Global trade and green energy

by Bud Ward

Wind turbines during a heatwave in Palm Springs, California, on July 14, 2023. Excessive heat warnings and watches were posted across California, Nevada and Arizona, where temperatures neared 120F (49C) in some places, the National Weather Service said. KYLE GRILLOT/BLOOMBERG/GETTY IMAGES

Leading climate scientists worldwide for some five decades have issued increasingly dire warnings about potential global dangers as a result of rapid warming of the Earth's atmosphere.

Their findings have echoed across peer-reviewed journals and professional conferences, and now are penetrating the daily consciousness of many citizens and of their policymakers.

Calendar year 2023 may be viewed by future historians as the breaking point in that long cycle. Record-breaking high summer temperatures across much of the planet have paired with another year of hellacious wildfires across much of Europe and North America, and with severe storms and flooding and parching droughts in other regions. Even with stiff competition for the daily broadcast, cable, and newspaper shrinking "news hole," those events have brought home for many the reality of what by now goes simply as "the climate crisis."

Given its obvious global impacts on the planet's atmosphere—and notwithstanding the immediacy of challenges posed by Russia's war on Ukraine and Hamas's war with Israel—the long-term severity of climate change and the resulting urgency of switching from fossil fuels to renewable energy sources now is encountering issues involving international commerce and trade. They relate to each other in vexing ways that some experts fear could impede much-needed short-term climate progress. The nexus between the rush for renewables and the seeming intransigence of international trade issues conspires to create a witch's brew of potential obstacles that could delay, or perhaps even preclude, needed progress in preserving Earth's climate, on which all people, animals, plants, and more rely.

BUD WARD *is an environmental journalist and journalism educator in the Washington, D.C./Virginia area. A co-founder of the Society of Environmental Journalists (SEJ) in 1989, he has authored/co-authored two books on environmental regulatory issues and has authored more than 1,000 bylined articles on environmental and journalism issues. He has served as a regular environmental analyst for National Public Radio's "All Things Considered" and "Morning Edition." In recent years he has conducted a series of full-day workshops for journalists, editors, and broadcast meteorologists on issues related to journalism and climate change science.*

Trade is an essential component of any credible effort to manage the risks of a warming climate, especially in an era defined by conflict between "open trade" and economic protectionism. Adding to the dilemma are a wide range of emerging and established geopolitical tensions that threaten to scuttle meaningful climate change management efforts.

This text first explores some of the factors driving the global effort to move away from fossil fuels. It then digs into some of the key issues involving trade in "rare earth" metals pivotal to building more renewable energy options. After a review of the most important clean energy options, it dives into the geopolitical issues that may be decisive in determining the efforts to decarbonize the global economy.

Renewables

Frequent use of the term "renewable energy" over the past years conjures up images of solar energy and of wind turbines, both onshore and off. That's only logical, but there are other energy sources that show promise: Specifically, nuclear energy and hydroelectric power may play a load-bearing role in future green energy production as well as hydrogen, which received a large investment from the U.S. Department of Energy.

But let solar and wind power—both of which will be subject to the whims of international trade forces—stand in as surrogates for the full range of new and advanced energy resources that are potential successors to fossil-fueled energy.

Solar and wind indeed have some interesting similarities, along with important differences, that distinguish them from each other and from other renewables and, most assuredly, from fossil fuels: They do not release climate-warming pollutants, and, as they replace use of fossil fuels, they can lead to reductions in the rate of increasing atmospheric temperature.

Importantly, solar and wind enjoy another quality that distinguishes them from fossil fuels: Market prices for both solar and wind energy resources have declined markedly over the past decade, making them economically competitive to fossil fuels in most markets worldwide. It's a trend that the International Energy Agency (IEA) and other climate and energy experts see continuing.

Along with increased use of solar and wind energy comes a need for better battery storage, reserving energy for when and where it is most needed. Improved battery storage, weight reduction, and alternatives are fruitful, and in some cases promising, areas of ongoing research internationally.

Think of it this way: Those old enough to remember may readily recall the classic one-word sentence from the 1967 movie, "The Graduate," starring Dustin Hoffman and Anne Bancroft: "Plastics." Were that movie to be made anew in 2024, the term du jour might well be "Batteries."

Key clean energy options

The IEA outlines where it thinks things are headed:

- Electricity becomes the core of the energy system.

It will play a key role across all sectors, from transport and buildings to industry. Electricity generation sources will need to reach net zero emissions globally in 2040 and be well on its way to supplying almost half of total energy consumption.

This will require huge increases in electricity system flexibility and network demand response, relying on batteries, nuclear power, hydrogen-based fuels, hydropower, and more—to ensure base and peak load power and reliable supplies.

Let's consider individually these three pillars of renewable energy—solar power, wind power, and battery storage—beginning with an explanation of key factors expected to rise in the context of international trade.

