A Realist Assesses the Energy Transition

Laurence B. Siegel
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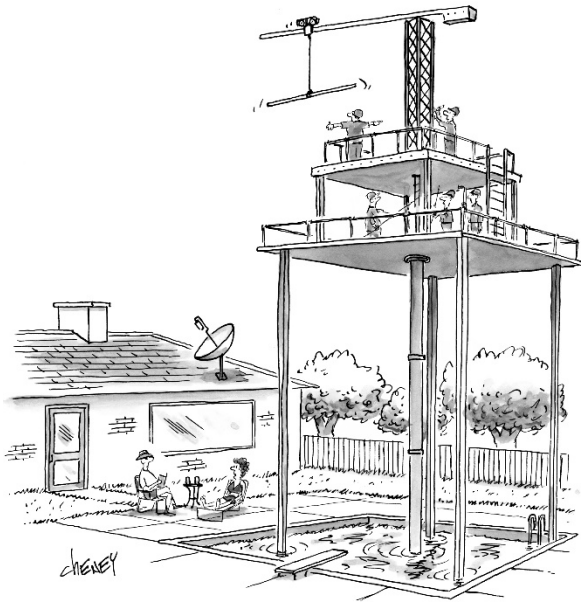
> There are only three things that make up the universe: energy, materials, information. That's it.
> The nature of those materials, the information about them, what we know about them,
> and how we can assemble them by using energy produces everything.
> Not some things but everything.
>
> –Mark P. Mills

Will the energy transition, from fossil fuel to other sources of energy, happen? It seems almost sacrilegious to suggest that it might not, or that the transition will be halting and incomplete. But Mark Mills, a physicist, venture capitalist, and energy and technology expert who spoke at Foundation Financial Officers Group in New York in April, powerfully made the case that fossil fuels will be an important part of the world economy for a long time to come.

The principal reason is that fossil fuels are many times more efficient as an energy source than the alternatives. And the raw materials needed to build out a fully electrified global energy industry are expensive, difficult to obtain, and subject to severe supply constraints.

If Mills is correct, then *preparing to adapt* to climate change, rather than trying to prevent it, becomes the most important priority.

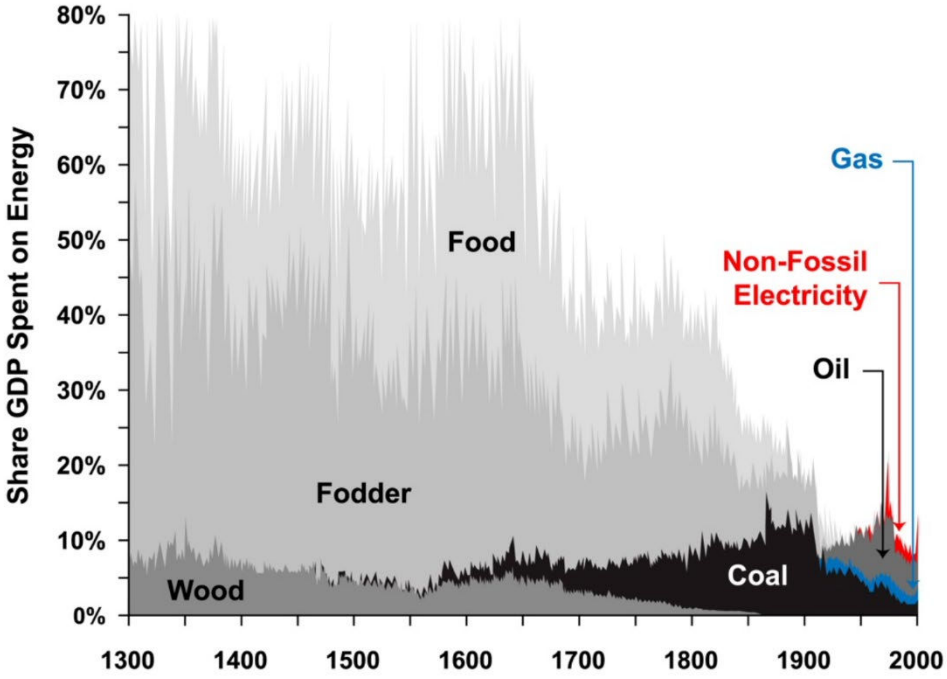


"I liked our little pool better before we authorized offshore drilling."

