7 baseload power that wind and solar cannot supply (Goldman Sachs, 2022).

Replacing nuclear power with solar and wind increases electricity costs and increases greenhouse gas emissions (Shellenberger, 2018; Storrow, 2022).

New York State prematurely shut down the Indian Point Nuclear power plant and removed 2069 MW of power generation. To replace Indian Point, New York will need 2,068 three-megawatt wind turbines that cover 250,000 acres. (Analysis assumes 90% efficiency of nuclear plant and 30% efficiency of wind turbines.) But even that wind power would need 24/7 backup power for the grid.

Today, 89% of New York's downstate electricity comes from fossil fuels, electricity rates are skyrocketing, and electricity-related greenhouse gas emissions are up 15% to 30% (Meigs, 2022; Storrow, 2022). Worse still, but completely predictable, New York's grid operator warned that the grid's "reliability margins will shrink in upcoming years" (Meigs, 2022). Translation: more blackouts in the future.

Germany turned off 14 nuclear power plants and adopted wind and solar. It then had the same problem: green power failed to provide Germany's energy needs. By 2020, Russia supplied half of Germany's natural gas and a third of its oil as Germany continued to gobble up coal (Wintour, 2022). Former German finance minister, Wolfgang Schäuble, now admits "We were all wrong" (Oberhaus, 2020). Germany is still debating what to do with its 3 remaining nuclear power plants but they will remain until April, 2023 at this writing (World Nuclear Association, 2022).

Germany's CO_2 emissions increased when it "went green." The National Bureau of Economic Research showed that Germany's nuclear power was replaced with coal power, that each year released of an additional 36 million tons of CO_2 (cited in Oberhaus [2020]).

Underinvestment

Underinvestment in oil and gas over the last 10 years resulted in record-low new field discoveries in 2021 (Figure 11). Total recoverable oil fell an astounding 9% in 2022 (Rystad Energy, 2022). This shortfall is "threatening global energy security" (ibid).

All commodities have been underfunded and are so greatly out of favor that their percent of the Dow Jones Industrial Average is at century low (Figure 12). All commodities go through cycles. But even today, after somewhat of a recovery after 2020, commodities as a percent of the Dow are still below 1972 levels. Today looks very similar to early 1970s, just before commodity boom of the 1970s (DeMis, 2021; Goehring and Rozencwajg, 2020b).

Certainly, low commodity prices and the poor returns from the energy sector after 2014 have contributed to underinvestment. But the advent of the ESG movement late in an industry "down cycle" has been diverting capital from oil and gas projects to inferior green projects.

ESG strongly disfavors oil and gas companies. Fitch is one of the three major rating agencies on Wall Street. It pushes down oil and gas companies' EGS scores. The company admitted that "Oil production will be among the sectors most severely affected by long-term ESG trends, second only to coal" (Fitch, 2021). A big part of any company's ESG score is how well a company adjusts to the IEA's "sustainable oil scenario" that projects oil demand at 25 million barrels per day in 2050 (ibid).

Companies list their stock on Wall Street to gain access to raise capital to conduct business. Low ESG rating influence oil stock prices. In 2022, energy exchange traded funds (ETFs) saw more net selling than buying even though the energy sector was the best performing sector in the S&P 500 for the year (Goehring and Rozencwajg, 2023). In fact, the energy sector was the only S&P sector to have a gain for the year (Anderson, 2022)!

ESG advocates with money are flexing their votes, and they admit it. Chris Ailman, Chief Investment Officer, California State Teachers' Retirement System stated in a press release, "We want [Exxon] to change from within. They need to wake up and recognize the future is different. Get out of the oil and gas focus" (cited in Goehring and Rozencwajg [2021]).

Special purpose acquisition companies (SPACs) are odd ducks even by Wall Street standards. SPACs do not have any assets when they go public on the stock market. They are also called "blank check" companies. Green SPACs have a mandate to acquire as-of-yet unidentified green energy assets. The good folks selling green SPACs tell the investors their green, ESG goals and say, "Trust us, we will buy the assets after you give us the money."

Green SPACs raised $40 billion in 2020 on these vague promises. Conversely, in the same year, oil and gas companies raised only $5.2 billion to develop their known existing oil and gas assets that they already owned (Goehring and Rozencwajg, 2020b).

The underinvestment theme is echoed by Morgan Stanley Chief Global Strategist, Ruchir Sharma. Writing in the Financial Times, "One broker recently wrote that of his firm's 400 institutional clients, only one was still willing to invest in oil and gas." (Sharma, 2021).

Cheap and abundant energy is needed for an energy transition because the machines for wind, solar and nuclear power need energy to build. Strangling oil and gas investments prematurely will make the energy transition more expensive and will force it to take longer (Sharma, 2021).

Mr. Sharma (2021) further contended,
"Building green economies will consume more oil in the transition period, but (oil) producers are not responding the same way *because political and regulatory resistance has darkened the future of fossil fuels*. Even as oil prices rise, investment by the big hydrocarbon companies and countries continues to fall. Instead, oil powers are reinventing themselves as clean energy powers" (emphasis added).

Legacy oil companies' evolution into "clean energy producers" might be caused by ESG groups like Engine No. 1 and CalPERS. After they get positions on the company's board, they force oil companies to take on green projects that are outside their expertise. Engine No. 1's mandate is to "reduce Exxon's carbon footprint by curtailing capital investments into its upstream oil and gas businesses." (Goehring and Rozencwajg, 2022a). ESG has a willful agenda to move money out of oil and gas and into green projects.

A Dutch court ruled that Royal Dutch Shell must cut its CO_2 output by 45% by 2030 to align with the Paris Climate Accord. Shell said, "We are investing billions of dollars in low-carbon energy, including electric vehicle charging, hydrogen, renewable and biofuels." Thus, Shell's upstream oil and gas business will be capital-starved because the billions for low-carbon projects will have to come out oil and gas exploration (Goehring and Rozencwajg, 2022a).

In 2020 alone, $700 billion went to ESG investments that deliver very little energy for the cost (Goehring and Rozencwajg, 2022b). Cumulative underinvestment since 2005 is estimated to be $2 trillion (Rozencwajg, 2022). Major oil and gas companies have waited too long to make long-term investments in green-field projects and their reserves have markedly dropped in 20 years (Figure 13). Under-investment does just not mean "drilling a well." The biggest underinvestment problem is that long-term, new-field exploration for oil and gas has not been undertaken.

Long-term plans for nuclear power plants are also not being readied today for tomorrow's energy needs. The DOE allocated 6 billion dollars for a program to keep current nuclear power plants operating (DOE, 2021), but there continues to be green pushback against nuclear power (e.g., Green America, undated) that can have terrible consequences such as Indian Point's closure.

Malinvestment and EROI

EROI measures the multiples of energy returned on the energy invested. ESG driven malinvestment is forcing money to low-EROI green projects (like wind and solar) that cannot meet future energy needs for baseload power (Goldman Sachs, 2022; Rozencwajg, 2022).

Energy is more than the basis of the economy. Surplus energy is the basis of modern civilization. For 1700 years, humanity lived in a feudal, subsistence agrarian economy because the only fuels available, wood and dung, had a low EROI of 5 (Rozencwajg, 2022). Society did not change for 1700 years. The adoption of coal with a higher EROI of 10 in the 1700's made the industrial revolution possible (ibid).

Subsequent energy EROI increases gave birth to the first-world world civilization of today. This social and economic evolution is entirely depended on developing fuels with ever-higher EROIs: wood and dung were replaced by coal, then oil, then natural gas, then nuclear (Rozencwajg, 2022). The list of fuel is a list of their EROIs in increasing order: coal, 10; oil and gas, 40; and nuclear, 75.

EROI Numbers

EROI varies across energy sources (Figure 14). An EROI of 7 is considered the economic limit. Wind and solar power require 24/7 back-up power, and their levelized cost of electricity is high when this defect is accounted for (Goldman Sachs, 2022, p. 8). Correcting for this deficiency gives the "buffered" EROI.

All weather-dependent power sources have buffered EROIs that are lower than the manufacturer's 'nameplate' EROI. Hydropower has a buffered "EROI" because it is affected by droughts, such as California's hydroelectric power loss during droughts (EIA, 2021a). Gas, coal, and nuclear do not have "buffered" EROIs because their energy is not controlled by the weather. They run 24/7.

Figure 14 is modified from Weissbach et al. (2013) and Wang et al. (2021). Since Weissbach et al.'s (2013) research, many "advocacy research" papers have published unreasonable EROI numbers in putatively "peer reviewed" journals. Some researchers provide absurdly high-EROI numbers for electricity generated by wind and solar and risibly low numbers for natural gas and nuclear power (e.g., Inman, 2013). Hall et al. (2013, their figure 3) showed natural gas and nuclear EROIs that are lower than EROIs for wind and on a par with solar's EROI.

Writing in Scientific American, Inman (2013) stated, "EROI of oil and natural gas (are) 20 at the wellhead and adjusted to take into account the typical efficiency of a natural gas power plant, around 40 percent to 45 percent." Inman (2013) implied the EROI of oil and gas is 10 in electricity generation.

Inman's (2013) analysis assumed that EROI is based only on electricity generating capacity. This assumption is false. Only 38% of natural gas is used for electrical generation (EIA, 2022b). Natural gas provides thermal energy to make fiberglass used in wind turbine blades. Fiberglass fabrication requires temperatures of 1270°C/3128°F (Gardiner, 2022).

Inman (2013) also suggested that nuclear power's high EROI of 75 was generated by nuclear industry researchers and therefore this makes the number suspect. However, Inman (2013) does not extend his suspicion of researcher's motives when ridiculously low-EROI numbers are put forth by environmentalists for oil, gas, and nuclear (e.g., Hall et al, 2013).

EROI have become a political/environmental football. But common-sense can be applied to sift out the real EROI number from "advocacy" numbers. First ask yourself: "If solar, wind, or biofuels had high EROIs, why do they need government subsidies?"

Compare the amount of material for solar and wind versus that for natural gas and nuclear (Figure 1). The data are from DOE—not from the Natural Resource Defense Council or the Sierra Club. The massive amounts of steel, iron, glass and other material used in wind and solar vs. natural power plants tells you by common sense that a lot more energy is used in fabrication of solar and wind machines than for natural gas or nuclear power. (More on this below.)

Next, compare the megawatt-hours produced for each million dollars invested (Figure 15). A generic shale gas well produces 5.8 times more electricity than wind, and 8 times more electricity than solar for each $1 million dollars invested. From looking at these two graphs, does it seem reasonable that a solar power plant would have higher EROI than natural gas?

Below are back-of-the envelope calculations of the power output for biodiesel, and for solar and wind compared to a Haynesville gas well. The data show broadly that the "advocacy research" EROIs are not consistent with common sense.

Malinvestment—Biodiesel

One energy company acquired a biodiesel company for $3 billion. Biodiesel has an EROI of about 2 (Wang et al., 2021; Inman, 2013). If the company had invested the $3 billion in drilling horizontal wells in the Permian basin it would have produced 5.5 times more power than biofuels in the first 4 years, assuming a EROI of 3 for biodiesel (Rozencwajg, 2022) (Figure 16).

Biodiesel has more problems than just a low EROI. Farming for biodiesel feedstock crops displaces land used for food production. Biodiesel requires massive amounts of petrochemicals to grow biodiesel crops. Agricultural petrochemical runoff produces the Gulf of Mexico Hypoxic Zone, commonly called the “dead zone” (NOAA [National Oceanic and Atmospheric Administration], 2017, 2020). According to NOAA, the Gulf of Mexico hypoxic zone is caused by “agricultural runoff combined with urban runoff that (make) the Gulf turn deadly” (NOAA, 2020). The other problem is that biodiesel might not actually reduce CO_2 emissions. As reported in USA Today, National Renewable Energy Laboratory (NREL) scientist Jordan Macknick said that corn production results in a “net addition of greenhouse gases to the atmosphere” (Petersen, 2021).

Thus, biodiesel cannot give a good return on energy (or money) investment; and it may not even reduce greenhouse gas (GHG) emissions but it contributes to the dead zone in the Gulf of Mexico. In other words, it is a malinvestment.

Malinvestment—Solar

The Roserock solar farm in Pecos County, Texas, is an excellent example of the malinvestment in energy and suggests the cost to power the nation’s grid with solar would be impossibly high. Roserock cost $405.259 million (Power Technology, 2021). It has an installed capacity of 212 MW, an annual power output of 362 GW–hour/year and covers 1300 acres (Wikipedia, 2023). Roserock has a 20 year service contract, according to ERCOT’s webpage (ercot.com).

Roserock contains 700,000 Canadian Solar CS6X–P photovoltaic (PV) solar panels (Roselund, 2015) that are installed on a one-axis tracker array (ibid). The power output of Canadian Solar’s PV cells declines over time. The decline is detailed in the company’s power output warranty.

The warranty states that no more than 3% power is lost in the first year, no more than 0.7% power is lost in years 2 to 25, and the PV panels will have 80% efficiency in the 25th year. The 20 year power output of Roserock in Table 1 used only 60% of the manufacture’s decline limits. Over its 20 year life, Roserock will produce 25,289,964 gigajoules of power, with 91% efficiency after 20 years.

The entire Roserock site was bulldozed flat and cement was poured across much of the site for the one-axis tilt solar array (Wikipedia, 2023). This completely destroys the ecosphere for plants and animals and leaves a barren moonscape, a parking lot. The author called this “stripmining for solar.” Anyone can look at large solar power plants on Google Earth and see this strip-mining (e.g., Topaz, Ivanpah). Also, tilling topsoil releases of CO_2 (Charles, 2007). Melillo and Gribkoff (2021) stated that “converting natural ecosystems like forests and grasslands to farmland disturbs soil structure, releasing much of that stored carbon and contributing to climate change.”

The cost for Roserock is reported by Wikipedia (2023) as $275 million, but this number is anomalously low. The price contradicts other publications and NREL full-costs averages for industrial solar power plants. The correct cost of $405 million is important because it affects the analysis. Justification of the $405 million cost is provided. Wikipedia’s (2023) stated cost of $275 million is only the *construction loan* cost. The number is explicitly reported as a “loan” in PV Magazine (Roseland, 2015) but it has, through shoddy

Wikipedia "science," been magically transformed into an apocryphal $275 million cost. Construction loans are only 70% of the total cost (Seppala, 2020; Chen, 2020). Assuming 70% financing, the $275 million loan amount gives a full project cost of $392 million—very close to Power Technology's (2021) price tag of $405 million.

National Renewable Energy Laboratory (NREL) data indicate a $440 million cost for Roserock. The average full-cost price for a utility-scale one-axis tracker PV power plant in 2015 was $2.08 per watt (NREL, undated; Ramasamy et al., 2022). Using the NREL's averages, Roserock's cost is inferred to be $440 million—again, very close to Power Technology's (2021) price of $405 million.

Haynesville Well Costs and Estimated Ultimate Recovery (EUR): Well costs for a Haynesville well were provided to me by a major operator from an actual well that was completed in January 2023. The $18 million includes drilling, logging, casing, fracking, surface facilities, roads, and survey. The Haynesville well cost in Table 1 also includes $30 thousand per month in operating costs for 20 years, totaling another $7 million for each well. The well's operational lifetime is intentionally inflated, but duration does not change the well's EUR, only the operating costs.

The operator reported that well costs have spiked up because casing and tubulars have gone up 30%, and rig rates are up 50% in the last 18 month. An EUR of 2 BCFG per 1000 feet lateral is used but it is low. Most operators claim EURs of 2.5 BCFG per 1000 feet of completed lateral.

The analysis presented in Table 1 is skewed to favor Roserock. The Haynesville well life is more likely to be 12 years, so the Haynesville well has artificially high operating costs by using a 20 year life. No operating costs are attributed to Roserock's 20 year life. Roserock's operating costs cannot be trivial. NREL (2023) showed average maintenance and operating costs of $17/kilowatt (KW)–year. Costs vary from $8 to $26/KW–year. Roserock's maintenance and operating costs are guesstimated at $700,000 per year based on NREL guidelines. One-axis solar tracker PV arrays require substantial power to track the sun. Expenses also include staff to clean the PV cells after dust storms. Albeit the op costs are left off for Roserock in this analysis to favor solar over natural gas.

The Roserock lifetime power is equal to 1.163 Haynesville gas wells (Table 1). Roserock needs 185 times more land, 14 times more money, and 8.2 times more material than 1.163 Haynesville wells.

Table 2 shows the energy lost by putting capital into low-EROI projects like Roserock. If the $405 million spent on Roserock Solar were invested in Haynesville gas wells, the money could drill 16.212 wells. Each well includes the $7 million in operating cost and no operating costs are attributed to Roserock. The Haynesville wells would produce 14 times more energy with only 1.7 times the material and use 93% less land.

Put another way, to match the power output of the 16.212 Haynesville wells, 14 Roserocks would need to be built at a cost of $5.6 billion. They would cover 18,200 acres of strip-mined earth. Power lines, transformers, and power relay substations would add to the cost.