Solar Energy

Ongoing reductions in costs of solar energy make it the leading renewable energy option for decarbonizing the energy economy and for "onshoring" U.S. energy production. Incentives resulting from the Inflation Reduction Act further induce more shifting to solar power, with Princeton University's "Rapid Energy Policy Evaluation and Analysis Toolkit" forecasting increased solar spending to about $321 billion by 2030.

Behind the numbers supporting substantial growth in solar energy are some widely accepted perceptions about solar:

As the most abundant energy source on Earth, the sun's energy is said to be sufficient to power humanity's energy consumption needs for a full year with the solar energy reaching Earth in just 90 minutes.

Energy from the sun is widely accepted as being reliable into perpetuity. From about 0.06% of the planet's energy mix in 2010, solar has grown to about 22% in 2020, providing more than 3% of global electricity generation.

Perhaps more than any other single factor, solar energy costs have shrunk substantially in recent decades, with further declines of more than 30% anticipated in the near future.

Those factors aside, it's generally accepted as a truism in the energy field that "there is no perfect energy source." For solar, the most widely circulated concern is that the sun doesn't always shine, with the implication that no sun means no solar energy. That's where battery storage of solar energy enters the dialogue.

Another concern often expressed is that solar power plants require acres and acres of land, rely on large volumes of water, and use hazardous materials that can present disposal issues. The Covid-19 pandemic illustrated that supply chain problems and rising costs of some components, such as aluminum, can reduce solar expansion. Again, there's no "perfect" energy source.

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Wind energy

That truism applies also to wind energy. With blades that can be 200 feet long, the 100-foot-tall turbines pose aesthetics concerns for some nearby communities and residents, especially when producing annoying whirring background noise. Siting concerns often accompany announced plans for new wind turbines, though once-common worries about their killing hundreds or thousands of birds have mellowed as actual numbers have gone down, largely a credit to changing windmill technologies.

While offshore sitings of wind energy turbines often generate years-long controversies among coastal residents and businesses, they can typically generate more electricity with fewer turbines than onshore turbines.

Again, like solar, costs of wind energy have decreased markedly over recent years relative to costs of fossil fuels, and these cost advantages, as with solar, are expected to continue for years ahead.

Increasing use of renewable energy

U.S. green electricity production is growing. Despite slackened growth in 2022 resulting from higher costs, project delays, supply chain disruption, higher global and domestic inflation rates, and the legacy of a global pandemic, the U.S. added 5.7 gigawatts (GW) of utility-scale solar generation capacity and 7 GW of wind capacity compared with the same eight-month period through August a year earlier. The two resources' combined share of U.S. electricity generation increased to 23% from 21% during the same period of 2021, according to the U.S.'s national renewable energy industry outlook.

Energy experts overwhelmingly point to solar and wind as the renewables most likely to increase in market share relative to other renewables and fossil fuels over the next decade. While nuclear energy is also expected to grow, many experts think nuclear energy is unlikely to increase its current (roughly 10%) global market share over the next several decades. The reasons? Unfavorable cost comparisons to renewables, difficulties in nuclear waste handling and disposal, long construction lead times, and, in some countries, widespread anxieties about security and safety.

"By 2050, the energy world looks completely different," the International Energy Agency (IEA) reports. "Global energy demand is around 8% smaller than today, but it serves an economy more than twice as big and a population with 2 billion more people. Almost 90% of electricity generation comes from renewable sources, with wind and solar PV [photovoltaics] together accounting for almost 70%. Most of the remainder comes from nuclear power."

Looking ahead about three decades, the IEA says, "Solar is the world's single largest source of total energy supply. Fossil fuels fall from almost four fifths of total energy supply today to slightly over one fifth. Fossil fuels that remain are used in goods where the carbon is embodied in the product such as plastics, in facilities fitted with carbon capture, and in sectors where low-emissions technology options are scarce."

Brookings Institution researchers Kemal Davis and Sebastian Strauss, in a February 2021 commentary, write that reaching net zero* by 2050 "is technically and economically feasible with existing and in-progress technologies." But they added an important qualifier: "It requires drastic shifts in behavior and massive policy interventions, including a degree of international cooperation that will be very difficult to attain."

**The term 'net zero' in the context of climate change means reaching a balance between carbon emitted into the atmosphere and carbon removed from it. 'Net zero' is achieved when no more carbon is released than is removed from the atmosphere.*

Nuclear Energy

No serious discussion of alternative or additional energy sources is complete without consideration of domestic nuclear power.

That has, in fact, long been the case, notwithstanding strong public attitudes generally opposing nuclear plants—or the disposal of nuclear wastes—near residential communities ("Not in my back yard!").

Proponents of expanded nuclear energy make the persuasive case that nuclear energy is cleaner than combustion of coal or oil. They maintain that nuclear power, especially advanced nuclear power options, must not be summarily dismissed, given widespread and serious concerns over global warming and the inability of solar and wind to provide base power for the electrical grid.