Energy has gotten radically cheaper

Mills began by showing, in Exhibit 1, that the proportion of the world's GDP spent on energy-in-the-large, including food and animal feed, has decreased by an order of magnitude since the early modern era. A society that spends upwards of 70% of its income on food and fodder is poor indeed. It's interesting that this picture began to improve in the mid- to late 1600s, a century before what we ordinarily think of as the Industrial Revolution.

Exhibit 1
Share of World GDP Spent on Energy (including Food and Fodder)



Source: Mark Mills

But energy costs as a share of GDP didn't really fall off a cliff until the rapid industrialization of the nineteenth century, powered by coal and then oil and gas. This may be counterintuitive: don't heavy industries use a lot of energy? Yes, but an industrial economy is so much more productive than an agricultural and handcraft economy that the denominator — world GDP — grew massively. Thus, the energy *share* fell even as the absolute consumption of energy soared.

And, interestingly, the energy share of GDP has remained about the same —around 10% — since the early 1900s. This is not because energy use remained stable, but because energy use and economic output exploded upward roughly in tandem.

Save the whales

We've undergone energy transitions before. Prior to the widespread use of liquid and gaseous fossil fuels, we obtained much of our energy for lighting and other uses by *killing whales*. Mills credits a Canadian doctor and geologist, Abraham Gesner (1797-1864), with saving the whales. Gesner invented kerosene. Although naturally occurring petroleum was not available at scale until later, Gesner devised a way of extracting kerosene from coal in 1845 and that was the beginning of the end of whaling. If ever there was an unsung hero of the environment, it's him.

Abraham Gesner

Source. Artwork by Irma Coucill

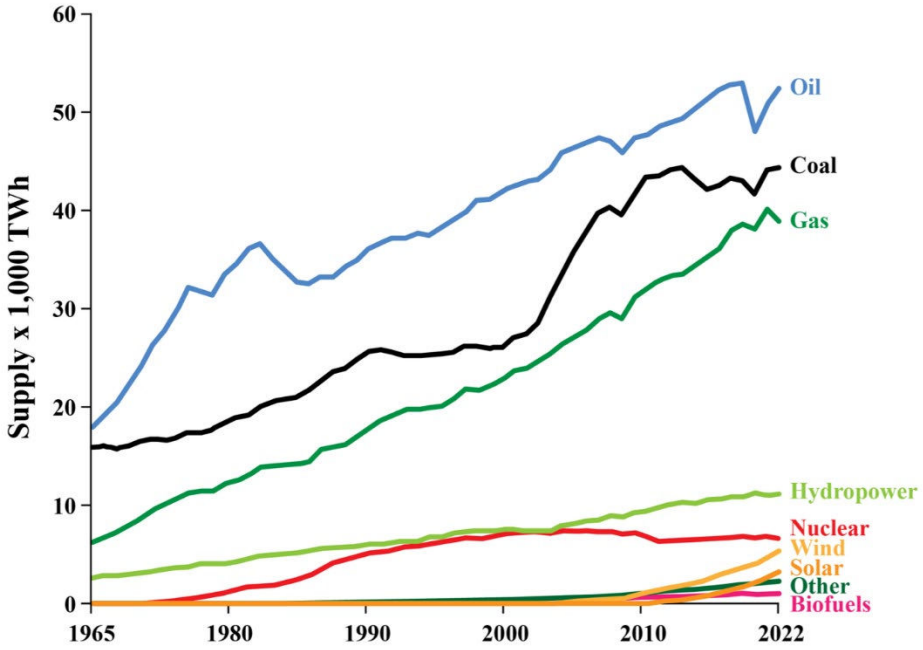
This nugget supports the idea, expressed in my 2019 book *Fewer, Richer, Greener*, that pre-industrial living is the most environmentally destructive way of life known to man. The more resources we have, the easier it is to protect and improve the environment. To get green, get rich.

Is fossil fuel use growing or shrinking?

Fast forward to the current time. There's good news and bad news on energy use. Let's start with the bad news.