As bleak as an investment in solar power is, it gets worse. Solar power cannot provide 24/7 power. After investing $405 million in Roserock, consumers still need to invest millions more in a 100% redundant power source (e.g., batteries, nuclear power) to keep their homes heated and the lights on at night. Goldman Sachs (2022) also pointed to this intrinsic defect of the required 24/7 backup power, and noted that the levelized cost of electricity (LCOE) is artificially low if this defect is not accounted for. They also concluded that solar cannot provide baseload power to the electric grid (ibid).

Solar PV cells might have a "nameplate" EROI of 4 put on the box by the manufacturer, but the "buffered" EROI is 2, or less. Solar power might be great for home rooftops to recharge an EV, but it can never provide baseload power to the grid (Goldman Sachs, 2022).

Malinvestment—Wind Turbines

Table 3 shows the power output of a 3 MW wind turbine over 25 years using a generous 33% efficiency. Cost is $1.6 million per megawatt for wind turbine. Same assumptions for Haynesville well. Again, no annual operating cost are applied to the wind turbine; replacement blades are included for free. (Wind turbine expenses are about $40,000/year). Wind turbine material shown in Table 3 represent the lightest wind turbine detailed in table 30 of the NREL report (Mone et al., 2017), but do not include 1000 tons of cement and rebar for each wind turbine base.

Twenty-eight 3 MW wind turbines are required to equal the power output of 1 Haynesville well. The 28 wind turbines would cost $100 million, not including operating expenses. The 28 wind turbine cost is 4 times the cost of 1 Haynesville well burdened with 20 years of expenses. They require 7 times more steel, copper, iron, and fiberglass than the one Haynesville well. The weight of the 28 wind turbines does not include the 1000 tons of concrete and rebar used for each wind turbine base.

The biggest social problems for wind power is that each wind turbine is taller than the statue of liberty, creates noise, can be seen for miles, and they kill a lot of birds and whales. Conservation groups hate them (e.g., Shellenberger, 2020; DeMis 2021). Local stakeholder opposition to wind and solar is growing (detailed below).

The data in Tables 1 and 3 show that for every $1 million invested in solar, wind, or natural gas, the energy returned is 0.063, 0.197, and 0.871 gigajoules respectively. In other words, the $1 million invested in a Haynesville well produces 14 times more energy than solar and 4.5 times more power than wind.

Figure 15 uses different calculations but also shows low returns for solar and wind power versus a generic shale well (Mills, 2019). Mills (2019) did not provide model input parameters. The conclusions of Mills (2019) are broadly similar to the analysis in paragraph above. Natural gas has a much higher ROI than solar and wind.

The data in Tables 1 and 3 allow for a comparison of the lifetime energy output per tons of material. Solar requires 8 times for material and wind requires 11 times more material for the same power output of a Haynesville gas well. Solar and wind materials include glass, steel, iron, cement, copper, etc. (Figure 1); the same material as a Haynesville well. These materials are energy intensive, even if when are made for green machines. More material means more energy, further suggesting solar and wind have lower EROIs than gas. This power-per-material analysis is rough because specific data on the weight of utility-scale solar is vague. But wind materials are extremely well-defined (Mone et al., 2017), as are the materials for a Haynesville well.

Summary

The analysis of solar, wind and a Haynesville gas well gives readers a basic understanding of EROI. If solar had an EROI of 25 and natural gas's EROI were 10, then solar should outperform natural gas in a simple comparison. It does not. Both solar and wind machines require much more money, material, and energy than a Haynesville well.

Putting money into biofuels, solar, and wind is malinvestment: little energy is returned to society for the enormous amount of money, material, and energy invested. This conclusion is consistent with Rozencwajg (2022), who coined the term "malinvestment" as applied to alternative energy.

The long-term problem of green malinvestment is that it is being multiplied across America in thousands of projects. More money spent for a much less electricity at the expense of oil, gas, and nuclear. The disparate funding is turbo charging the coming commodity super cycle. Public utilities are catching on to the coming problem. The Mid-Atlantic utility grid operator PJM Interconnection predicts that by 2030, wind and solar power will only add about 50% of the power lost by retiring fossil fuels power plants (JPM, 2023).

The US power grid generated 3,400,000,000 MW–hours of non-green electricity in 2021, excluding wind and solar (Energy Information Administration [EIA], 2021b). To replace US nongreen electricity with wind turbines would require another 431,250 3 MW wind turbines at a cost of $1.5 trillion. They would cover 52 million acres (area equal to Kansas), spaced on 40 acres per 1 megawatt. To replace US non-green electrical generation with Roserocks would require another 9400 Roserock-sized solar power plants at a cost of $3.8 trillion. They would cover 12.2 million acres (area equal Massachusetts and Vermont combined). Most states do not have a desert, like Pecos County, so power output would be lower and more solar would be needed. The cost numbers do not include power lines, transformers, or sub-stations. Solar and wind are not feasible for baseload power to the grid (Goldman Sachs, 2022).

The number of wind turbines or Roserock solar plants calculate above are before America plugs in 275 million electric cars. The US power grid would still be unreliable. The numbers above do not include a 24/7 backup power supply (batteries, nuclear, natural gas, etc.). The number of wind turbines and solar plants estimated here might seem large, but they are low compared to the Princeton Net Zero Study (Larson et al., 2021) in their all wind and solar case, discussed below.

Greenflation: The exorbitant costs for green energy led a fund manager Luke Gromen to coin the term "greenflation." Editorials in the *New York Times* did not disagree with his prediction, they just contended that "Greenflation will be worth it" (Wagner, 2022). Some opined that greenflation is "a necessary step" (Blas, 2022). However, others saw greenflation as a negative feed-back loop that is hampering the energy transition (Sharma, 2021).

Unrealistic Net Zero Goals

Much of the energy transition, and the goal of "net zero by 2050", is based on unrealistic buildouts for wind and solar power plants. Princeton University's Net Zero America Report (Larson et al., 2021) is the most detailed and carefully thought-out research that shows *how* to achieve net zero carbon emissions in the US by 2050. In fact, it is the only report on *how* to get to net zero by 2050. A short summary is provided by Merrill (2021).

Princeton's team includes 18 engineers and an environmental consulting company. It presents 5 scenarios, ranging from 100% wind and solar to almost 100% nuclear.

The report is outstanding in its detail. And that is its foible—detail. When you read exactly what is involved to get to net zero, it becomes clear it is entirely unrealistic. A few of the unrealistic milestones include:

- A cost of $2.5 trillion by 2030 *in addition* to business-as-usual energy spending.
- Most of the build out, and costs, "will be after 2030."
  - The total cost might be $10 or $40 trillion. Report is vague on costs after 2030.
- 1.5 million new wind turbines covering 250 million acres.
- 17 million acres of solar panels that would require 9 billion PV panels (PV cell number is based on Roserock PV panel density per acre).
  - PV cells are trash after 25 years, so PV cells would need to be continuously replaced starting even before the 2050 finish.
- A 5.2 fold increase in power lines.
  - America's power grid is "biggest machine on earth" (Martin et al., 2020).
  - It took 60 years to build the power grid (EIA, 2021b).
  - This means building 5.2 American power grids in 27 years.
- Building 250 1 GW nuclear power plants.
  - Planning and permitting the 250 nuclear power plants needs to begin today.
- An unprecedented "green" mobilization, comparable to World War II in spending and national commitment.

Transition Realities

The reality is that the energy transition will have to follow an all-of-the-above solution, rather than aspiration ideals (DeMis et al., 2022a). The energy transition has significant environmental impacts that communities and conservation groups are opposing (DeMis et al., 2022b). This environmental impact will constrain the buildout and greatly prolong implementation. Yergin (2021) recounted that the energy transition will be complex because oil and gas are so fundamental to modern society that people do not realize how much they rely on hydrocarbons in their daily lives; the people at North Face certainly did not.

Government Out of Money

All energy transition scenarios included hefty government grants. Princeton does not seem to be aware that the Federal government is out of money. World War II's mobilization created massive federal debt. The US debt today is above World War II levels. Deficit spending trillions of dollars to "save the planet," added onto today's debt, will only bankrupt the country. It will but do nothing to stop global warming because there are no efforts to control emissions include China, the world's largest CO_2 emitter.

China announced will build 200 more coal-fired power plants. The 200 "more coal-fired power plants … has alarmed Western officials" reported in the New York Times (Bradsher and Krauss, 2022). John Kerry said the 200 plants "…would *actually undo the ability of the rest of the world to achieve a limit of 1.5 degrees*" (emphasis added; ibid, 2022). Fidgeting with solar and wind in the US spends money it does not have to reduce emissions it is not producing.

Anyone who can read without moving their lips by now realizes that climate "solutions" must start with curbing China. Boycott, divesture, and sanction (BDS) worked on South Africa. Going BDS on China would be an appropriate start to solving the climate problem. Terraforming the earth be a global solution.

Too Many Applications, Fewer Built

The reality is that power-grid operators have been flooded with green power connection applications but can only handle a fraction of the volume. In 2021, 8100 solar and wind projects were waiting on technical review, up from 5600 in 2020. (Hiller, 2023). From 2000 to 2016, only 23% of the power-generation projects that applied for grid connection were actually built (ibid).

Despite billions being poured into "renewable energy" from the Inflation Reduction Act, new wind installations *fell* 77.5% in Q3 2022 vs. the same quarter the year before (ibid). New solar installation also *fell* 40% in 2022 vs. 2021, as reported by the Solar Energy Industries Association and Wood Mackenzie (cited in Hiller [2023]).

Over 19 GW of wind and 60 GW of solar power plant proposals were withdrawn from the grid connection application process, according to a study by Lawrence National Laboratory (cited in Hiller [2023]).

End of Cheap Money and Inflation Impacts Green Power Too

For the last 5 years, wind and solar projects have ridden the same cheap financing (i.e., low interest rates) that made the shale boom possible. They also benefited from low energy prices. Ultra-low cost of capital is going away: interest rates are rising, and the Federal Reserve is unwinding its balance sheet (meaning it is taking money out of the economy). Inflation is rising too.

Commonwealth wind is an excellent example effects of inflation, higher cost of money, and increasing energy prices on green power. The enormous, material-intensive machines required to harness the low-density energy of wind and solar (see Figure 1) mean lots of capital- and energy-intensive mining and fabrication.

The offshore Commonwealth Wind project had a nameplate capacity of 1.2 GW. It is now “no longer viable” because the electricity purchase agreement is too low to cover the costs (Newburger, 2022). The original contract did not charge enough for electricity given the developer’s now increasing cost of financing, materials, and energy (Rozencwajg, 2022).

Supply-Chain Snags

The collapse in new green projects is also the result of supply-chain snags and long waits. Average delivery time for high voltage equipment has risen from 20 weeks to 70 (Hiller, 2023). Solar panels imported from China have slowed because US legislation has forced a crack-down on Chinese-produced PV panels based on human rights concerns (ibid).

Social License is gone for Utility Scale Wind and Solar

Many communities are opposed to large-scale wind and solar power plants. Rural communities do not want their bucolic countryside despoiled with 400 foot tall wind turbines or carpeted with thousands of acres of solar panels that provide power to people in a distant city (DeMis et al, 2022b; Malanga, 2023; Carlton, 2021).

One community in Pennsylvania banned a solar power plant that would have only covered a tiny 137 acres because it was “too big” (DeMis, 2022b). Ten counties in Ohio have banned commercial wind and solar power plants (Malanga, 2023). San Bernardino County is the largest county in California and lies due east and is contiguous with Los Angeles County. It banned commercial wind and solar power for out-of -county use, as reported by the Los Angeles Times (DeMis et al, 2022b). Vermont and Maine are effectively off limits to wind and solar (DeMis, 2022b, Malanga, 2023).

Bryce (2021) published a list of 327 wind power plants that have been canceled. He also maintains a public Renewable Rejection database of canceled wind and solar projects (Bryce, 2023), currently listing 485 canceled projects.

Disinformation and Yellow Journalism

The few news outlets that cover community stakeholder opposition to wind and solar attribute local opposition to mythical “funding from the Koch Brothers,” or to “fossil fuel industry disinformation.” Noted author Robert Bryce has contacted every news outlet that has made the Koch Brothers or fossil fuel disinformation claim. Not one has returned his calls, emails, or provided any evidence of their yellow journalism accusations (Bryce, 2022). Mr. Bryce has interviewed stakeholders in the communities where these yellow journalism claims had been leveled: locals have never heard of the Koch brothers (ibid).

Environmental Opposition to Energy Transition Minerals

Astronomical growth in demand for critical energy minerals has been predicted by the IEA (2021b) and is shown in Table 4. Unfortunately, the IEA did not project the increased need for steel and cement which are major components in wind and solar machines (Figure 1) and are also major sources of greenhouse gas.

Energy mineral demand will increase 200% to 4000% for these metals because, according to the IEA, the supply is not keeping up with demand (ibid). The US imports 50% of its nickel, 76% of its cobalt, and 40% of its copper (Gunasekara, 2022).

IEA's conclusion of coming commodity scarcity, and rising commodity prices, has been independently confirmed by Mills (2021). And the predictions are already coming true: the price of lithium has soared nearly 1000%, and nickel is up 300% in 2 years. There is a clear need for more mineral for the energy transition.

Morgan Stanley's Chief Global Strategist R. Sharma (2021) noted,
"New government-directed spending is driving up demand for materials needed to build a cleaner economy. At the same time, tightening regulation is limiting supply by discouraging investment in mines, smelters, or any source that belches carbon. The unintended result is "greenflation": rising prices for metals and minerals such as copper, aluminum and lithium that are essential to solar and wind power, electric cars, and other renewable technologies."

Environmentalists oppose the very mines needed for the energy transition. Environmentalists, regulatory agencies, and lawsuits have blocked mines for energy transition mineral. Stalled or blocked mines include: Alaska's Pebble (copper, gold, and rhenium), Minnesota's Twin Metals (copper, nickel, cobalt), Nevada's Thacker Pass (lithium), and Maine's Newry (lithium).

The Associate Press called the EPA actions "a rare veto" when it blocked mining the Alaskan Pebble deposit on January 21, 2023 (Bohrer and Whittle, 2023). Pebble LP CEO John Shively called the EPA's actions "unlawful" (ibid).

The Biden Administration canceled two federal mineral leases held by Twin Metals, Minnesota, in 2022 (Kraker, 2022). Not to be outdone, Secretary of Interior Haaland just signed an order withdrawing 225,000 acres in the Superior National Forest from mining ***and geothermal leasing*** for two decades (Karnowski, 2023).

The Twin Metals area, located on the Precambrian Duluth Complex, is rich in copper, nickel, cobalt and other minerals needed for the energy transition. Curiously, the Associated Press reported the ban as a "move to protect Minnesota Wilderness" (ibid), as if any mining or even geothermal energy *a priori* degrades the wilderness.

Neither Karnowski (2023) nor the Department of Interior's webpage make any mention of where key minerals like copper, nickel, and cobalt for EVs will come from, yet supposedly, all cars will be EVs by 2035.

The Thacker Pass lithium deposit had a permit issued in 2020. But it continues to languish in legal limbo from multiple court challenges coming from environmentalists (Rothberg, 2022) and Native Americans (Bahouth, 2021).

The Newry lithium pegmatite deposit of Maine is touted by a local Maine newspaper to be the "world's richest lithium deposit" (Cough, 2023). *The Maine Monitor* stated that the Department of Environmental Protection classified the lithium-bearing mineral spodumene as a "metallic mineral." On that basis it denied the owners a permit for a large open-pit operation. The owners are appealing (ibid).

The Rhyolite Ridge lithium deposit in Nevada is a glimmer of hope for the energy transition. The Energy Department provided a $700 million loan, but the loan "is conditional on Ioneer (the operator) securing the necessary permits to proceed with mining operations" (Graber, 2023). The timeline from first permit to a functioning mine is about 15 years (IEA, 2021b). Rhyolite Ridge lithium might be in a Tesla by 2037. That is, if it is not buried by endless legal challenges like Thacker Pass.

Peak Minerals

Wind and solar require much more material per terawatt-hour than natural gas or nuclear power (Figure 1). The planet hit "peak minerals" decades ago (Northey et al., 2014). Global copper ore grades are under 1% and falling (Figure 17). Now is not the time to pursue a *"mine, baby, mine!"* solution to the climate problem.

Pursuing material-intensive wind and solar power will cause more demand. Demand will drive up prices to astronomical levels (Mills, 2019). More mining will mean that "actions are required to counter the upward pressure on emissions from mineral production" (IEA, 2021b). This is "IEA–speak" for the fact that a "Gharwar" of diesel fuel will be needed to mine the 0.5% copper deposits for the green machines that will cut carbon emissions from burning fossil fuel (irony intended).