Some proponents of nuclear energy acknowledge that the production stage required to scale nuclear energy may raise some legitimate concerns over environmental problems. Again, there's no "perfect" energy source.

However, many experts do not put substantial weight in arguments that the use of nuclear power for energy generation need necessarily lead to increased risks of nuclear weapons proliferation, another concern of some opposing nuclear powered-adversaries. But even if such worries were somehow taken off the table, major concerns persist about the exceptionally high costs associated with nuclear power, particularly relative to renewables, and about siting and permitting delays contributing to unavoidably lengthy and drawn-out lead times for construction.

It's not uncommon to hear mentions that popular support for nuclear energy could increase significantly *only* if the feared most adverse consequences of global warming themselves become widely unacceptable to the public and elected representatives and civic leaders.

Few responsible speculators at this point can argue unequivocally that that last turn of events is itself inconceivable. In that case, support for nuclear energy indeed could increase.

Only time will tell.

David Yeager, project manager for Vistra Zero, looks over the battery array in the old generator building at the Moss Landing Power Plant in Moss Landing, Calif., on January 13, 2021. Vistra Zero is the largest energy storage system of its kind in the world, able to store up to 300Mw of power. It uses lithium-ion batteries to capture excess electricity from the grid and release it when needed later, typically during solar and wind down times. CARLOS AVILA GONZALEZ/THE SAN FRANCISCO CHRONICLE/GETTY IMAGES

suppressing both the weight and the cost of batteries.

"Battery storage capacity in the United Sates was negligible prior to 2020, when electricity storage capacity began growing rapidly," the U.S. Energy Information Administration (EIA), says in a December 2022 report. "The remarkable growth in U.S. battery storage capacity is outpacing even the early growth of the country's utility-scale solar capacity," the agency continues. "U.S. solar capacity began expanding in 2010 and grew from less than 1.0 GW in 2010 to 13.7 GW in 2015…Much like solar power, growth in battery storage would change the U.S. electric generating portfolio."

Increased battery storage capacity can help solve an "intermittency problem," storing extra energy produced by wind or solar generators for when that energy is most needed. The EIA reports that developers are planning more than 23 large-scale battery projects—ranging from 250 megawatts to 650 megawatts—by 2025.

Lithium-ion batteries are the leading storage technology for those large plants, but the whole range of battery storage technologies is expected to remain an area of active research for years to come. It's reasonable to expect significant technological changes involving batteries and storage in coming years.

Increased battery storage

Solar and wind do bear a common characteristic: The sun doesn't always shine, and the winds don't always blow. Both renewable energy sources depend on batteries to store energy. With adequate storage, the cloudy days impediment and the absence of winds need not be prohibitive concerns. Batteries remain a key linchpin in the evolution to clean energy sources.

Battery storage is critical not only as it applies to the needs of stationary facilities, but also to support transportation activities.

"The next decade will be big for energy storage in general and for batteries in particular," says Prescott Hartshorne, a director of National Grid Ventures, which does energy and energy storage work in the U.S. and the U.K. "Storage enables further renewable generation both from an operational and reliability perspective. It's also a key piece of our utility customers' ongoing evolution and transition to renewables."

Research efforts across the planet are aimed at both increasing battery storage capacity and, especially in the production of electric vehicles (EVs),

Conundrum of rare earth metals/minerals

The following points, drawn largely from the World Bank report, illustrate some of the issues to be addressed in bringing about the hoped-for smooth transition to carbon-free energy options. Remember here that the specific rare metals now thought essential in this transition must be application-specific: what works for "green" wind energy may be totally unsuitable for solar or for battery storage, and vice versa. Furthermore, what makes sound economic sense in a global warming goal of no more than a two-degree Celsius warming increase may be off-the-charts expensive in limiting warming to 1.5 degrees Celsius.

Key metals

Solar Technologies—Four widely used technologies prevail for building solar photovoltaic (PV) cells:

- crystalline silicon cells, comprising roughly 85% of the current market;
- copper aluminum selenide (CIGS), a "thin film" technology with potential material reduction and manufacturing advantages;
- cadmium telluride, also a thin film technology, with some competitive cost advantages, but with highly toxic cadmium and questionable future supplies of tellurium; and
- amorphous silicon of amorphous silicon-germanium cells, the remaining "thin film" technology, but suffering from lower performance.

The 2015 market share of all thin film technologies was about 8% of the total annual production. The four solar technologies' significant metal content differs widely.

"The balance between these [solar energy] technologies has huge implications for metals such as indium, silver, and zinc," the World Bank report notes. Estimating future demand for those technologies "will define the demand for a wide range of metals."

Energy storage batteries—This application includes lead-acid, lithium-ion, and "other" categories including various battery chemistries: nickel-metal-hydride and sodium-sulfur and non-battery storage such as pumped-storage hydro, flywheels, and hydrogen.