On an aggregate basis, fossil fuel use just keeps going up and up and up, as shown in Exhibit 2. This is due to population growth and economic growth, and counteracts the steady increase in the energy efficiency of most heating, lighting, industrial, and transportation uses.

Exhibit 2
World energy supply, by energy source, 1965-2022



Source: Mark Mills

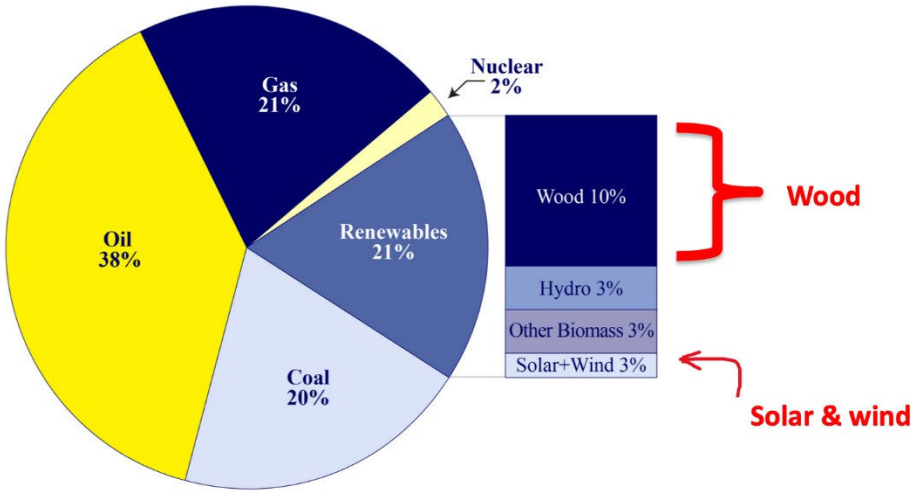
Note the uptick in "new" renewables (wind and solar) toward the end of the period. It's not much, but it's in the right direction and additive to one of the oldest renewables, hydropower, which increased steadily over the period. The failure of nuclear power to grow at all in the second half of this period is a global embarrassment. "Other" includes geothermal, which has some promise.

The good news is that, on a *per capita* basis, fossil fuel use has been relatively stable for 40 years and oil use has actually gone down. This decline is due to increased efficiency, not a decrease in the demand for the services oil produces.

But, because of economic growth in the world's poor regions (and we don't want that to stop!), the demand for fossil fuels keeps rising and will continue to. Only 7.5% of households in India have cars, a number that will grow in that increasingly prosperous country. Sub-Saharan Africa is in a similar situation not as far along that path.[1] These regions do not have the energy infrastructure to support a rapid switch to electric vehicles. Oil bears, watch out.

Mills summarizes his skepticism about the current state of the energy transition with Exhibit 3. This discouraging diagram indicates that renewables other than wood (yes, wood is still used to generate energy and is still important) sum to only 9% of global energy supply.

EXHIBIT 3
CURRENT GLOBAL ENERGY MIX



Source: Mark Mills

[1] PPP GDP per capita as of 2022/2023: India $9,172, sub-Saharan Africa $4,640 (World Bank data).

But won't this energy mix change radically?

Mills says no. It will change glacially, as the environmental cost of using fossil fuels is balanced against the financial, technical, and human cost of not using them. Meanwhile, as Mills wrote in the Pittsburgh Post-Gazette: "To reduce the world's use of hydrocarbons, we need to use … more hydrocarbons."[2]

In the very long run, a transition from fossil fuels to other energy sources *will* happen. Even if CO_2 emissions were harmless, there is only so much oil. We are nowhere close to running out of it, but as it becomes more difficult to find new deposits (the easy ones having been exploited first), its price will go up relative to other energy sources. This would cause an old-fashioned economic — as opposed to political or moral or engineered — energy transition.

Living in a material world

Moving on from energy to materials… Of the three "things" that Mills described in the epigraph as making up the whole universe — energy, materials, and information — materials are the least appreciated in the modern world. Everyone is aware of the importance of energy, and if you are reading this you probably manipulate information all day, but we take materials, "stuff," for granted.