The Sierra Club North Star Chapter decried the low grade at Twin Mines in Minnesota as a reason to stop the mine, "The low-grade character of the rock formation, less than 1% of the ore, would be produced as copper, nickel and trace metals, with waste rock comprising the remaining 99%." (Sierra Club North Star Chapter, 2023). Chris Knopf, Executive Director, Friend of Boundary Waters Wilderness, wrote that "The concentration of copper is so poor … it would only add 0.19% to global copper production" (Knopf, 2023).

Well then, by this very logic, I am sure Sierra Club and Mr. Knopf are opposed to all wind and solar power because copper ore grades around the planet are all less than 1% (Figure 17).

Another problem with mining for energy transition mineral is … ESG! ESG principles are being adopted around the globe. This means slower mine expansions and a slower energy transition for the planet. The same third-world miners that American greens rely on so they can have their unspoiled utopian wilderness in Minnesota now have the same environmentally conscience. Stakeholders in Peru are now saying, "not in my back yard"—just like the Sierra Club in Minnesota. So why are the environmental desires of white Sierra Club members more important that the same concerns of people in Africa or Peru?

Morgan Stanley Global Strategist Sharma (2021) wrote,
"ESG used to be a luxury of rich nations. No longer. ESG pressures are restraining supplies even from Latin America. (In Chile and Peru) mining projects that used to take 5 years can now take 10 or more. One big copper project in Peru, scheduled to open in 2011, remains unfinished owing to resistance from the local community. Chile has adopted two sweeping environmental rules and is considering a new royalty that could make some of its biggest mines unprofitable."

This paper cannot detail every ore grade and every issue for every mine. Copper is a key mineral in the energy transition. It makes the point for all energy transition minerals. Moving to material-intensive low density energy machines just as the entire planet slides past "peak minerals" means shortages and rising prices: a commodity super cycle.

Implicit Racism in Saving the Planet

Some of the "save the planet from climate change" actions are implicit racism. Ultra-white Norway is Europe's second-largest gas supplier after Russia. In September 2021, Norway agreed to increase natural gas exports by 2 billion cubic meters (1 cubic meter = 35.3 cubic feet) to alleviate Europe's energy shortage (Adomiantis, 2021). This was before the Ukraine War. But today, Norway is lobbying the World Bank to end financing of fossil fuel projects in Africa (Ramachandran, 2021). So it is okay for white Norwegians to increase hydrocarbons for other white Europeans, but poor black Africans cannot have hydrocarbons?

Uganda's President Museveni wrote "Solar and Wind Force Poverty on Africa" in the *Wall Street Journal*, complaining that the western aid-industrial complex is keeping Africa in poverty:
"NGOs are pushing Africa to solar and wind, leaving them with unreliable energy. This forestalls Africa's attempts to rise out of poverty, which require reliable energy. Western nations have put a blanket ban on public funding for a range of fossil-fuel projects abroad, making it difficult for Africa to make the transition to cleaner *<u>nonrenewable</u>*" (emphasis added; Museveni, 2021)

Targeting of Africa by white NGOs has been called "Green Colonialism" (Ramachandran, 2021) or "Energy Apartheid" (Friedman, 2014). The author sees no reason to use such euphemisms. It's racist.

Ms. Mutiso's 2020 TED Talk, "The Energy Africa Needs" detailed the energy inequality being forced on Africa and says Africans want reliable natural gas and oil—not the energy white NGOs want to force on it. She calls it racism too (Mutiso, 2020).

When the administration was not shutting down Minnesota mines, its State Department pledged to help build EV battery supply chains in the Democratic Republic of Congo and Zambia (Kavanaugh, 2022). The DRC produces 70% of the world's cobalt. Zambia is the world's 6th largest copper producer (ibid).

Kara's (2023) "Cobalt Red" detailed on the inhuman conditions in the "artisan" cobalt mines in DRC. "Artisan" is a nice word that means men, women, and children toiling by brute force—no backhoes or trucks. The mines are "hand-dug" pits. He recounted "a hellscape of craters and tunnels, patrolled by maniacs with guns." Mr. Kara reported visiting a mine where "more than 3 thousand women, children, and men shoveled … under a ferocious sun."

Mr. Kara estimated that 30% of DRC cobalt is "artisan," and that conditions in the country make it impossible to differentiate "artisan" vs. fair-trade cobalt. Mr. Kara pointed to the illegitimacy of Western tech, car companies, and NGOs for espousing "zero tolerance on child labor" even though fair-trade cobalt is nearly impossible to verify in DRC and that the working conditions and child exploitation are an open secret.

Environmental Colonialism and Minnesota Twin Mines: Let's juxtapose the DRC and Minnesota to drive the point home. Perhaps the current Administration or the Sierra Club can import sub-Saharan black Africans to hand-dig the copper, cobalt, and nickel at the Twin Mines deposits and, by the logic of the Sierra Club, make the Minnesota mine environmentally acceptable. Can readers now see the implicit racism in current policies?

Wouldn't it be better for American energy security and human rights if the EV supply chains, including mining, were cited here in the US?

Federal Reserve Policy and Commodities

The US debt will impact commodity prices, oil and gas prices, and the energy transition. The national debt is now 120% of GDP. The Federal Reserve will need higher inflation (above the 2% target) to monetize the national debt. This issue stands outside all the other factors addressed above but the federal debt and the annual deficits will definitely effect commodity prices (e.g., DeMis, 2021).

Only once before has the US debt been this high, just after fighting National Socialism in World War II (Figure 18). The US was able quickly reduce debt after World War II because it was the only country on the planet whose factories were not bombed to rubble.

The US used two tools to reduce the national debt after World War II: economic growth and inflation. The US GDP grew by 75% in real terms (corrected for inflation) in 15 years by selling everything to everybody on the planet as the world rebuilt (Figure 19). Over the same time, cumulative inflation was 45% (Figure 20). These combined factors reduced debt to 50% of GDP by 1963 (Figure 13). For reference, US GDP has increased a tepid 28% in the last 15 years.

But the economic conditions today are completely different. The US is now a twin-deficit country: annual budget and trade deficits. US annual deficits have averaged $1 trillion per year since 2008 (Federal Reserve Bank of St. Louis, 2023).

No one is buying what America sells. America's manufacturing employment is now as low as it was in 1941, before World War II (Federal Reserve Bank of St. Louis, 2023). Unless Dell starts building computers in the US and selling them to the Chinese, the Federal Reserve's only tool to reduce the debt is by inflating the economy and devaluing the currency.

Congress could cure the debt crisis by cutting spending. But in today's political climate, the idea of bipartisan collaboration by Congress to reduce spending is risible.

Debt-Death Spiral

Interest on the volcano of US debt continues to grow and consumes more of the US Treasury's income. Federal government interest payments topped $840 billion dollars in Q4, 2022 (Federal Reserve Bank of St. Louis, 2023), an amount equal to the Department of Defense budget, and about 40% of entitlement spending. According to CNN, "The US is paying a record amount of interest on its debt. It's only going to get worse" (Luhby, 2023). The trend of ever-larger payments on the Federal debt is exacerbated by the Federal Reserve rising interest rates, which pushes up the cost of money to the government by increasing interest paid on Treasury bills.

The Federal government has been printing money to cover deficits. Annual Federal deficits have averaged $1 trillion per year since 2008. The White House just released estimates that revenue to Treasury will be $4.7 trillion in 2023 and the deficit for FY '23 will be $984 billion (Amadeo, 2022).

Annual deficits going forward will increases the nation debt and thus annual interest payments on the federal debt will continue grow. The government will have to print more money to pay for its programs because interest payments consume all revenue. Printing more money causes bond buyers to ask for higher rates, which pushes up interest payments on the national debt, which in turn pushes up annual interest payment, which leads to more money printing. This is a debt-death spiral. It will spawn inflation. This does not end well for the US … or your children.

Inflation forces commodity prices higher, as happened in the 1970s (e.g., DeMis 1996, 2019). The US debt by way of inflation will push commodity prices higher.

Effects on Commodity Prices

All commodities will rise because of deficit spending by the US and by other OECD central banks as they continue to pursue the repeatedly failed policy of trying to print their way to prosperity. Making price projections for all commodities, e.g., minerals, oil, gas, steel, pork bellies, etc. is beyond this paper. The analysis will focus on oil and gas price.

Oil prices trend to rise during times of inflation so that OPEC can maintain purchasing power. Historically, over the long term, OPEC has offset losses in purchasing power from inflation or change in the value of the dollar with nominal price increases when supplies are tight (DeMis, 1996, 2000, 2019, 2021). When oil supply was abundant and the dollar was low, as happened in 1995, OPEC just had to tough it out. It could not raise prices (e.g., DeMis, 1996, 2000).

When supply is tight, OPEC recovers lost purchasing power from the erosive effects of inflation or drops in the value of the US dollar by increasing nominal prices (e.g., DeMis, 1996). This point asserts casualty between a loss in purchasing power and OPEC actions, and that oil price rises in the 1970s were in response to inflation. Many people either confused the oil price rises with geopolitics (e.g., Yergin, 1991) or think oil prices are a driver of inflation. A review of OPEC statements confirms the asserted causality.

Before the December 12, 1970, OPEC meeting in Caracas, Venezuela, OPEC resolved that the reference prices for OPEC oil should be adjusted for drops in the dollar to maintain "purchasing power of member countries oil revenues" (Salman, 2004). Mind you, this was years before the 1973 oil embargo. By March 1973, OPEC was demanding an amendment of the January 1972 Geneva Agreement in response to the falling value of the greenback. OPEC wanted "full compensation as a result of the devaluation of the US dollar" (Middle East Economic Survey, 1973).

In 1977, Iraq's oil minister was quoted in the New York Times, "Although we sell a barrel of crude oil for $13, its effective purchasing power is no more than $5" (NYT, 1977).

In 1995, OPEC was vociferous about the effects of the declining value of the dollar and the cumulative effects of inflation on their budgets (Tachibana, 1995; Hammadi, 1995; Platt's Oilgram News, 1995; DeMis, 1996).

The Great Inflation was from 1965 to 1982 (Bryan, 2013). The forgotten Arab Oil Embargo of 1967 is a good example of OPEC price impudence in the face of excess supply (DeMis, 1996). OPEC could not immediately raise oil prices in response to inflation or to the devaluation of the US dollar after the Bretton Woods agreement collapsed because of oversupply of oil (DeMis, 2019).

By 1973, the price of corn and wheat had doubled, and the price of gold had tripled before OPEC raised oil prices (DeMis, 1996). In 1974, eight years into the Great Inflation, oil supply became tight. OPEC was able to triple prices in three years (Figure 21).

A simple proxy for OPEC's purchasing power is the relationship of oil to gold in nominal prices, as was first defined by DeMis (1996). The two prices track each other closely (Figure 22). The ratio of gold to oil also measured OPEC purchasing power (ibid). One ounce of gold roughly buys 13 barrels of oil when supply and demand are tight. Today, nominal gold price is $1900 per ounce, so one ounce of gold buys 23 barrels. Oil is undervalued. For oil to gain its historic parity to gold, oil prices need to be $135/barrel (Figure 20)

In 2020, the gold-to-oil ratio rose to 56 (Figure 23), an unprecedented signal that oil was undervalued (DeMis, 2021). DeMis (2021) suggested oil had bottomed out, that oil prices would rise to $200 in the near future, and that history was more or less repeating the early 1970s. The oil bear market was coming to an end.

Unknown to the author at the time, Goehring and Rozencwajg (2020b) used DeMis' (1996) gold-to-oil ratio method and came to the same conclusions. They suggested, "Given today's ratio (of gold to oil), we believe an extremely strong buying opportunity is presenting itself in oil and oil-related stocks."

At this writing, many financial gurus predict a global recession in 2023 or 2024. Such a recession might decrease demand for oil and gas, as happened in 2008 and during Covid. Oil and gas prices might drop. Such timely price drops, if they occur, will be "head fakes" on a larger commodity super cycle.

Near term, oil prices will settle in $85–150 range, but excursions to over $200 should be expected. Longer term, $200 oil might become the floor as OPEC+ maintain its purchasing power in the face of rising inflation, and possible dollar devaluations (DeMis, 2021).

Natural gas prices will rise. The price difference in natural gas between Europe and Japan ($20/million cubic feet of gas) and the US ($2.74/million cubic feet of gas) will converge somewhat. Prices in the US will rise to meet global prices, but only until congress gets involved. It would be difficult to imagine, given politicians sensitivity to gasoline pump prices, that they would allow natural gas prices to rise above $12 for very long.

Conclusions

This paper suggests many factors will be working in concert to push commodity prices higher. One or several of the factors might not materialize as predicted and the outcome will be the same: commodity prices will rise.

A commodity super cycle is coming. It will be driven by supply-demand imbalance, and many other factors including, underinvestment in oil and gas, turning off nuclear power plants, inflation, deficit spending, and pouring billions into low-EROI green projects.

America is trying to electrify its economy by moving to the lowest density, lowest EROI electricity sources—wind and solar—that cost the most and require the most energy. A train wreck is coming. The energy gap between the energy the world needs and the current growth in energy supply is only getting larger the longer ESG acolytes ignore nuclear, work to defund oil and gas, and pour money into low-EROI projects. The world needs high density, high-EROI energy investments today.

When higher energy prices hit, it will be too late to immediately pivot back to oil, gas or nuclear because of the long cycle time to bring forward new gas provinces or build new nuclear reactors. At that point, the commodity super cycle will be in full swing.

Readers might think that rising commodity prices will usher in halcyon days of a boom. Maybe not. At this writing, many oil and gas independents are reporting their costs of casing and tubing have risen 30 to 50% in the last 2 years. Rig rates are up 50%. Rig rates and steel can rise during inflation too. The inflation caution applies even more to green machines. They require much more material and energy to fabricate. Inflation and rising energy prices have already killed the Commonwealth offshore wind project.

America, and the world, has gone too far down the green energy path, devoting too much capital into low-EROI projects, and not putting enough capital into oil, gas, and especially nuclear power. The solution to the emissions problem will have to include all energy sources. Getting politicians, NGOs and green acolytes to realize there is a crisis might require a crisis. After the California blackout crisis of 2020, utility consultant Robert McCollough likened the power grid to brain surgery: “You can’t make mistakes. People actually die when you mess up” (Malanga, 2023).

Let us hope it does not come to that. Humans have a tremendous capacity to learn and adapt. The current collision course of the energy transition and the increasing shortages in oil, gas, and nuclear power means the coming commodity super cycle will be unprecedented.

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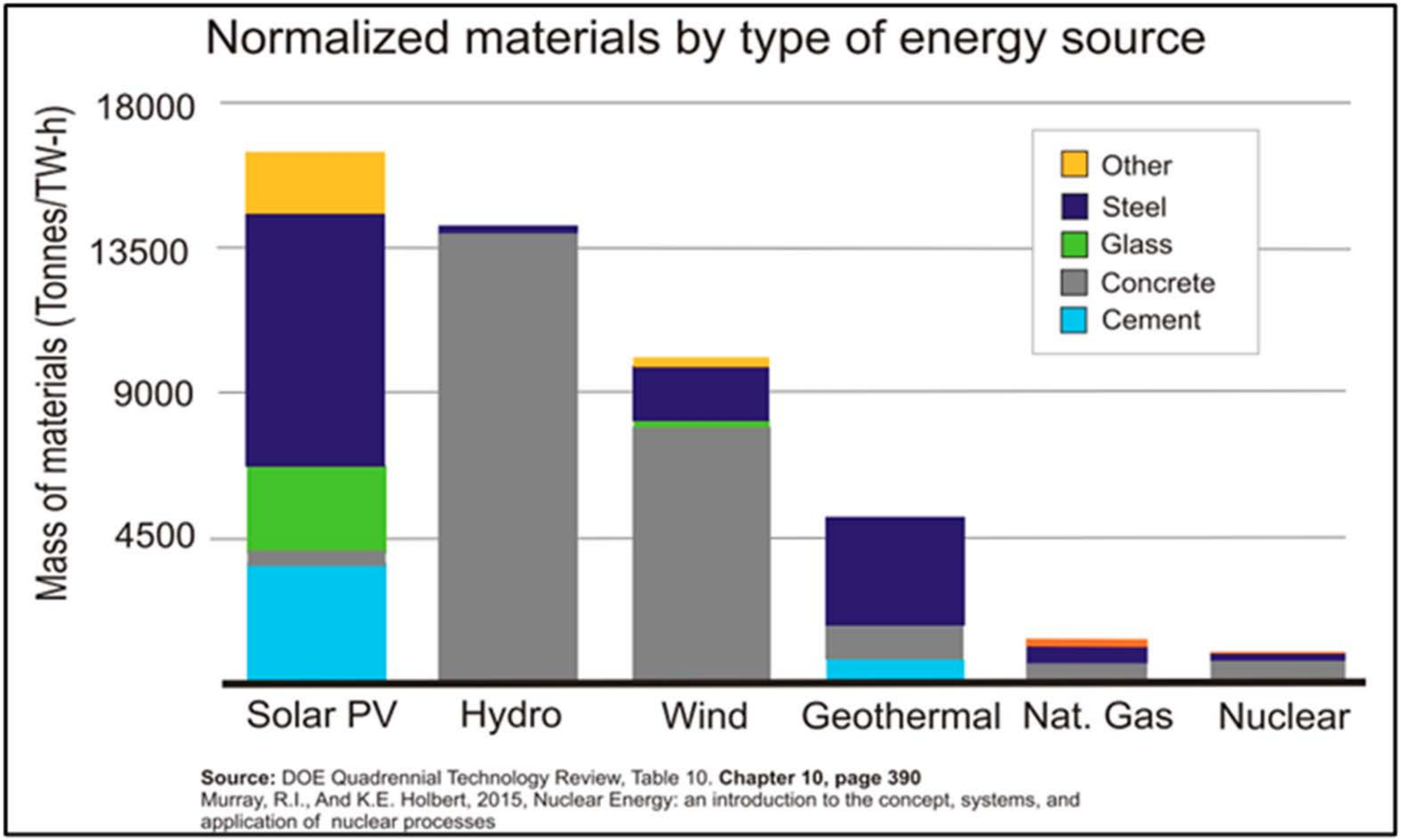

Figure 1. Materials required for different power sources, normalized per terawatt-hour of electricity. Solar and wind require 10 to 18 times more material, and by inference more energy, than natural gas or nuclear power plants. Increases in energy costs will disparately impact wind and solar because they require the most mining and materials. Data from DOE (DOE, 2015).