The more established technology involves lead-acid batteries, historically less costly than lithium-ion batteries but having poor power-to-weight and energy-to-weight ratios.

Lithium-ion batteries have excellent energy-to-weight ratios, and prices have been decreasing significantly.

Wind Power—Larger turbine sizes and economies of scale in recent years have reduced generation prices, making wind, like solar, competitive with fossil fuels generation. Electricity production generated by wind power, especially for on-shore rather than off-shore wind, is expected to increase "rapidly" over the next three decades. (The World Bank cites evidence of "overly conservative estimates of expected penetration levels of renewable technologies."

Two wind technologies exist for the wind industry market, with differing needs for metals. Offshore wind turbines, expected to rely "almost completely" on direct-drive design, are estimated to be about 50% of total installed generation capacity by 2050. "But the split between onshore and offshore installations, and even between geared and direct-drive installations in these two locations, remains uncertain."

An illustrative problem

Despite the clear need for more renewable energy sources, a series of technical, economic, and political obstacles block the way.

One of the most illustrative concerns in the production of green energy infrastructure is the need for vastly increased mining of rare earth metals. These metals are essential to the production of electric vehicles and more advanced batteries, both of which are necessary innovations in a reduced-carbon infrastructure. The challenge facing the U.S. in a nutshell: Several of the key metals—nickel and cobalt, and bauxite as a key component of aluminum—are found in countries and regions adversarial to U.S. interests. Even in countries amenable to U.S. interests, the mining and extraction of these metals pose serious environmental, water quality, and public health risks for local workers and populations.

With the increasing demand for rare earth metals and ores (such as nickel, lithium, and cobalt), policy makers and the public will need to be sensitive to a range of critical questions, the answers to which in many cases will depend on factors such as:

- Which rare earth metals are best suited for which specific applications?
- Which individual countries have the largest and most accessible supplies of the individual metals?
- How and whether those individual countries will be open or resistant to making those resources available to other countries, and at what cost?
- For which such prized resources are there now, or might there soon be, suitable substitutes or other options available at commercial scale, and, again, at what cost?

Looking ahead, rare earth metals will be a critical component in more efficient and cleaner renewable energy and increased battery storage options. Notwithstanding their essential utility to the energy transition, these metals also present some specific challenges in how they are accessed and used.

"Known unknowns" and "unknown unknowns," to borrow from former U.S. Secretary of Defense Donald Rumsfeld, loom large in discussions addressing the building blocks to the global transition to carbon-free energy.

Given the innumerable uncertainties in any "smooth" transition, it's notable that, as a World Bank report says, "little attention has been paid to the implications of growing demand for materials required in the construction of renewable technologies and zero-emission infrastructure." The report draws a contrast to the volumes written about declining demand for fossil fuels, in particular coal, in such a transition.

Especially notable when considering the shift from a fossil-fuels-driven economy toward a "green energy" future is the consensus noted by the World Bank that:

"All literature examining material and metals implications for supplying

Street vendors at Conkary's Petit Bateau commuter train station walk next to wagons used to transport bauxite from the mining areas to Guinea's main port in Conakry's Kaloum neighbourhood. Despite a wealth of valuable minerals like diamonds, gold, and aluminum ore, Guinea ranks as one of the poorest countries in the world. Only about a third of residents have access to electricity, and the country's 32% literacy rate is among the lowest in the world. JASON FLORIO/REDUX

Other strategies: carbon capture and sequestration, and geoengineering

Carbon capture and sequestration (CCS) and, separately, geoengineering, are two critical climate management strategies that must be considered both in the context of climate change and of related international trade matters.

There are two types of CCS. The first involves the extraction of greenhouse gases directly from the air, after which they are deposited underground or otherwise stored. The second involves the capture of emissions from the combustion of fossil fuels, such as from power plants or industrial facilities.

The ideal "net-zero" goal of climate change management is to eliminate the use and, thereby, the atmospheric emissions of fossil fuels. No combustion (in effect, stranding trillions of dollars' worth of fossil fuels in the earth) would mean no emissions. However, progress in that direction notwithstanding, what then of the emissions from those fuels that are burned while in the transition to renewables?

In those cases, CCS, and perhaps also at some point geoengineering, may make up the difference. Note that CCS itself consists of two key components—first capture, and then sequestering where the carbon cannot be released into the atmosphere. Both of those components pose as-yet-unresolved challenges.

CCS involves capturing carbon dioxide (CO2) after combustion so it can be stored permanently and not released into the atmosphere. Underground geological formations are critical here. CCS of this sort is nothing new: it's been used at various locations and in varying amounts worldwide. Some commercial-scale facilities already operate throughout the world, with more in planning stages. Far more still will be needed.

Of course, CCS has its proponents and its opponents. While some see CCS as a way to help justify continued production of oil, others argue that it incentivizes the continuation of combustion that might otherwise give way to renewable energy sources.