Our recent ancestors, however, did not. In 1910, some 1.2 million Americans out of a labor force of 37.5 million were engaged in the dangerous vocation of mining. That's 3.2% of the labor force. (Today the number is 556,000, or 0.36% of our many times larger working population.) Materials were on everybody's mind, especially those who did not know if their spouses would return from work that day in a box.[3]

The nine materials basic to modern life

Yet we need materials now as much as we did in 1910. Which materials? Ed Conway, a Harvard professor and journalist, says in his book, *Material World*, that the "six raw materials that shape modern civilization" are sand, salt, iron, copper, oil, and lithium. In *How the World Really Works*, Vaclav Smil, one of the world's leading experts on both materials and energy, identifies the building blocks of modern life as ammonia, plastic, steel, and cement. (Ammonia is used for fertilizer and, without it, many of us would starve.) Removing the one duplicate — steel is mostly made of iron — that's nine materials which underlie the way we live. Without them, energy and information wouldn't help us much.

[2] On December 6, 2023 at https://www.post-gazette.com/opinion/Op-Ed/2023/12/06/mills-hydrocarbons-energy-transition-oil-gas-coal/stories/202312060007.

[3] My father-in-law was in a coal mine fire. He survived. It was not that long ago (about 1948).

DECARBONIZING THE WORLD – NECESSITY OR PIPEDREAM?

From Mills' New York speech, here's his take on the role of materials in an energy transition:

> To decarbonize the world's electric system — forget about everything else, just electricity, one-fifth of the world's energy — you'd have to build and install 1000 three-megawatt wind turbines, each the size of the Washington Monument, *every day for 30 years*.
>
> That construction program isn't possible and it isn't going to happen.

So, what *will* happen? "We're going to try anyway," Mills continues,

> and that will result in a much greater use of physical materials. If you go up the chain from a [fossil-fuel driven] combustion turbine to a hydro dam to a wind turbine to a solar array, the physical quantity of common materials — steel, glass, and concrete — goes up tenfold per unit of energy delivered to society. The same hour of light in this room, same hour of heat, same hour of computer time, requires a tenfold increase in common material use.
>
> This has to have a cost consequence. Those materials are widely available but it costs money.

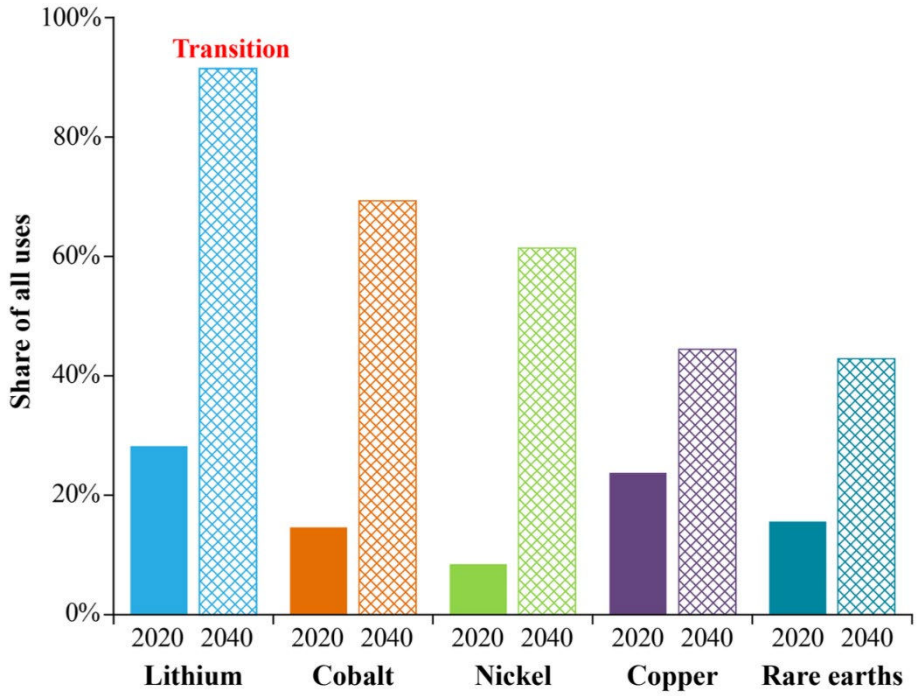
Mills then noted that the "more interesting" challenge is the use of metals and minerals that are rare. In the contemplated transition from fossil fuels to renewables, the use of such materials rises *20-fold to 50-fold* per unit of energy delivered to society. The analogy shifts from the slender Washington Monument to the massive Great Pyramid at Giza:

> The world *already* digs up an amount of earth equal to 7000 Great Pyramids per year to shift from gas, oil, and coal to the minerals required for the energy transition. These include nickel, cadmium, tellurium, obviously lithium, and cobalt among other minerals. You would have to dig up 50,000 Pyramids' worth of the Earth each year to get [enough of] those minerals [to complete the transition].

Such an effort, Mills concludes, would "result in energy minerals utterly dominating the use of minerals for all purposes" as shown in Exhibit 4.

EXHIBIT 4

IN AN ENERGY TRANSITION, MATERIALS USED FOR ENERGY WOULD DOMINATE ALL OTHER USES



Source: Mark Mills

Because Exhibit 4 is a little hard to read, let's interpret it using one material, lithium. In 2020, lithium used in the production of energy amounted to 27% of all the lithium used in that year. In 2040, if the energy transition goes as planned (which, Mills reminds us, it will not), lithium used for energy will amount to 91% of all lithium used in that future year. Note that the denominator, the total amount of lithium used in a year, changes over time, presumably increasing not decreasing. So energy-related uses of lithium will crowd out other uses and also send the price skyward. The same holds for cobalt, nickel, copper, and rare earths.

Materials, then, are a constraining variable — likely *the* constraining variable — for the oil-to-renewables transition. (There's also money. The supply of materials and of money are tightly bound together by the supply-demand-price system.)

"WE'RE GOING TO SEE HOW HOT IT GETS"

"If something cannot go on forever, it will stop," said Herb Stein, the Nixon Administration economist and father of the better-known economist and entertainer Ben Stein. Applying this principle, if something cannot happen, it won't. We cannot build and install 1000 three-megawatt wind turbines a day for 30 years, and we probably cannot (and should not try to) dig up 50,000 Great Pyramids' worth of dirt each year to obtain rare minerals. So a full energy transition from fossil fuels to renewables will not happen. We are going to continue to emit a significant amount of carbon dioxide into the atmosphere and, as the economist and blogger Tyler Cowen is reputed to have said, "Mostly we're just going to see how hot it gets."

No nukes is good nukes? Think again

But a *partial* decarbonization transition *will* happen, because it's both needed and possible. It will involve lots and lots of widely disliked nukes. (By "nukes" I mean fission reactors. If fusion becomes commercially viable at scale during the relevant time horizon, all bets are off.) Going the nuclear route, we'd have to build and fuel 5,000 three-gigawatt reactors to replace the fossil-fuel energy we consume today. But that's just a start! As the developing world industrializes and becomes prosperous, future energy needs will be a multiple of current needs.

I'm not a nuclear engineer, so I don't know if this building program is doable, but it sounds more practical than covering the Earth with wind turbines, solar panels, and battery farms. There are already 436 nuclear reactors in the world, and we haven't been trying very hard to build new ones. A 10x ramp-up is ambitious but does not sound completely out of reach. The materials requirements, including both uranium fuel and whatever reactors are made of, would be daunting, but those are topics for another day.

So, encourage your kids to get degrees in nuclear engineering, not "green tech." (Nuclear is the real green tech.) Those who prefer a more outdoorsy occupation should look into uranium mining.[4]