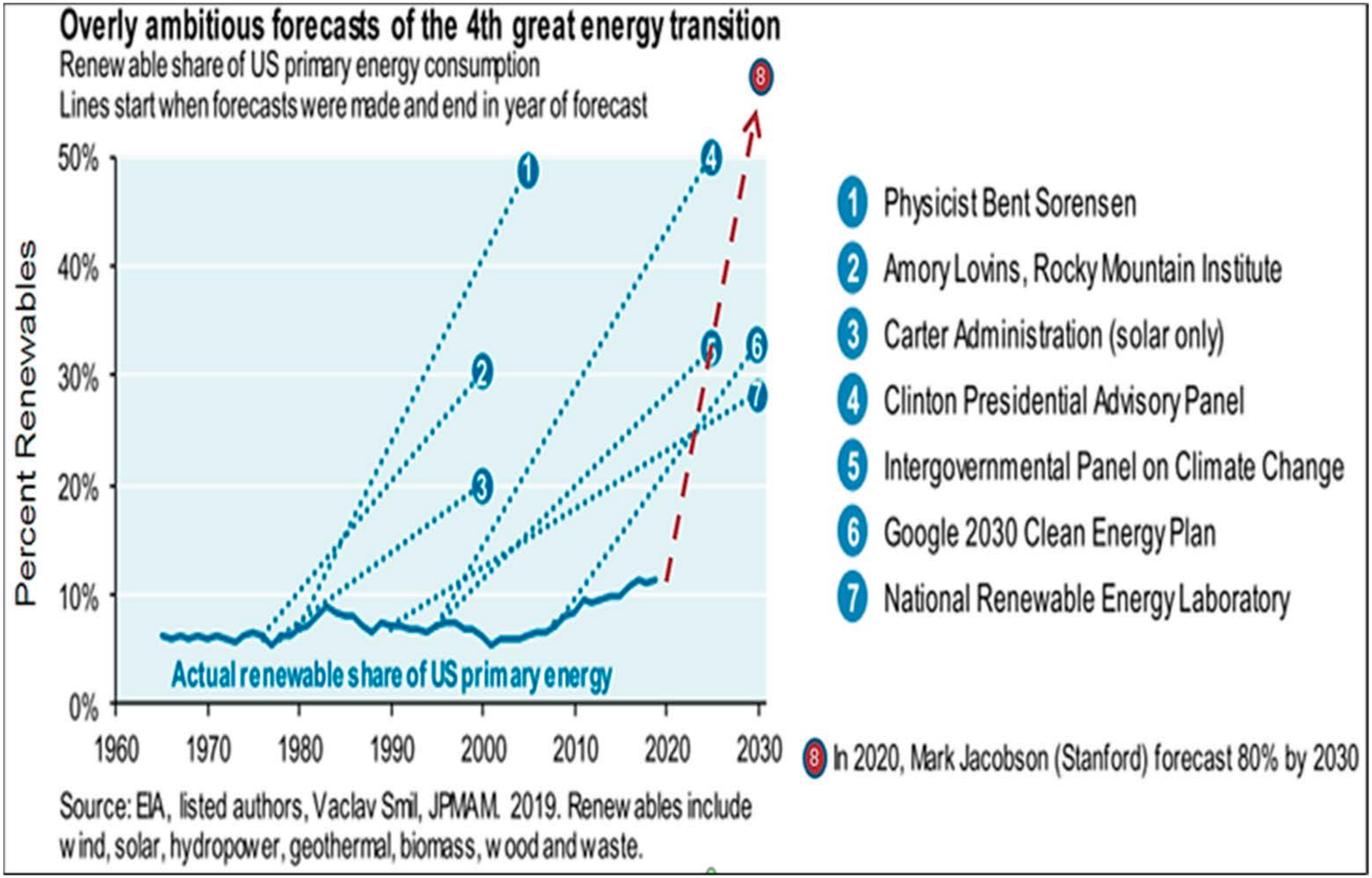

Figure 2. Forecasts of a renewable energy transition date back to the 1970s energy crisis. Seven of eight predictions have proven wrong. Maybe the 8th time will be the charm. Graph from Cembalest (2021).

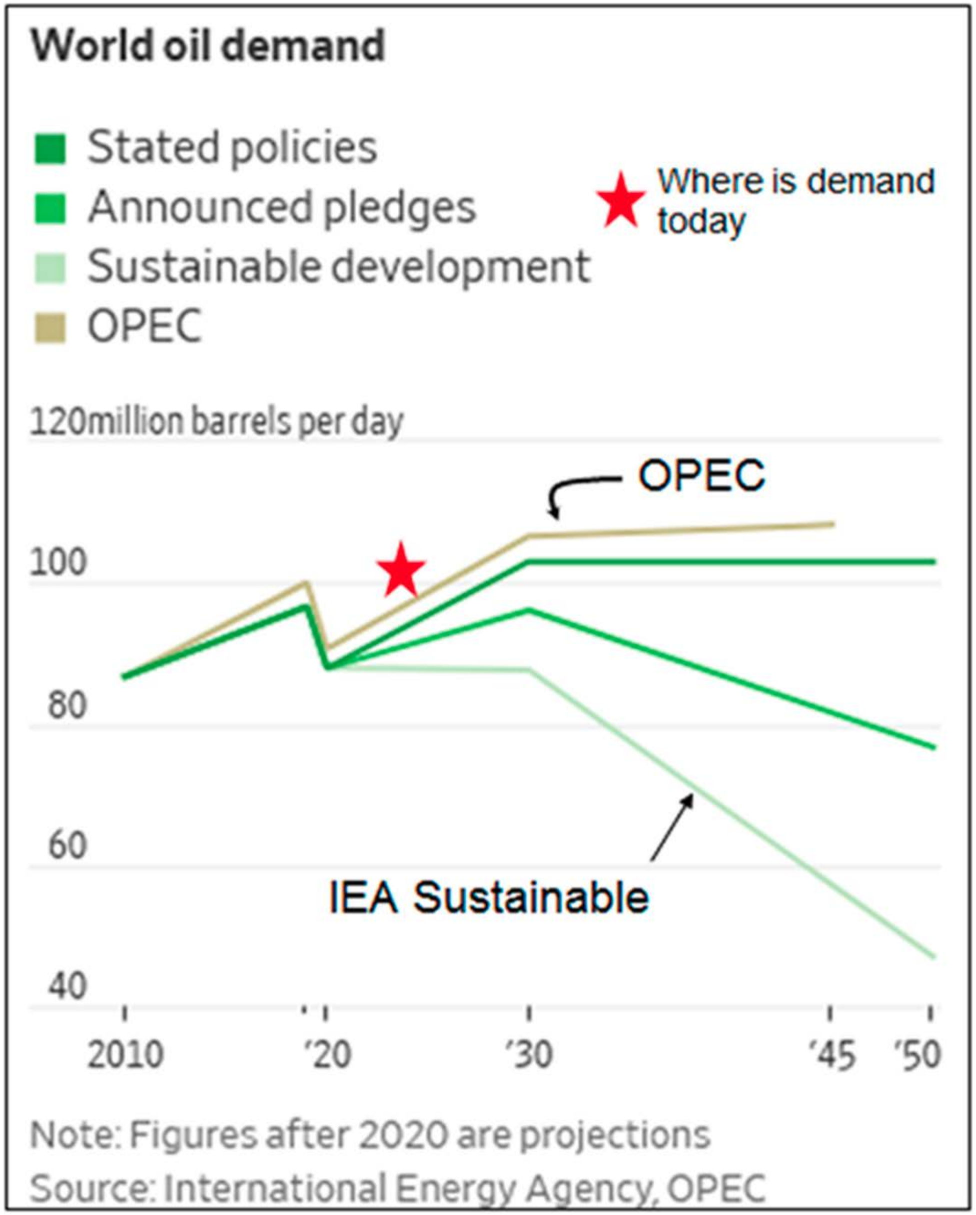

Figure 3. Projections of future oil demand compared to 2022's demand (red star) (modified after Lee [2021]). World demand will hit 101.7 million barrels of oil per day demand in 2023. Many people misunderstood the IEA's (2021) Net Zero report as a demand projection. It was a "prescriptive scenario."

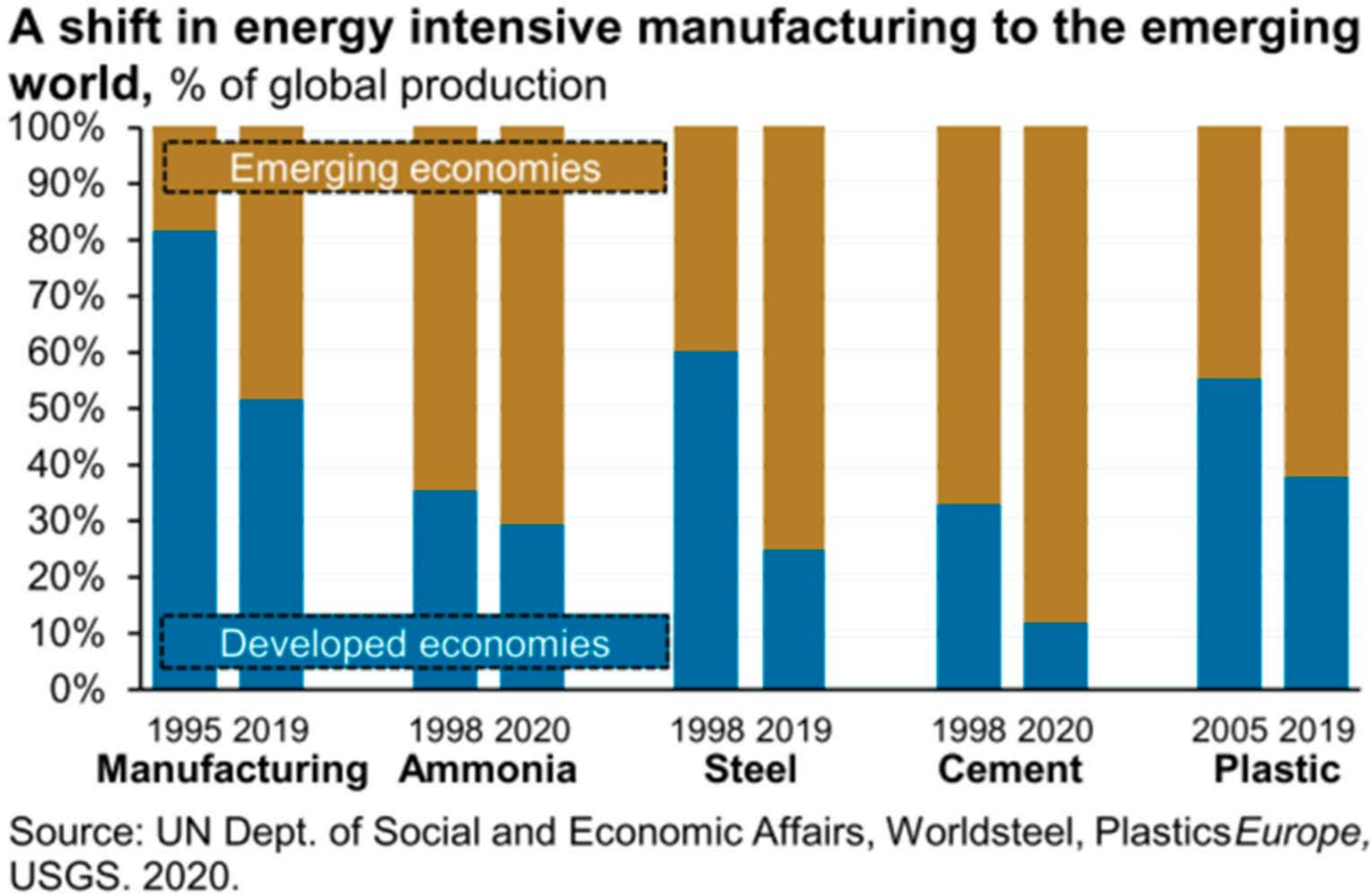

Figure 4. Energy intensive industries moved to non–OECD countries in the last 20 years. Graph from Cembalest (2021). The reduction in OECD CO_2 emissions did not decrease global emissions, it just transferred them to emerging countries.

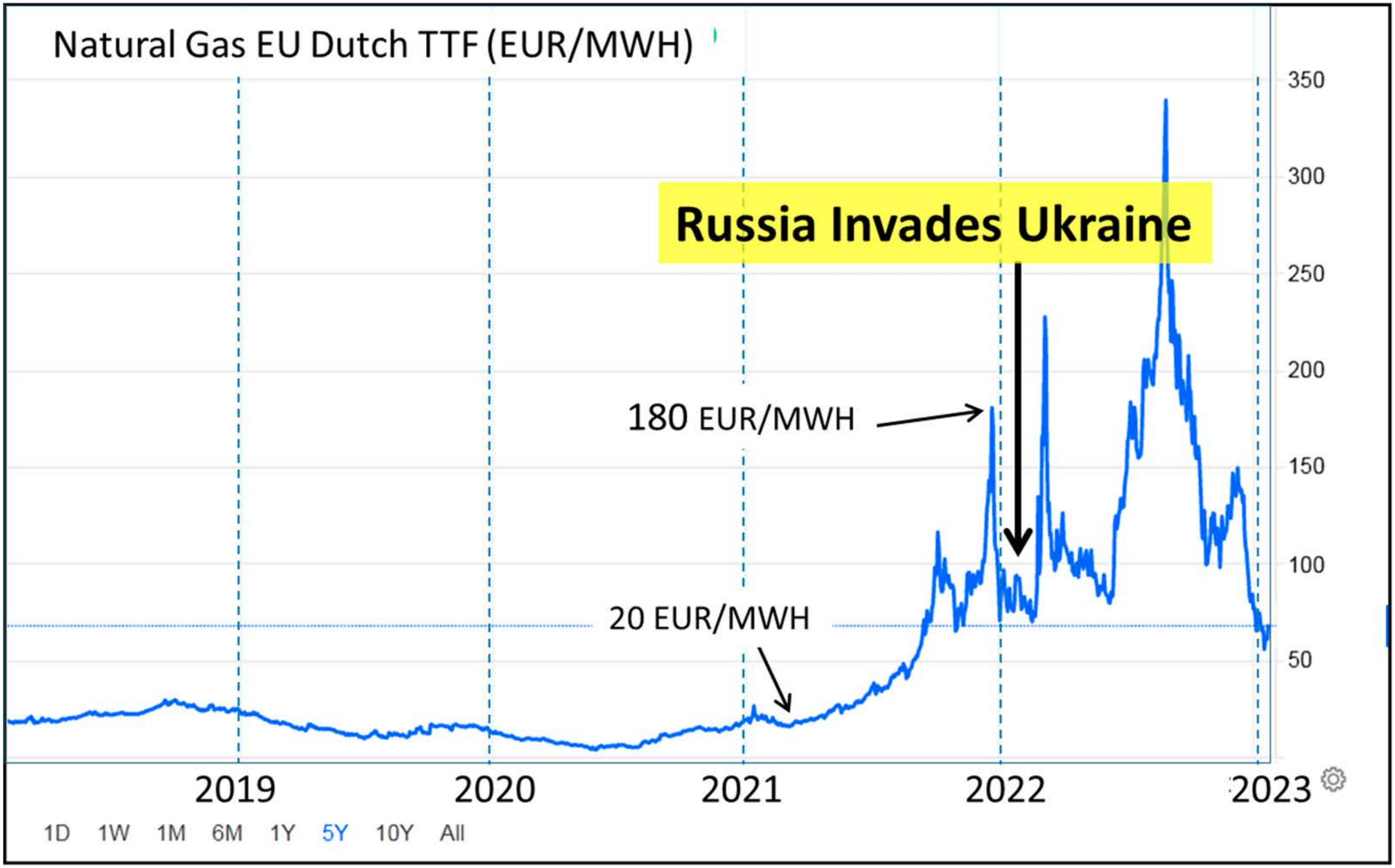

Figure 5. Natural gas prices in euros per megawatt (MW)-hour. Prices increased 9 fold in one year before the Russian invasion of Ukraine. Russia's invasion did not create Europe's energy crisis. Source: Trading Economics (2023).