There are technical, technological, permitting and siting, and economic barriers impeding further applications of CCS. Furthermore, some harbor concerns that no "permanent" underground storage may really be permanent, perhaps leading to future leaks.

There are different "flavors" of CCS also to consider, some inevitably having higher demands for technological components or specific building blocks than others. Biological carbon sequestration can take place in soils and oceans. With oceans, cooler and nutrient-rich waters can absorb more carbon dioxide than warmer seas, a potential concern given that oceans generally are getting warmer and more acidic specifically because of climate change.

Through photosynthesis, University of California Davis researchers have pointed out, carbon can be sequestered and stored as soil organic carbon, opening the way for storage of carbon through "new land management with calcium and magnesium minerals, forming 'caliche' in desert and arid soil." Efforts are under way to accelerate the carbonate forming process, using finely crushed silicates in the soil to store carbon for longer time periods.

Forests and grasslands also can serve as valuable "carbon sinks." Fallen leaves and branches store carbon, but they also can pose fire concerns, reducing forests' potential for carbon sequestration. Grasslands, somewhat more resilient, have the advantage of storing most carbon underground.

Carbon stored in underground geological formations can be derived from industrial sources producing steel or cement, or from power plants or natural gas facilities. The carbon in these cases is injected into porous rocks for storage.

Extensive ongoing research into CCS is continuing throughout the world as concerns about increasing climate change risks intensify.

Geoengineering

Geoengineering the climate generally amounts to deliberate and long-term modification of the planet and its natural systems to reduce global warming. In the context of climate change, the term does not include short-term regional efforts such as cloud-seeding, undertaken to increase rainfall in a region over the short term.

As with CCS, there are variations of geoengineering: Broadly, they focus on methods of solar radiation management, SRM, which involves reducing the amount of solar radiation, sunlight, reaching earth's surface. This reduction is brought about by the injection of various chemicals into the upper atmosphere.

Not so many years ago, it almost seemed that the subject of geoengineering the atmosphere was verboten in pleasant company, especially when discussants included scientists.

Generally dismissed as a "break-glass" worst case scenario, not even close to being a "Plan B," the mere researching of geoengineering options was readily dismissed as being too fraught with unwanted and unintended consequences: Adamant critics warned that the research alone could open doors to actual implementation, thereby fueling more pollution of the sort the geoengineering was intended to help reverse.

Only if the adverse impacts of climate change become so unequivocally serious and damaging, this logic flows, might one resort to such a serious remedy. Its consequences? Unknown and in many ways unknowable, but certainly negative. Regional and local climate impacts such as flooding, droughts, or wildfires seem inevitable. And it's generally accepted that geoengineering, once launched at a global scale, must be continued indefinitely, and surely for more than 100 years. As such, geoengineering raises some serious ethical, equity, and moral concerns not easily resolved. It would be, at best, a dubious gift to our heirs and to future generations.

(For more information on these climate strategies, see Topic 3)

clean technologies agrees strongly that building these technologies will result in considerably more material-intensive demand than would traditional fossil fuel mechanisms."

Knowing the specific rare elements/metals likely to experience increasing market shares in a carbon-free economy is just the first part of the challenge. The real uncertainties arise concerning the carbon-free technologies for which they will be deployed, the timing involved in the transitions to each, and, in some important cases, the specific applications within each category and the known locations of ample deposits, vast amounts of which are located in China. *The Economist* reports that "The transition to clean energy will spark decades of demand for the metals needed to multiply solar and wind parks, power lines, and electric cars. Latin America holds more than a fifth of the global reserves for five critical metals" and "already dominates the mining of copper, pervasive across green technologies, and holds nearly 60% of the world's known resources of lithium, used in all main e-vehicle battery types." Also, there's the issue of the geographic sites at which suitable, accessible, and economical supplies will be available.

In addition to issues of which rare metals fit with which green technologies and in what time frame, there also are concerns related to which countries' rare metal resources are accessible in the first place—and at what economic and environmental costs. This is where trade and economic factors and potential political and environmental, health, and safety regulatory concerns will come up, in some cases facilitating trade with particular countries while impeding it with others.

For instance, bauxite ore is a principal component of aluminum, a metal subject to increasing demand as part of efforts to trim unnecessary weight from electric vehicles, EVs, and their batteries. *The Washington Post* reports that Guinea, "one of the poorest countries on earth," sits on "the world's biggest reserve of bauxite." Home to more than 13 million people, Guinea also is "already seeing an unprecedented boom in its bauxite exports" given growing global interest in EVs. At what expense? Guinea already reports a loss of farmland, reduced crop yields, and devastated fishery harvests resulting from mining activities and development. Furthermore, locals face serious drinking water quality problems following the bauxite mining initiatives.