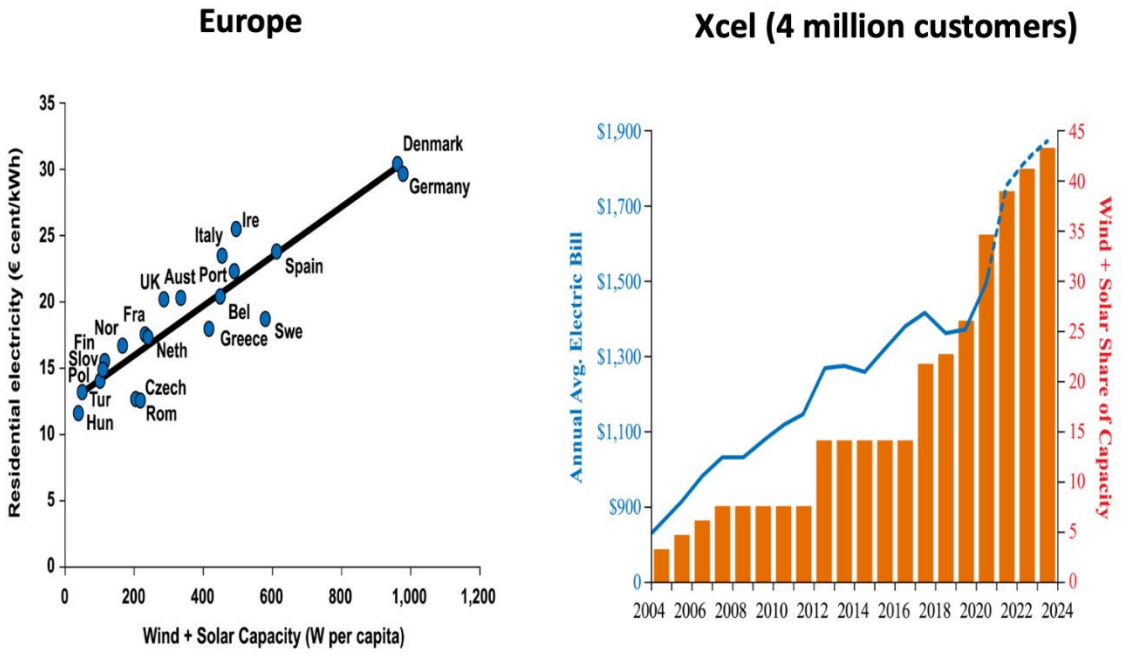
Renewable energy – cheap or expensive?

While the news media trumpet the rising capacity and cost-efficiency of solar, wind, and other renewable energy sources, Mills offers evidence that (at least so far) renewables have increased, not decreased, energy costs paid by the consumer.

Exhibit 5 has two panels, the left one comparing electricity costs across countries at a point in time, and the right one comparing electricity costs in one location (the midwestern United States) over time. Looking at the scatter plot of European countries, the x-axis is *per capita* wind and solar capacity, and the y-axis is electricity cost to the consumer. There's a nearly perfect correlation, but not in the direction you might hope for: the more wind and solar capacity, the higher the cost! And the differences are not trivial — the highest-cost countries, Denmark and Germany, sock the consumer with almost three times the electricity cost of the cheapest country, which is Hungary.

[4] A very nice primer on uranium mining is at https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/uranium-mining-overview.

EXHIBIT 5
HOW ELECTRICITY COST VARIES WITH WIND AND SOLAR CAPACITY



Source: Mark Mills

The right panel of Exhibit 5 shows the evolution of electricity cost as wind and solar capacity are added over the last 20 years in the Xcel Energy service area in the United States. The x-axis is time, and the two y-axes are, respectively, the wind and solar share of the company's capacity (right hand side, orange columns) and cost (left hand side, blue line). As renewable capacity was added, from almost nothing in 2004 to nearly half the company's total capacity in 2024, annual average electric bills soared from under $900 to almost $1,900. While general inflation and possibly an increase in electricity use can account for part of this rise, consumers are obviously paying more than they used to.

Why, when wind and solar generation cost per kilowatt-hour is widely reported to have fallen below fossil-fuel cost? Because of the very high fixed costs of wind and solar, which must be amortized over time in consumers' electric bills. In his Pittsburgh Post-Gazette article, Mills writes,

> A pivotal reality is found in the nature and location of the critical upstream industries that make [renewable energy] possible. Fabricating wind, solar, and battery hardware entails a radical increase in the use of a range of minerals from copper and nickel to aluminum and graphite, and rare earths such as neodymium. The increases range from 700% to 4,000% more minerals per unit of energy production.