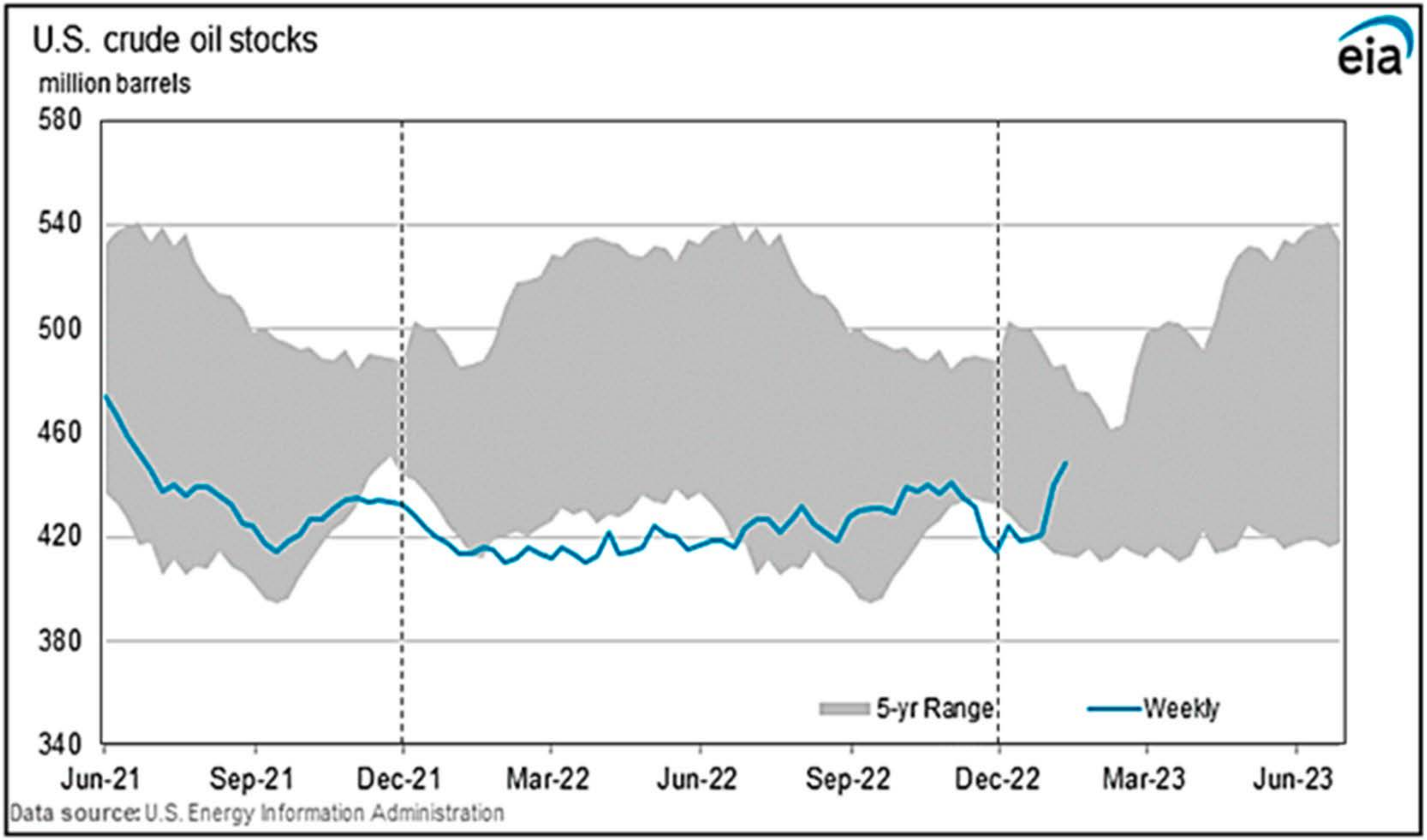

Figure 6. US oil stocks throughout 2022 were at historic lows.

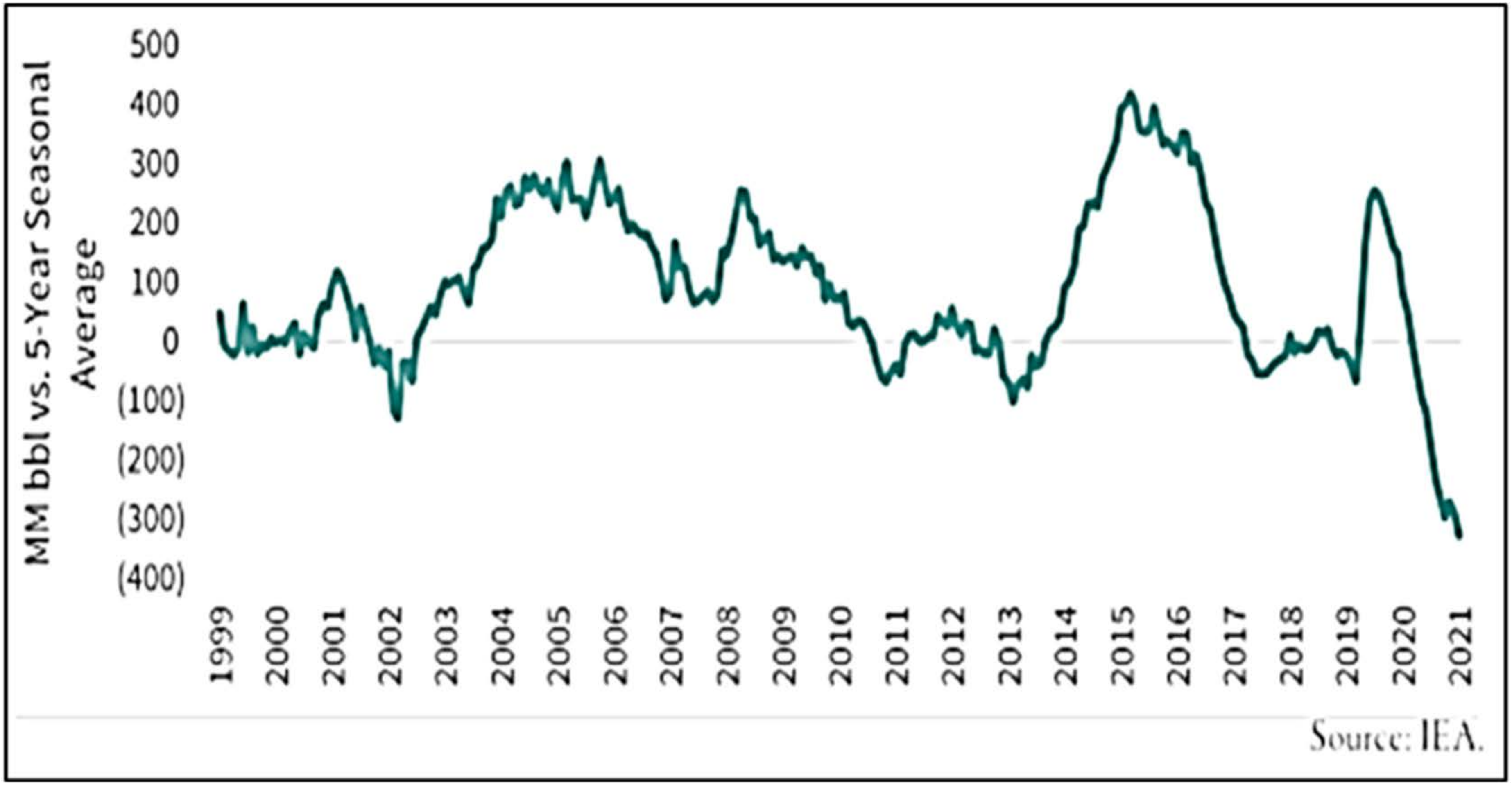

Figure 7. OECD oil inventory vs. five-year seasonal average. Curve normalized to 1999 base. OECD oil inventory has dropped to a historic low. Graph from Goehring and Rozencwajg (2022b, reprinted with permission).

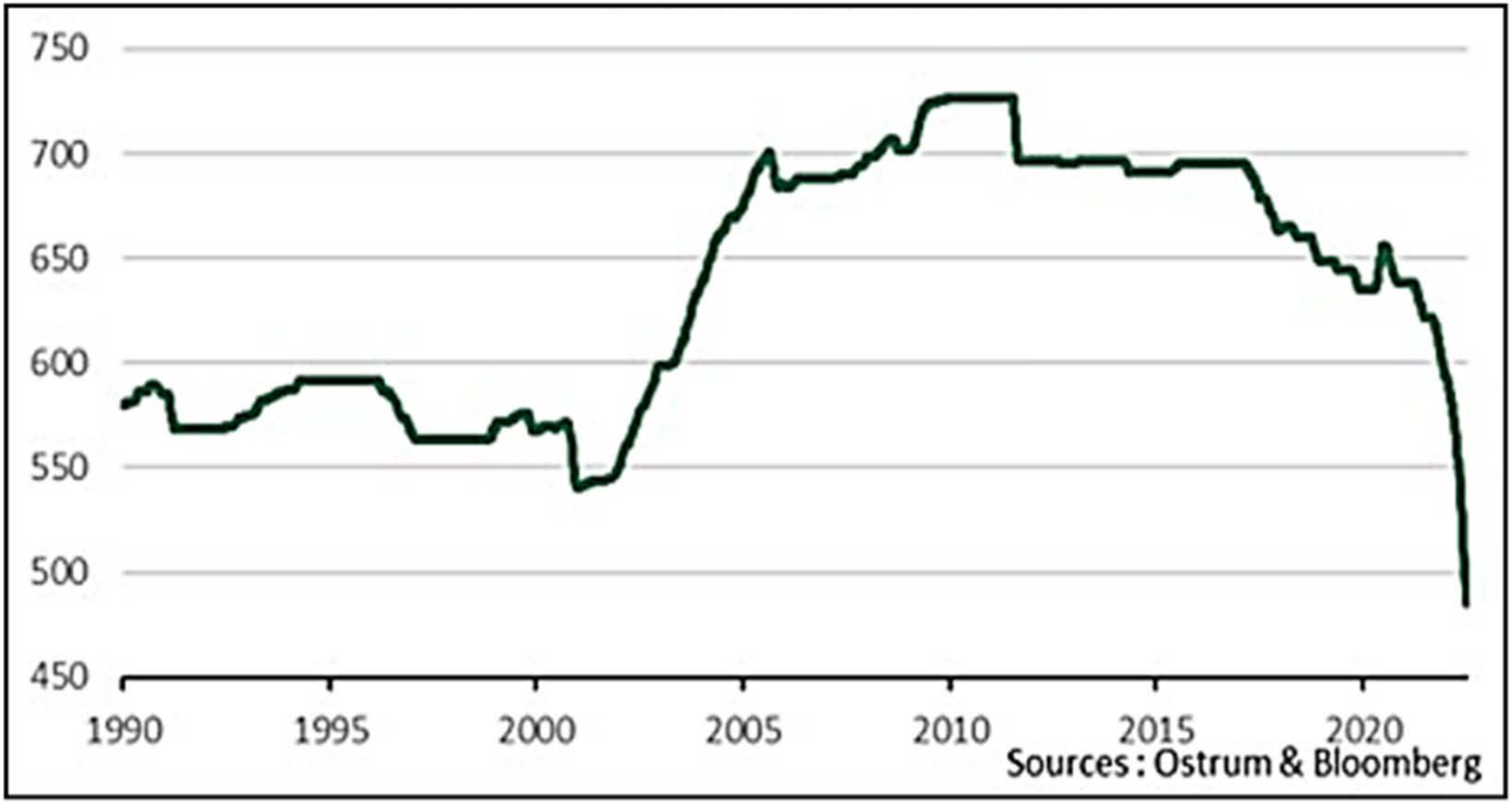

Figure 8. The Strategic Petroleum Reserve experienced historic drawdown in 2022, and now is at its 1984 level, during the filling phase.

	2015	2020	Change
Venezuela	2.8	0.6	(2.2)
Saudi Arabia	12.5	12.0	(0.5)
Nigeria	2.4	1.6	(0.8)
Angola	1.9	1.2	(0.7)
Kuwait	3.2	2.7	(0.5)
Libya	1.5	1.2	(0.3)
Algeria	1.2	1.1	(0.1)
Iran	3.8	3.8	--
UAE	3.4	4.2	0.8
Iraq	3.7	4.8	1.1
Congo	0.3	0.3	--
Equatorial Guinea	0.1	0.1	--
Gabon	0.2	0.2	--
Total	**37.0**	**33.8**	**(3.2)**

Figure 9. OPEC production 2015 to 2020. OPEC in 2020 was pumping 3.2 million barrels a day less than in 2015. Many OPEC members have not been able to hit their production targets. The world is very near it pumping capacity today (from Goehring and Rozencwajg [2021], reprinted with permission).

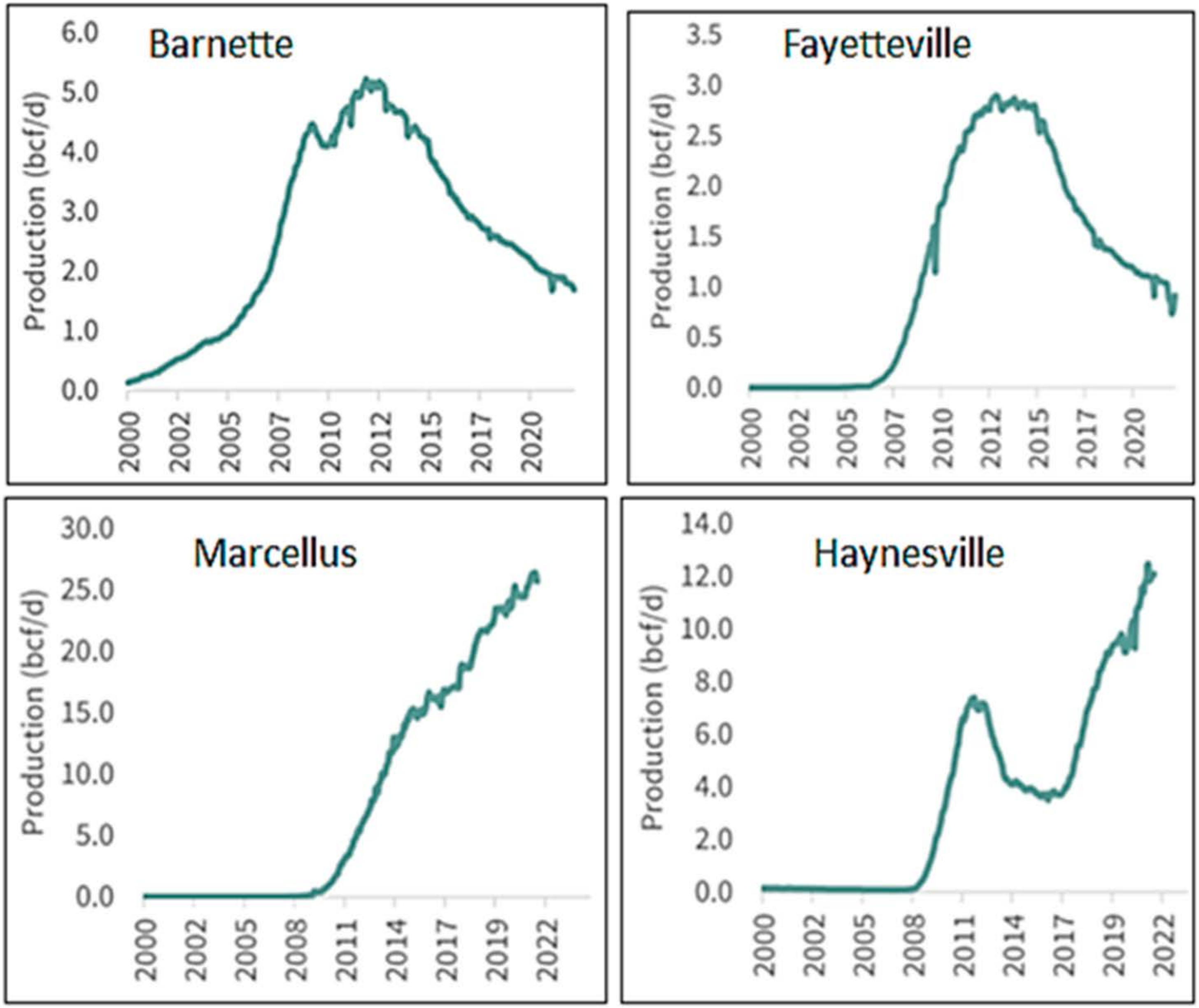

Figure 10. The four major shale gas plays of the US. The Barnette and Fayetteville are clearly in non-reversible decline. The Marcellus and Haynesville data suggest the fields might begin to decline in the next two years. Graph from Goehring and Rozencwajg (2021, reprinted with permission).