Other countries in the Global South may face, or already face, similar problems. "The Latin America region (Chile, Brazil, Peru, Argentina, and potentially Bolivia) is in an excellent position to supply the global climate-friendly energy transition," according to the World Bank. "The region has a key strategic advantage in copper, iron ore silver, lithium, aluminum, nickel, manganese, and zinc," and along with Africa "should also serve as a burgeoning market for these resources."

Again, examples from among many already apparent:

An April 27, 2023, report in *The Washington Post* illustrates the dilemma, beginning "One of the poorest countries on Earth has become a crucial player in the world's green-energy transition." It continues:

"Guinea, a West African nation of more than 13 million people, is home to the world's biggest reserves of bauxite—a reddish-brown rock that is the main source of aluminum. That light metal, in turn, is essential for electric vehicles because it allows them to travel farther without recharging than if they were made of steel. And over the current decade, when experts expect global sales of EVs to increase almost ninefold, demand for aluminum will jump nearly 40%, to 119 million tons annually, industry analysts say."

The article reports that Guinea's government "has reported that hundreds of square miles once used for farming have been acquired by mining companies for their operations and associated roads, railways, and ports." Villagers "have received little or no compensation." In the next two decades, the paper reports based on government analyses, "more than 200,000 acres of farmland and 1.1 million acres of natural habitat will be destroyed by bauxite mining."

More than half of the world's lithium, critical for battery storage for electric vehicles, comes from Latin America, as does roughly 40% of the world's copper and some 25% of its nickel. A form of "green-resource nationalism," as *The Economist* describes it, is taking place in some countries in the region, along with rising interest in export bans of nickel ore and of bauxite, the latter critical in making aluminum and for reducing weights—and thereby increasing mileage—of electric vehicles and of energy-storage batteries.

The proverbial game-changer on this issue, however, is China, given the global dominance the country enjoys on metals (both basic and rare earth), solar panels, and services required to supply technologies in a carbon-constrained future. The World Bank, in its report, writes that China's "production and reserve levels, even when compared with resource-rich countries (such as Canada and the United States, and to a lesser extent Australia) often dwarf others."

Bottom line: A lot depends on which technologies gain prominence, and where and when, over the next few decades. Much also relies on how readily, if at all, key countries make their rare earth resources available beyond their own borders. There are constant efforts in renewable system research and design to reduce the need for rare earth metals and minerals that are difficult and/or expensive to access and then to procure.

Will consumers and vehicle-makers worldwide tilt demand toward all-electric vehicles, thereby increasing need for more bauxite, cobalt, copper and lithium? Or will existing inventories of aging "gas guzzlers" hold out against new EVs? For how long? Will various national governments succeed in incentivizing selection of EVs? And, if not, what roles might the private sector adopt to help fill voids? And, finally, as seen from the United Auto Workers' 2023 strike against the traditional "big three" automakers, what might be the economic and political impacts of EVs' requiring fewer manufacturing and service workers across the board than required by fossil-fuel powered vehicles?

Geopolitical issues involving clean-energy transition

For many, questions about climate change have evolved over the years from a focus on whether and if… to a focus on what to do about the serious climate challenges we now face: What kinds of policies might best incentivize practical and effective risk management actions?

As the IEA says in its annual World Energy Outlook for 2022, "the risks of further energy disruption and geopolitical fragmentation are high." Those risks must now be addressed in the context of a ticking clock that experts say calls for effective actions sooner rather than later.

As the long-debated underlying scientific evidence for years had been, the public policy options can be complex and controversial. Many can elicit the "now comes the hard part" reaction in addressing the what-when-and-how of policy action choices confronting modern societies worldwide.

In addition, geopolitical issues certainly will evolve and change over time, complicating any coordinated international efforts set in motion today. Sometimes, those changes can develop rapidly, as, for instance, with Russia's invasion of Ukraine and its impacts on global energy and food supplies, and President Biden's recent executive order restricting semiconductor trade with China.

In contrast, rapid changes are un-

How two of the U.S.'s most highly respected climate scientists view clean energy geopolitics

Richard B. Alley, Ph.D., of Penn State University, and Lonnie Thompson, Ph.D., of The Ohio State University, both members of the National Academy of Science, are two of the most honored and respected climate scientists in the U.S. and, indeed, in the world. They offered these remarks when asked by the author of their views on the nexus between climate science and climate policy development.

Dr. Richard B. Alley:

"Solving" climate change has indeed been difficult, but scientific uncertainties have not been truly so important for decades. As documented in many excellent sources, the foundations for understanding global warming from fossil-fuel burning were sketched out during the 1800s. The predictive quantum-mechanical framework of radiative transfer came about from the US Air Force helping target heat-seeking missiles and calculate climate change after World War II. By the time I started helping the United Nations Intergovernmental Panel on Climate Change, IPCC, (in its 1995 report), the main outline of the scientific understanding was taught in widespread undergraduate classes. Scientists were increasingly documenting that the uncertainties are mostly on the "bad" side—if we continue to drive warming, the resulting damages could be a little less or a little more than expected, or a lot more if we trigger abrupt climate changes or ice-sheet collapses or other tipping points.