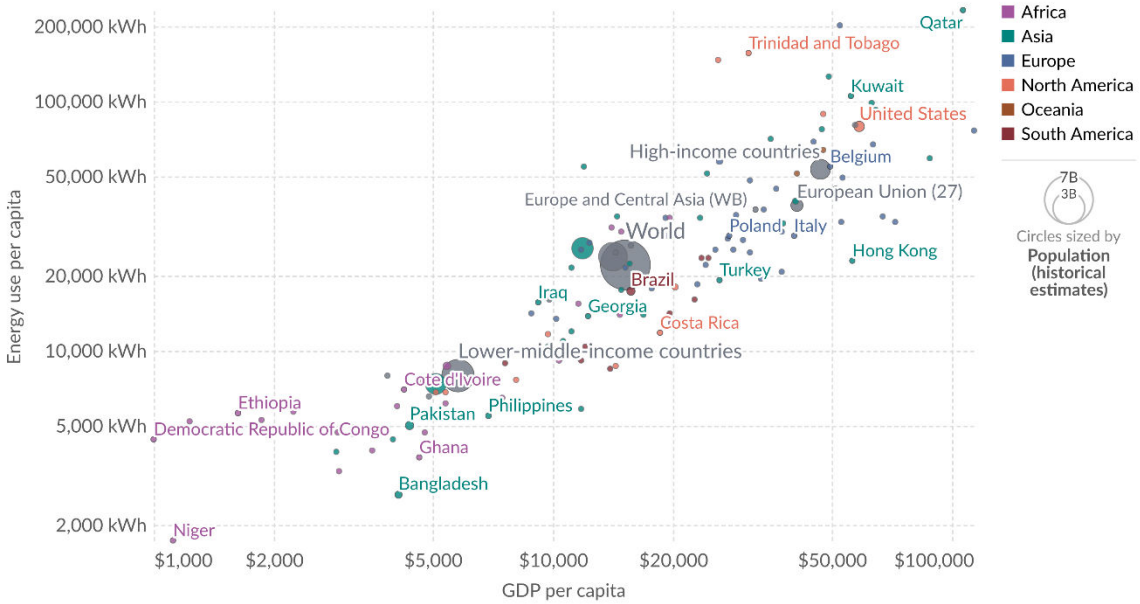
> The spending to meet the wind, solar, and [electric vehicle] mandates will require an astonishing, unprecedented increase in output from the old-school industries of mining and mineral refining. The transition will require hundreds of billions of dollars invested in hundreds of massive new mines, somewhere. Yet, both existing and planned world mining capacity won't come close, by factors [of] two- to tenfold, to meeting the demands if the "transition" is in fact pursued.

We are back to things that won't happen because they can't. If Mills' analysis is correct, we are pushing the limits of the possible, if not exceeding them, in committing to the electrification of almost everything in a short time frame.

Conclusion

Some would say that it's worth sacrificing almost everything we value in life to "save the planet." I disagree, and it's pretty clear Mills disagrees too. I do not think life on a warmer Earth will be without problems — mass migration, protection of coastal cities from rising water, and changes in agricultural patterns are just the obvious ones — but we can and will adapt to these eventualities. The alternative, radically reducing carbon emissions, is incompatible with civilization in a world of eight billion people. I close with an exhibit from Mills that speaks for itself.

Exhibit 6
Energy use per capita vs. GDP per capita (2015 data)



Source: Our World in Data. Additional information is at the link. The dots are sized in proportion to the country's population. India is the large bubble just to the right of $5,000; China is the similarly sized bubble overlapping the very large "World" bubble between $10,000 and $20,000. Because of economic growth and inflation, 2024 numbers are larger but the pattern is the same.

Would you rather live in a country that is to the right of the World bubble or to the left of it? Economic growth is pushing almost every country rightward, toward prosperity. Pushing them back to the left on this chart would be the cruelest joke ever played on what Frantz Fanon called “the wretched of the Earth.”

Don’t do it.

Laurence B. Siegel *is the Gary P. Brinson director of research at the CFA Institute Research Foundation, economist and futurist at Vintage Quants LLC, and an independent consultant, writer, and speaker. His books,* Fewer, Richer, Greener *and* Unknown Knowns*, explore ideas in economics, investing, environmentalism, and human progress. His website is* http://www.larrysiegel.org*. He may be reached at* lbsiegel@uchicago.edu*.*