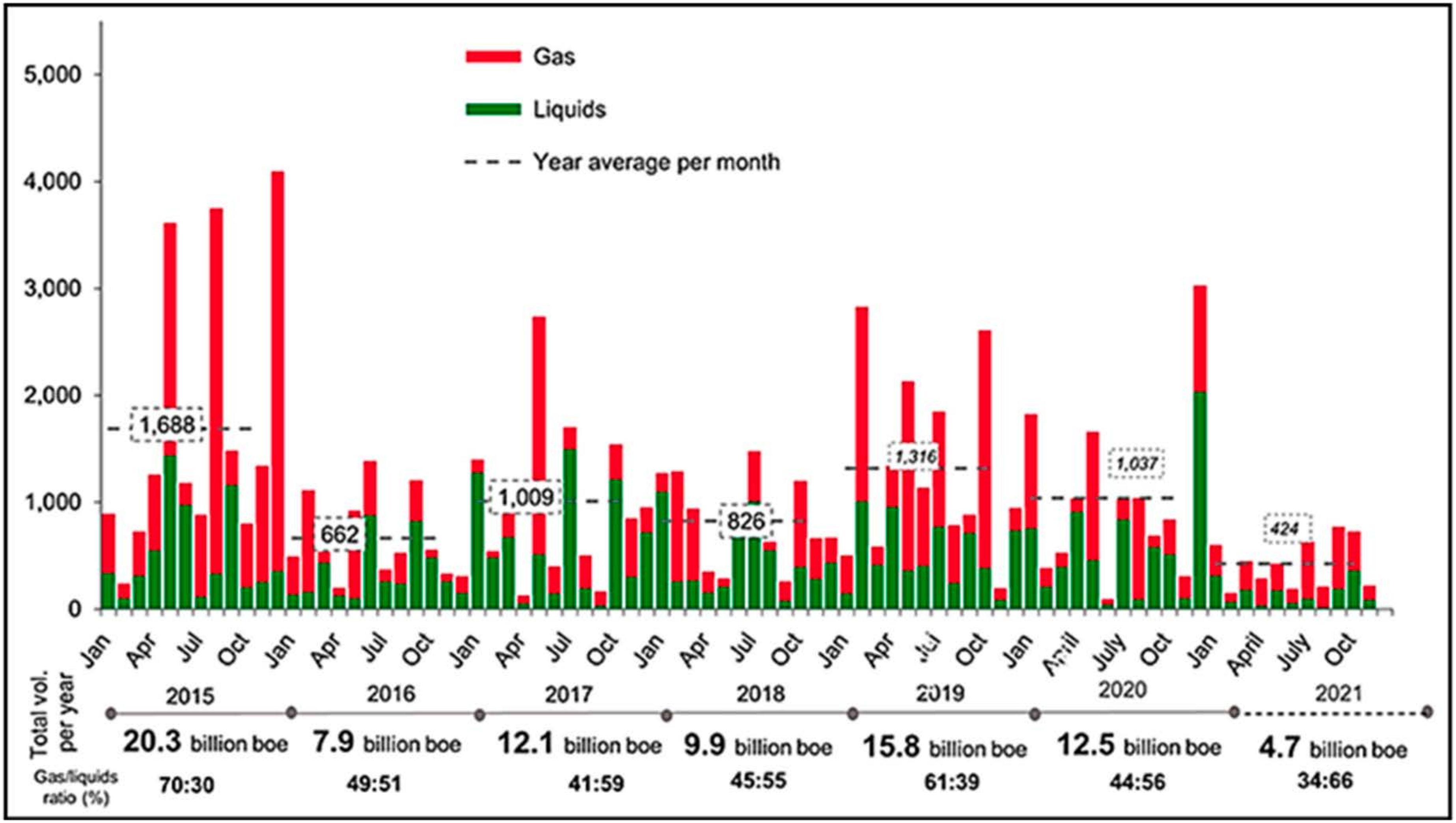

Figure 11. New field discoveries in 2021 were the lowest in 75 years. Volumes discovered were not enough to offset current oil and gas fields' decline and demand growth from population and economic growth. Source: Rystad Energy (2022).

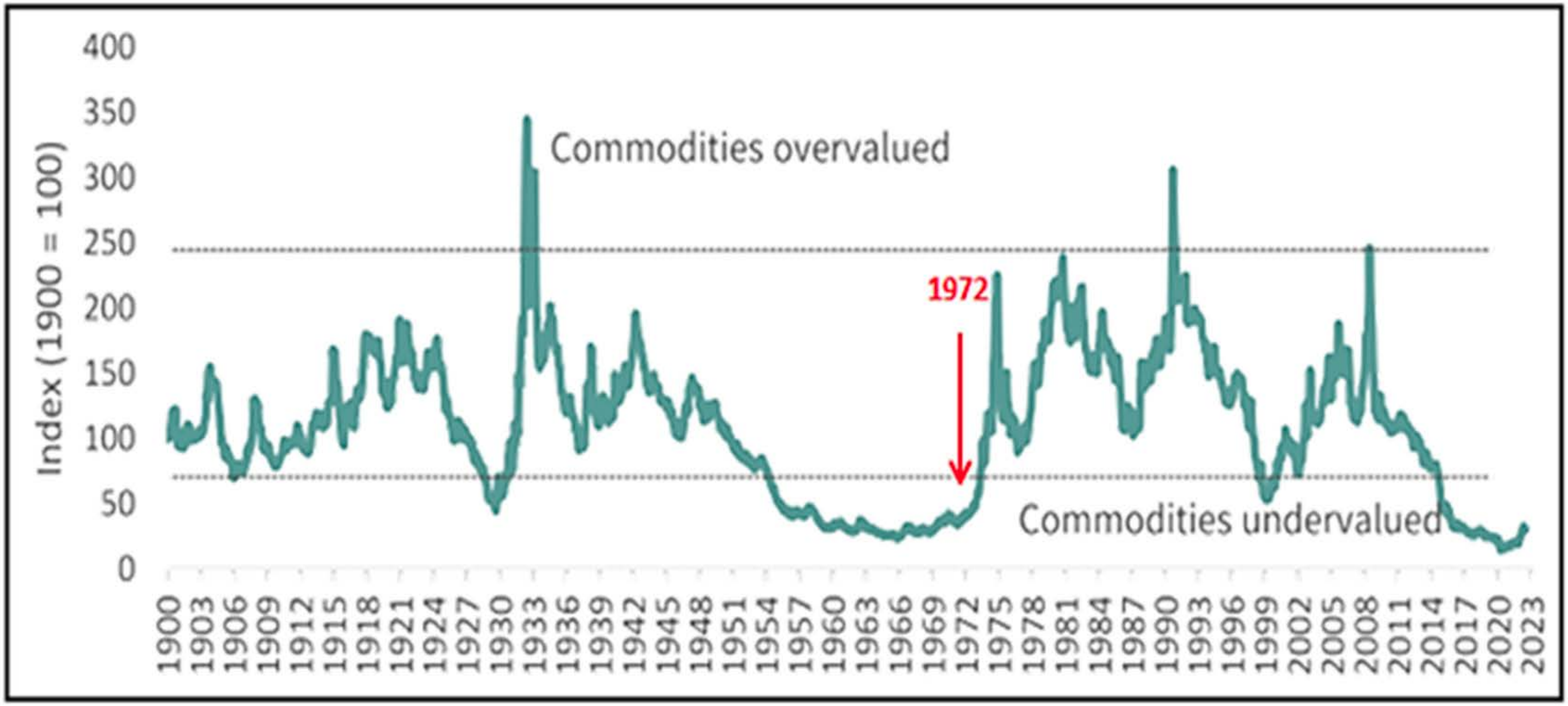

Figure 12. Commodities relative to Dow Jones Industrial Average, 1900 to present, 1900 = 100. Commodities clearly go through cycles. Commodity prices today are more undervalued than they were in 1972, just prior to the 1970s "decade of commodities." Graph from Goehring and Rozencwajg (2022a, reprinted with permission).

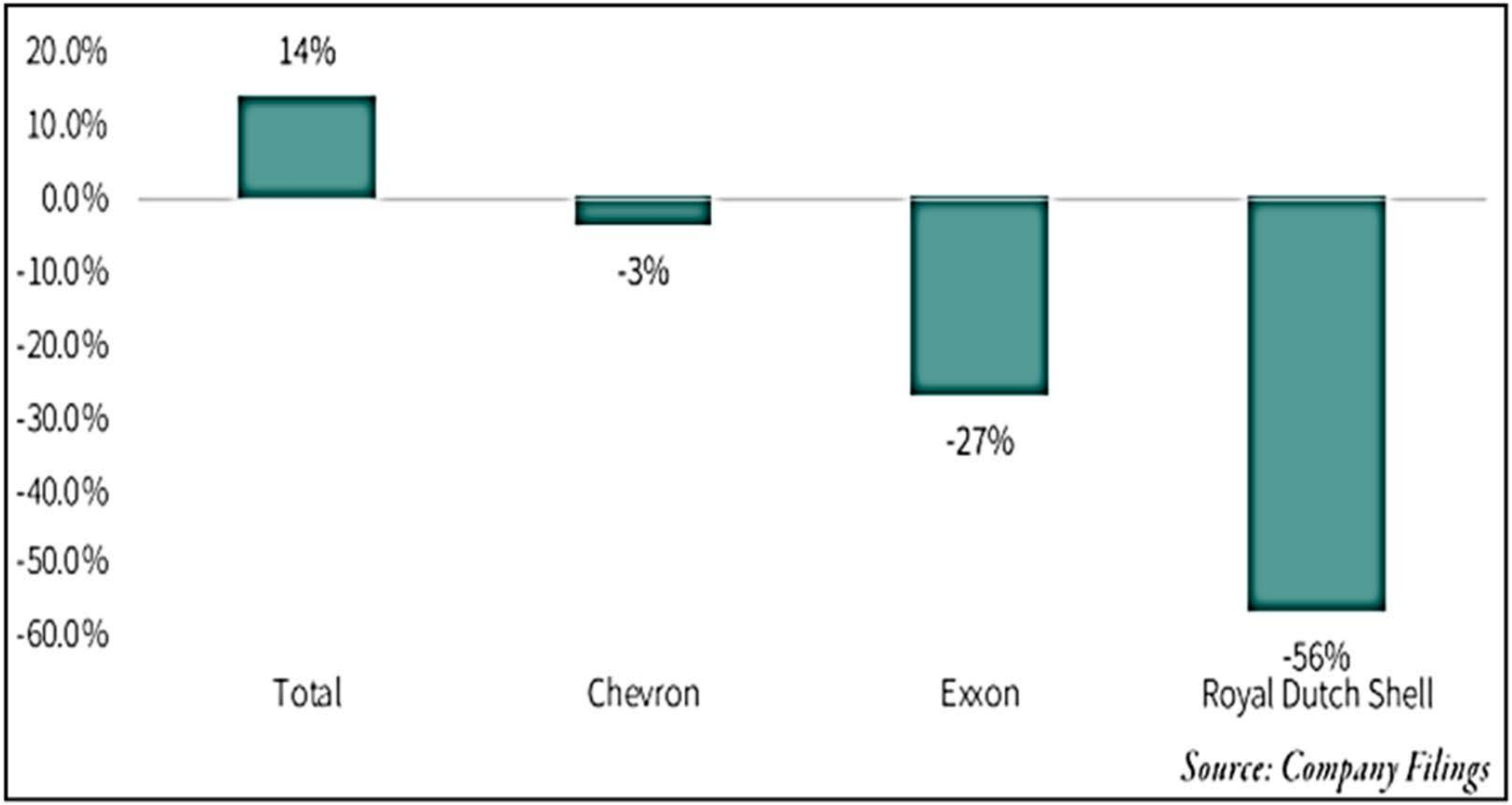

Figure 13. Major oil company's reserves growth 2000 to 2020 (BOE) (from Goehring and Rozencwajg [2021, reprinted with permission]).

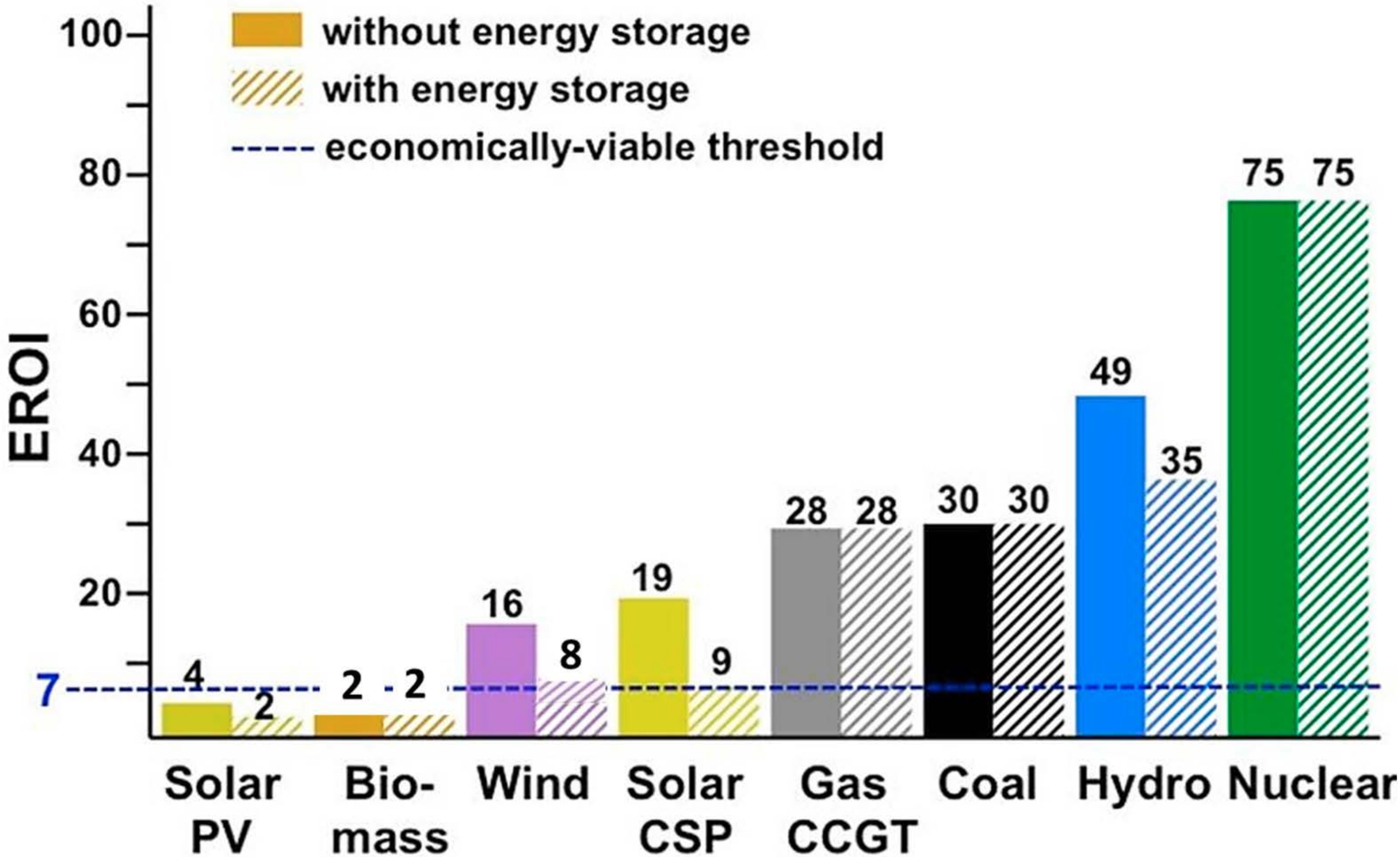

Figure 14. Energy returned on energy invested (EROI). Both the "nameplate" and the "buffered" EROI are shown. Natural gas, coal, and nuclear can run 24/7. They do not have a "buffered" number. Solar CSP indicates concentrated solar power. Gas CCGT means combined-cycle gas turbine. Data modified after Weissbach et al. (2013). Biomass EROI is approximated from range of 1.28 to 2.23 reported by Wang et al. (2021).