But despite the rapid rise in use of renewable energy, we continue to rely deeply on fossil fuels. Over recent years in the USA, for example, external use of energy to take care of our heating and cooling, lighting and plowing, and trucking and so much more, has been roughly 100 times as much as what we can do for ourselves from the energy in our food. The great majority of that external energy has come from a fossil-fuel system that has taken more than a century to build in its present form, and that is woven into our communities, our economy, and our politics, with vast resources. "Scientific uncertainty" long has been one of many arguments used and misused in discussions of ways forward to build a truly sustainable energy system, but the science has continued to be accurate and reliable with no major changes in understanding. The scholarship is clear that we can use this accurate science to build a better energy system, helping the economy and the environment if we can get the policies right.

Dr. Lonnie Thompson

Over the last four decades, data from ice cores, glaciers, and other sources have proven that Earth's climate is changing rapidly, and that carbon-based energy use is largely responsible. One of the greatest challenges of the 21st century is dealing with this unprecedented, global-scale change, since virtually all human activities are affected by climatic fluctuations.

We have the potential to transition to carbon-free societies through developing technology to slow carbon-based greenhouse gas emissions, advancing battery technology, and reducing the cost of renewable energy below fossil fuel energy. However, many of these technologies depend on rare earth elements that are most abundant in countries such as China and Russia, both of which at times have adversarial relationships with the U.S. and other countries and also with each other.

Earth's inhabitants now face a slow but inexorably developing crisis in which all nations must cooperate for the ultimate welfare of current and future generations. Despite political and economic rivalries, ultimately the global community must work together to slow the pace of human-caused climate change and to mitigate its worst impacts. Human actions have created the unfolding climatic and environmental crises, but we must implement international policies to make our energy production and consumption sustainable.

heard of concerning basic scientific evidence—for example, that increased emissions of human-caused carbon dioxide emissions further warm the atmosphere, and that elevated concentrations of greenhouse gases in the atmosphere need to be reduced.

Another example of the kind of change that could lead to a different set of geopolitical factors: Scientists are actively seeking effective alternatives to some of the essential metals and ores seen today as irreplaceable. For example, promising research suggests that sodium may someday replace or complement lithium as a key component of energy storage batteries.

Adding further to the challenge is the reality that effective policy responses can involve differing approaches at the local, regional, national, and/or international levels. In some cases, a step taken even by a local or regional government can delay or impede national or international efforts, even if only by leading to drawn-out litigation. "Many a slip twixt the cup and the lip," the familiar English proverb reminds us.

More must be considered also given that actions taken to manage global climate could inflict further damages to the natural environment regionally or locally, potentially increasing public health risks. The concern here is that we appear in some cases to have to further foul local and regional natural resources, such as clean air and finite drinking water supplies and drinking water quality, in order to control the even more perverse adverse impacts of a warmer atmosphere globally.

In such situations, the most serious impacts, as often is the case, are likely to disproportionately affect minority and traditionally underserved populations, the most vulnerable populations. The sad irony is that those groups are precisely those who have played the smallest roles in creating the anthropogenic (human-caused) warming in the first place.

The rift between wealthy and poor countries inevitably will widen.

The 'illusion' of a smooth glide path on energy transition

Geopolitical issues—as they apply specifically to climate change initiatives and to other global efforts—are anything but simple. They often present a numbing mix of uncertainties and unknowns.

Columbia and Harvard University academics Jason Bordoff and Meghan L. O'Sullivan write in *Foreign Affairs* about some "waxing lyrical about the geopolitical benefits of the coming transition to a cleaner, greener energy" and "an end to the troublesome geopolitics of the old energy order."

"Such hopes," they wrote, "were based on an illusion."

Staff members work at a workshop of a photovoltaic technology company in Yancheng, east China's Jiangsu Province, Sept. 6, 2023. Yancheng has boosted green and low-carbon development by advancing new energy industries such as wind and photovoltaic power in recent years. LI BO/XINHUA/GETTY IMAGES

They wrote just months after the start of Russia's war with Ukraine that "even the most optimistic evangelist of the new energy order had realized that the transition would be rocky at best."

Why? Because "the energy transition and geopolitics are entangled."

It may yet be tempting for some to boil down the green energy international transition to a very few words: China and the United States. This approach holds that the ultimate successes and/or failures of managing climate change risks will be shaped by the timeliness and effectiveness of actions taken—or not taken—by those two superpowers.

"The return of great-power rivalry in an increasingly multipolar and fragmented international system, the effort of many countries to diversify their supply chains, and the realities of climate change," Bordoff and O'Sullivan wrote in that *Foreign Affairs* piece, will add further stress to meeting the challenges posed by a changing climate. And the nature of the geopolitical issues directly involving just the U.S. and China likely will shape the geopolitics of virtually the entire world. Developments underscoring continued and heightened tensions between the U.S. and China throughout 2023—including and going beyond the future independence of Taiwan—do nothing to lower such concerns.