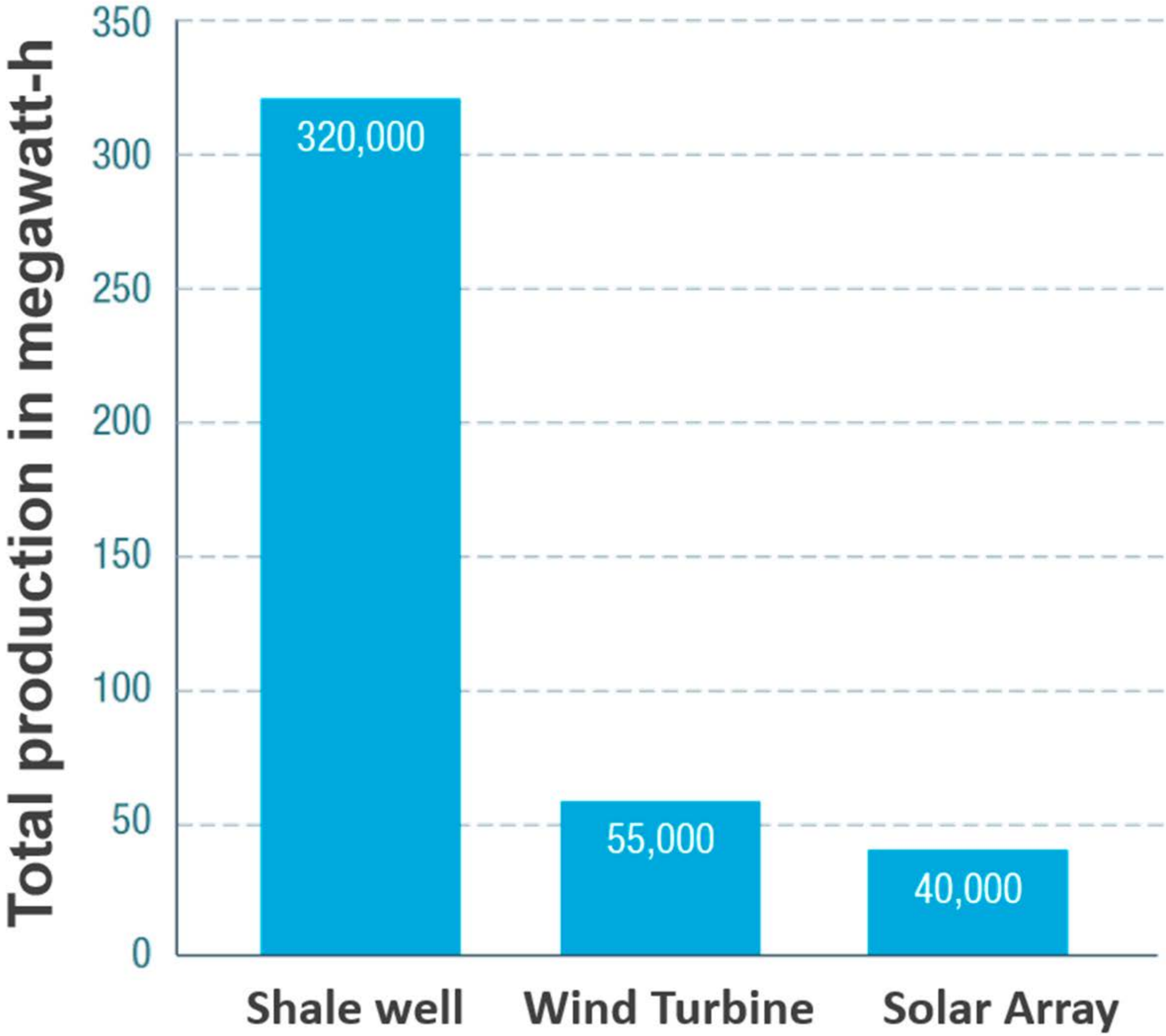

Figure 15. Total electricity in megawatt-hours over 30 years for each $1 million invested in shale well, wind and solar power sources (from Mills [2019]). Natural gas produces 5.8 times more electricity than wind, and 8 times more than solar for each $1 million invested.

Energy return on $3 billion Investment
Permian Horizontals vs biofuels

Permian Horizontals
200 mm bbls in first 4 years
30:1 EROI
1.1 billion gigajoules in 4 years

Biofuels
45 mm bbls in first 4 years
3:1 EROI
200 mm gigajoules in 4 years

Figure 16. If the $3 billion spent on buying a biodiesel company had been invested in drilling wells in the Permian, it would have produced 5.5 times more energy in the first 4 years. Data and analysis by Rozencwajg (2022).

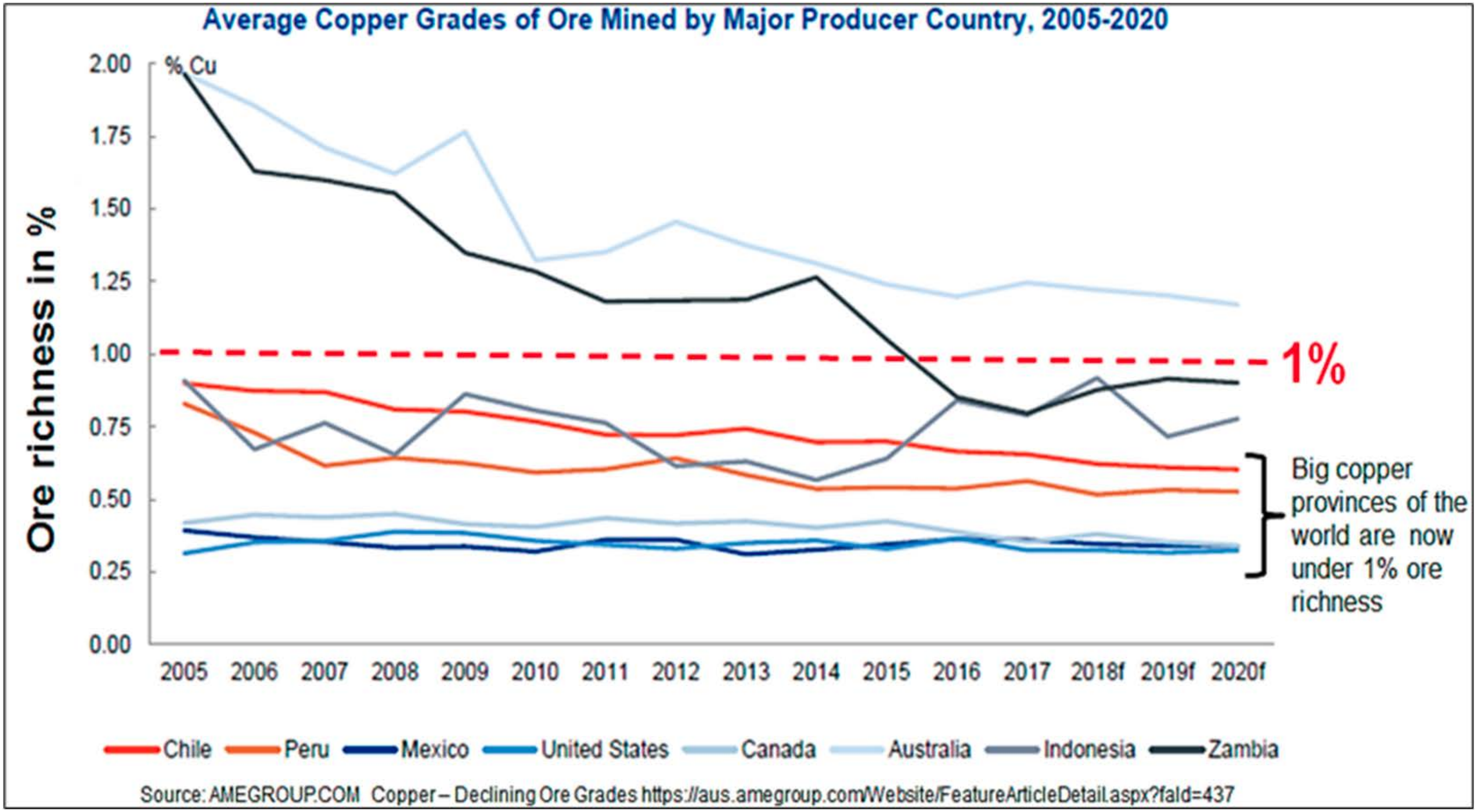

Figure 17. The planet has past "peak minerals." Graph modified after Northey et al. (2014).

Figure 18. US debt as a percent of GDP 1825 to present. Debt spiked in World War II but quickly fell to 50% by 1961. The debt reduction was accomplished by growing the economy at a blistering pace and allowing inflation to rise while keeping total debt constant. Today the debt to GDP is as high as World War II. Graph based on data from Longtermtrends (2022).

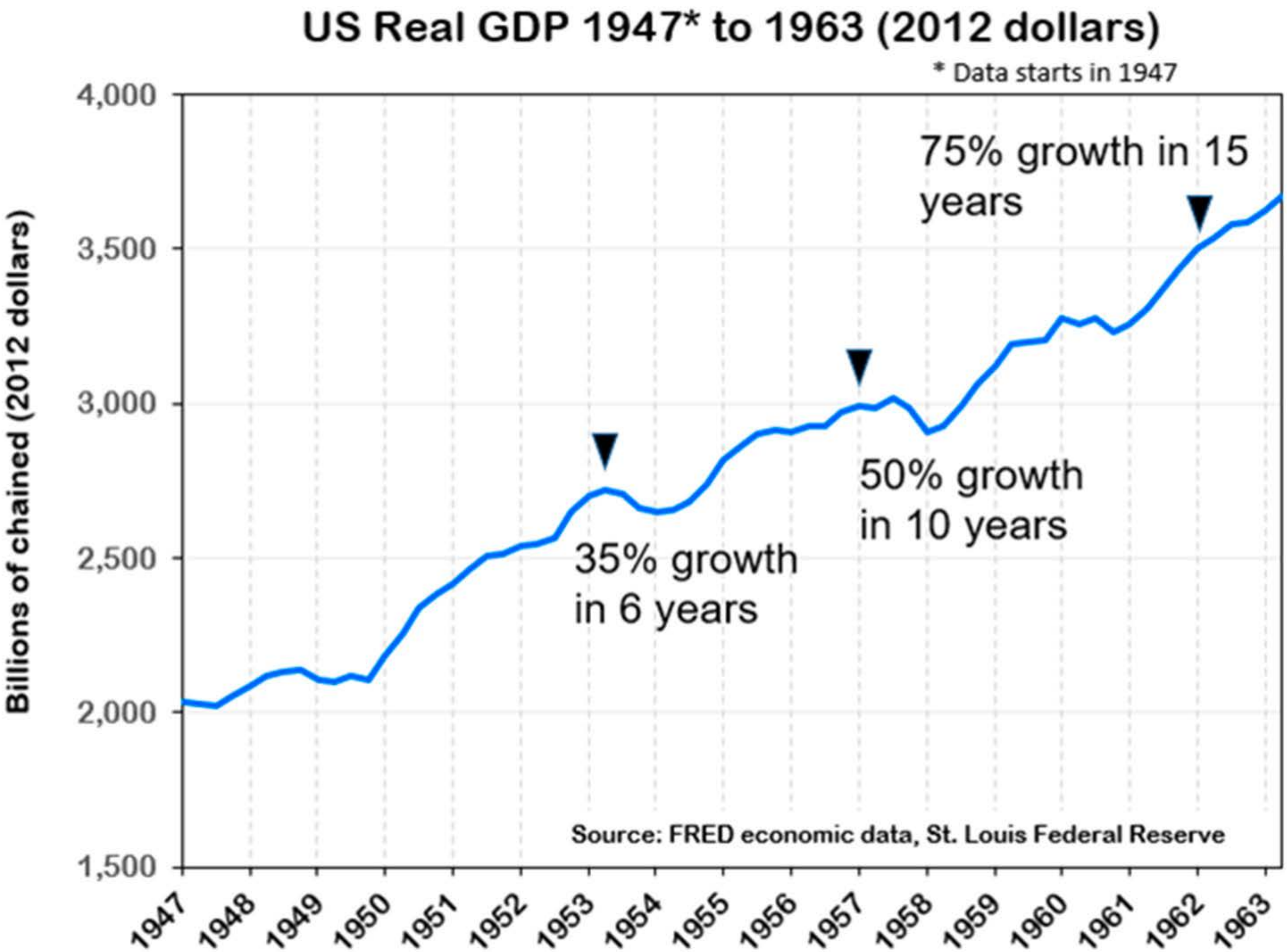

Figure 19. Growth in US GDP in real terms (meaning growth corrected for inflation) after World War II, 1947 to 1963. The economy exploded because America had the only manufacturing base on the planet that was not bombed to rubble. Data from Federal Reserve Bank of St. Louis (2023).

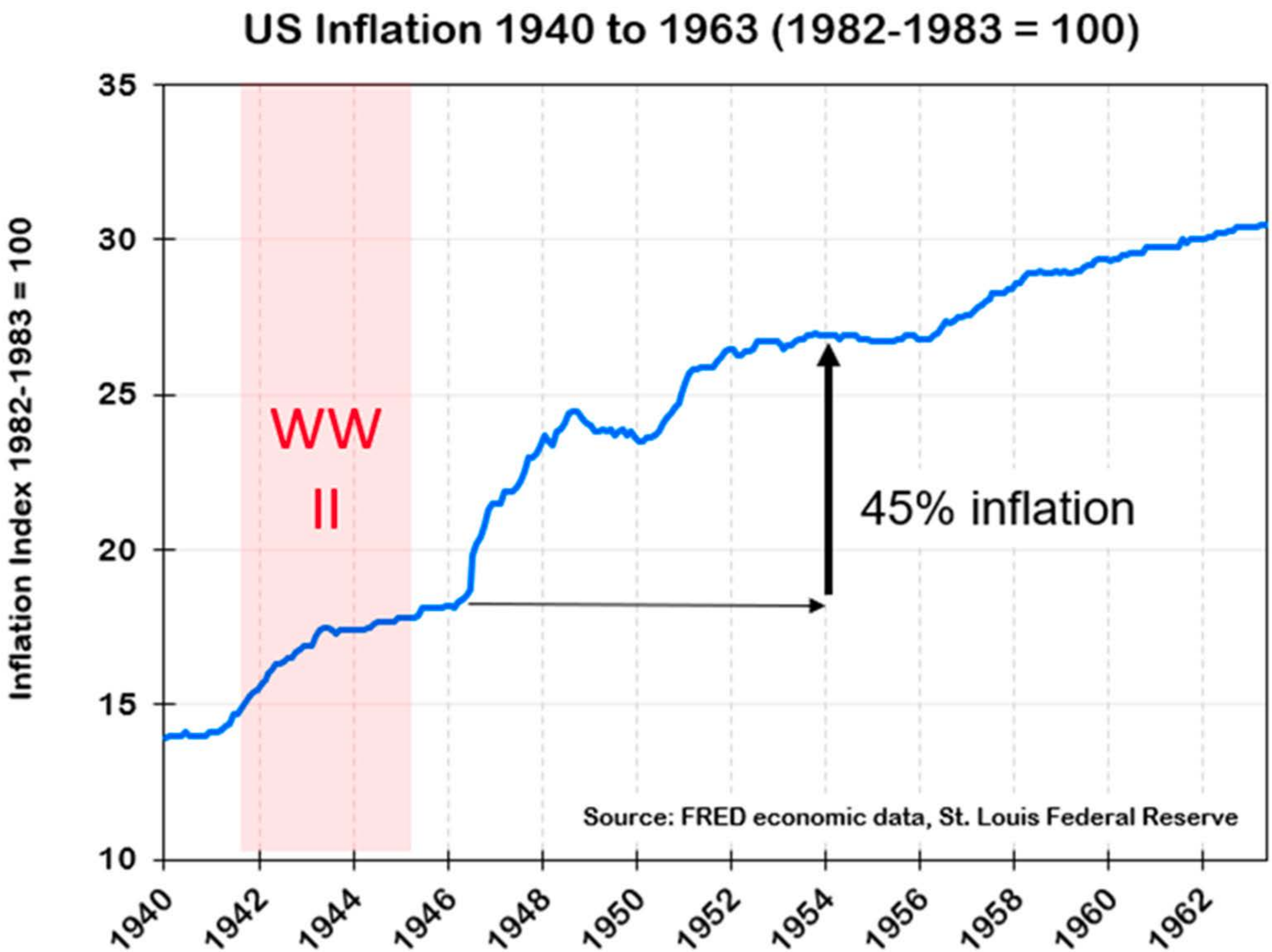

Figure 20. US Cumulative inflation after World War II. In eight years, the US had 45% inflation. Data from Federal Reserve Bank of St. Louis (2023).

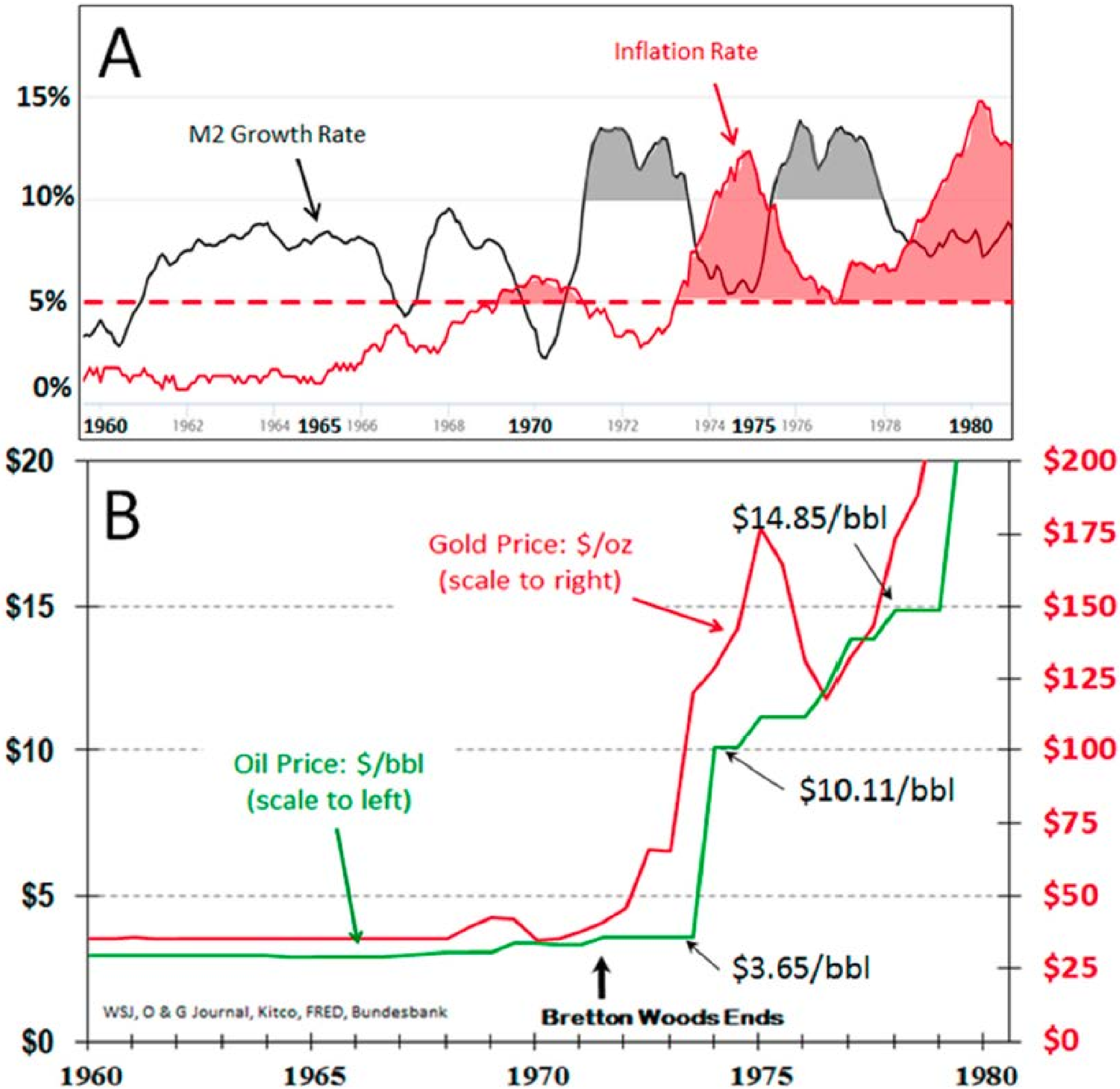

Figure 21. (A) Money supply (M2) and Inflation rate. (B) Oil and gold prices in dollars-of the day. Inflation and growth in M2 lead oil price rises, 1960–1981. Oil prices rose in response to the declines in US dollar and inflation (DeMis, 1996, 2019). Profligate growth in the money supply in 1960 drove inflation. M2 exceeded 10% in 1971 to 1973 and again 1975 to 1978 (gray shading). The Bretton Woods Accord pegged the US dollar to gold but it ended in August 1971. The dollar fell 21% in 20 months after Bretton Woods ended and gold soared to $120/oz *before* OPEC raised prices. OPEC actions were a response to lost purchasing power. Modified after DeMis (2021). Inflation and M2 money supply data from Longtermtrends (2022).

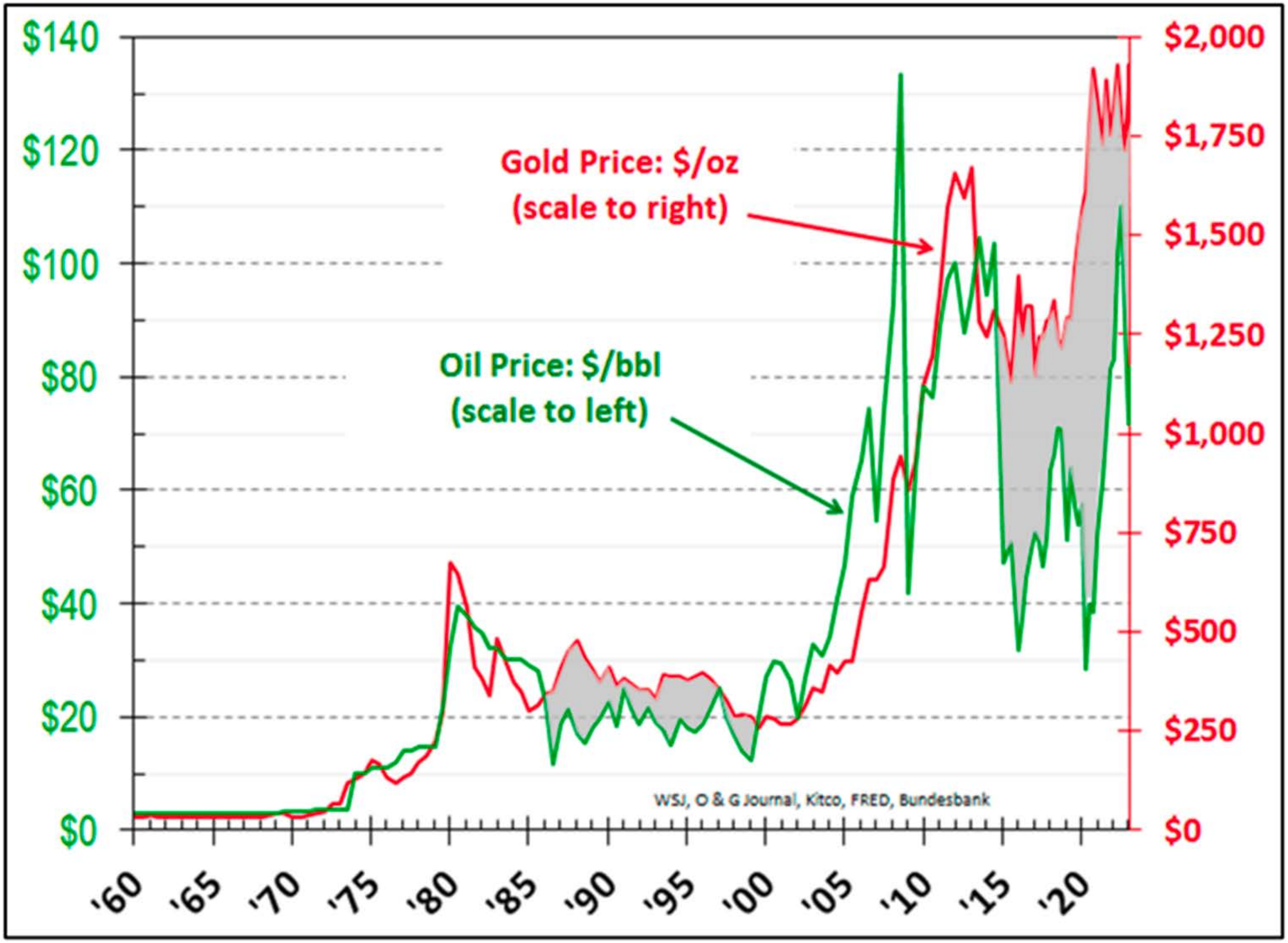

Figure 22. Price of gold and oil in dollars-of-the-day. The two prices track each other over long periods of time. During times of excess supply, this relationship becomes decoupled (areas shaded gray). When supply is tight, OPEC makes up for lost purchasing power (DeMis, 1996, 2019). Oil prices need to rise to $135 per barrel to restore the goldoil price relationship.

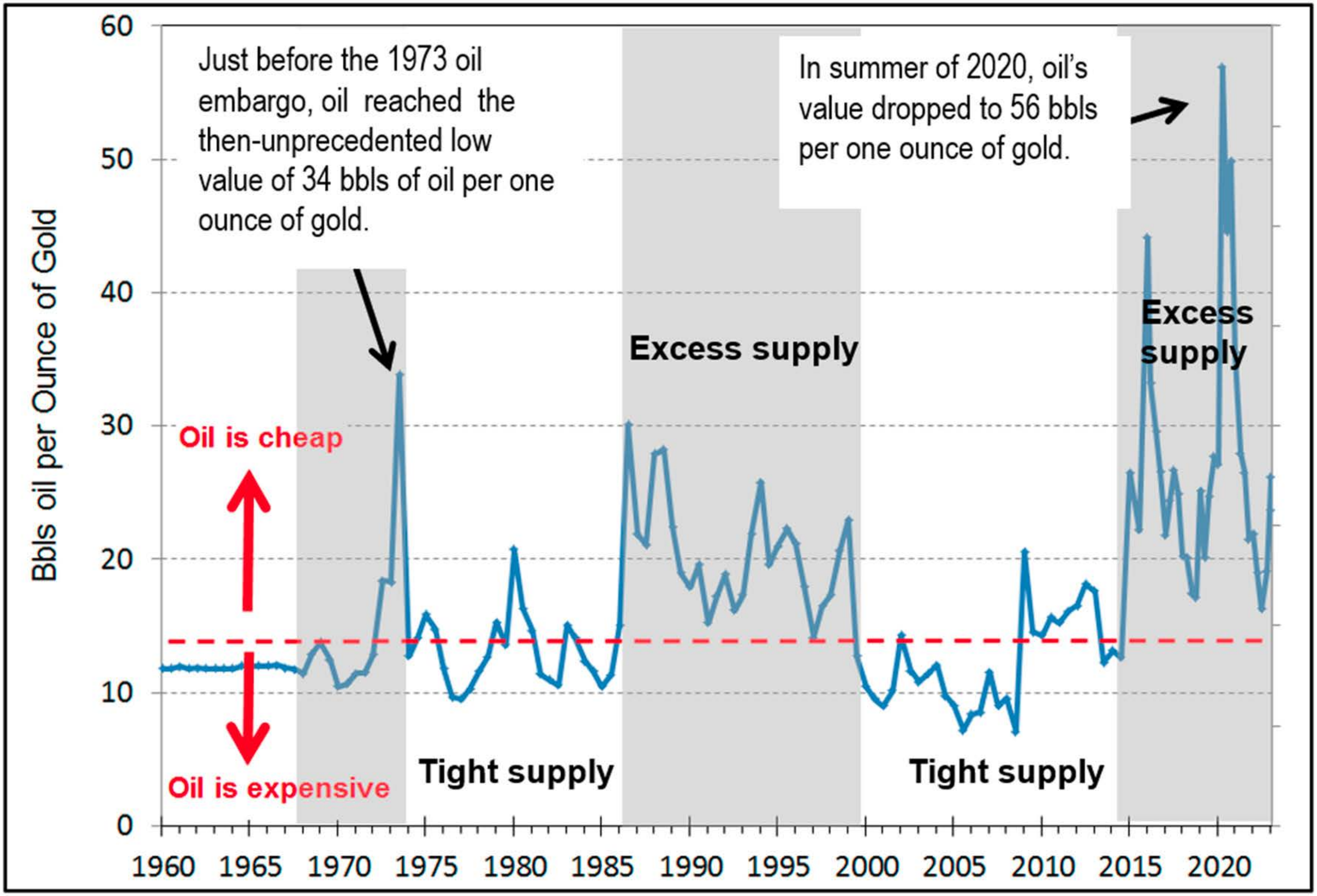

Figure 23. Number of barrels of oil one ounce of gold can buy. Times of excess supply are shown in gray when oil was relatively cheap with respect to gold. Compare to Figure 21. Before 1971, the price of gold was fixed at $35/oz by the Bretton Woods Accord, therefore the relationship pre–1971 is artificial. In summer of 2020, oil's value relative to gold was at an all-time low, and signaled the excess supply cycle was ending (DeMis, 2021).

Energy, Land, Cost, Material Analysis

	Roserock Solar	Haynesville Well	Haynesville Equivalence	
	20 year contract life per ERCOT	10,000' lateral metrics (22,000' MD; 2.0 BCFG/1000' lat)	1.163 Haynesville wells equals power output of 1 Roserock	Difference
Megawatt-Hours[1]	7,035,477	6,047,600	7,035,477	same
BCFGE EUR	23.27	20	23.27	same
Gigajoules[2]	25,327,717.9	21,771,360	25,327,717.9	same
Land used, Acres	1300	6	7	186x
Cost Millions*	$405.3	$25.0	$29.08	14x
Material (Tons)	6328	664	772	8.2x

Footnotes:
1 - one Gft^3 NG = 302380 MWh
2 - one Gft^3 NG = 1,088,568 GJ

*No operating cost included for 20 year contract life of Roserock.

*Well cost $18 million D&C, surface facilities, plus 20 year of op ex at $30K/mo totaling $7 million.

Table 1. Roserock Solar and Haynesville energy comparison. Roserock power output over 20 year contract life is also shown in billion cubic feet of gas equivalent and gigajoules. The base-case Haynesville well is center column (shaded gray). EUR of 2 billion cubic feet of gas per 1000 feet lateral is low. Roserock uses 186 times more land, costs 14 times more, and uses 8.2 times more material to produce the same power as 1.163 Haynesville wells. No operating costs are included for Roserock. Twenty years of operating costs ($7 million) are added to each Haynesville well. This analysis intentionally favors solar but solar is still a poor investment.

	Roserock Solar	Haynesville	
	20 year life metrics	$405 million put into 16.212 Haynesville wells	Haynesville Roserock Solar
Megawatt-Hours[1]	7,035,477	98,043,691	14x
BCFGE EUR	23.27	324	14x
Gigajoules[2]	25,327,717.9	352,957,288	14x
Land Used, Acres	1300	97	7%
Cost Millions*	$405.3	$405.3	same
Material, Tons	6328	10,758	170%

Footnotes:

1 - one Gft^3 NG = 302380 MWh

2 - one Gft3 NG = 1,088,568 GJ

*No operating cost included for 20 year contract life of Roserock

*Well cost $18 million D&C, surface facilities, plus 20 year of op ex at $30K/mo totaling $7 million

Table 2. Economic malinvestment is manifest in a comparison of the power that could have been produced by investing Roserock's $405.3 million in Haynesville wells. For price of one Roserock, 16.212 Haynesville wells would produce 14 times more power and only occupy 7% of the land as Roserock. The Haynesville wells use 70% more material.

Energy, Land, Cost, Material Analysis

	3 MW Wind Turbine	Haynesville Well	Haynesville Equivalence	
	25 year life	10,000' lateral metrics (22,000' MD; 2.0 BCFG/1000' lat)	0.0358 Haynesville wells = 25 year life one of 3 MW wind turbine	Difference Wind and Haynesville
Megawatt-Hours[1]	216,810	6,047,600	216,806	same
BCFGE EUR	0.717	20	0.717	same
Gigajoules[2]	709,560	21,771,360	709,746	same
Land Used, Acres	120	6	0.215	558x
Cost Millions*	$3.6	$25.0	$0.90	4x
Material, Tons[3]	248	772	9	3.6%

Footnotes:
1–one Gft^3 NG = 302380 MWh
2–one Gft^3 NG = 1,088,568 GJ
3–material from NREL (2015)

*No operating cost included for 25 year life of wind turbine. Wind turbines are space 60 acres per MW.

*Well cost $18 million D&C, surface facilities, plus 20 year of op ex at $30K/mo totaling $7 million.

Table 3. Three MW wind turbine and Haynesville energy comparison. Wind turbine power output for 25 years. Base-case Haynesville well is center column (shaded gray). A single wind turbine requires 248 tons of material (Mone et al., 2017). Wind turbine material does not include 1000 tons cement and rebar for base. Twenty-five years of wind turbine power is 3.58% of a Haynesville well's power output. Twenty-eight wind turbines equal the power output of one Haynesville well. The 28 would require 6696 tons of material, not including the base, and cost $100 million, or 4 times the cost of 1 well.

	Demand growth by 2040
Lithium	up 4200%
Graphite	up 2500%
Cobalt	up 2100%
Nickel	up 2500%
Manganese	up 800%
Rare-earth minerals	up 700%
Copper	up 200%

Table 4. Growth in demand by 2040 for key energy transition minerals (Source IEA, 2021).