Will the two leading superpowers, and other powerful countries following suit, approach current and future climate initiatives with an increased commitment to trade protectionism and to nationalism? Will the key countries' international commerce and trade postures be driven by increasing selective taxes or tax credits, tariffs, trade restrictions, barriers, or embargoes? Or might a growing spirit of international accord develop to confront the "common enemy" of an excessively warming atmosphere? Will a growing U.S. and China spirit of cooperation and togetherness incentivize other powerful economic interests—India, Australia, advanced Western European and Pacific countries, Canada, and more—to join such a concerted collaborative effort?

The questions, of course, come

Tata Steel steel mill close to the North Sea coast on October 5, 2023, in Velsen, Netherlands. Tata steel is one of the major polluters in the Netherlands in terms of CO2, nitrogen, and heavy metals such as lead and mercury. Residents around Tata Steel, formerly Hoogovens, have been concerned for some time about carcinogenic substances falling into the area. SJOERD VAN DER WAL/GETTY IMAGES

more easily than do the well-reasoned answers. Consider, for instance, a few examples of the countless kinds of geopolitical issues and impediments to be addressed and, one can hope, overcome:

- Saudi Arabia's flirtation with China and Russia and concerns that it may well lead to its being less sympathetic to U.S. interests, given what it and others see as an up and down wavering of the U.S.'s strategic commitment to the Middle East;
- The increased interest on the part of many countries to enhance and diversify their own energy supply chains—and also simply to foster their own energy supply market shares—in light of their growing concerns about over-reliance on unpredictable foreign sources;
- Growing concerns among countries over energy security challenges they fear in coming years and decades, both as they may involve the health, productivity, and well-being of their own populations, and as those challenges would affect essential infrastructure resources such as highways, rail transit, public utilities, and health care and agricultural production resources;
- In the U.S. and other key countries, uncertainties over whether a change in near-term presidential or congressional leadership will lead to substantially different approaches to implementation of, or financial support for, landmark climate provisions of initiatives such as, in the U.S., the climate change provisions of the Inflation Reduction Act.

Even with the inevitable reduction in worldwide use of fossil fuels, Bordoff and O'Sullivan point out, "geopolitical risks may increase as global production becomes further concentrated in countries that can produce at low cost and with low emissions, many of which are in the Persian Gulf." They write that the share of global oil supply by OPEC producers will rise "from around one-third today to roughly one-half" by 2050. They note also an estimate by oil giant BP that the OPEC countries by then will produce a "very high and consequential…large share of a tiny pie," about two thirds of global oil supply "even if annual demand is falling."

One possible approach for the U.S.? "Friend shor-ing": turning to "less risky" friendly countries such as Norway and Canada, and "penalizing less friendly oil sources"—think here Iran, Libya, and Venezuela—with import taxes "or even sanctions." Bordoff and O'Sullivan acknowledge such actions could lead to "backlash and retaliation," such as higher prices and output reductions (for instance of Saudi Arabian oil).

And what about the unintended consequence of a "clean-energy" transition that involves increased adverse environmental and health impacts at local and regional scales, such as releases of polluted water or mining wastes into potable water supplies, or increased emissions of harmful air pollutants? Mining and extraction actions aimed at securing needed amounts of some "rare earth" ores and metals vital to a clean-energy transition have been widely reported as raising serious public health concerns, further evidencing the "no perfect energy source" reality.

In the end, once the scientifically challenging issues are resolved, and once a critical mass of the broad global public commits to seriously addressing climate change, the obstacles potentially presented by geopolitical realities still may long delay or impede effective progress on reducing global climate pollution and avoiding the most serious adverse impacts of a rapidly changing climate. The challenges are clear; the most effective responses to them are less so.

Discussion questions

1. The transition from a fossil-fuel based economy to an economy overwhelmingly—and perhaps ultimately entirely—based on renewable energy sources is likely to have a devastating economic and societal impact on certain population groups long tied to their familial pasts. What role should national and state governments play in helping to smooth that transition for those—such as coal miners refinery workers and their families—adversely affected by the transition?

2. Nuclear power is seen as a carbon-free energy source versus fossil fuel resources, although critics fairly point to adverse climate impacts resulting from development and transport of nuclear energy resources, though not during combustion. What do you see as the optimum role for domestic nuclear power in a transition to a "net-zero" economy? How can nuclear power overcome some of the most common concerns of critics—high costs, long permitting and construction delays, concerns over national security, and disposal of nuclear wastes?

3. *The Economist* recently framed things this way: "Growth is the best way to lift people out of poverty and improve average living standards. But in the developing world, more growth still leads to more emissions.... It is a battle over what is worse: a poorer today or a hotter tomorrow?" How to weigh the adverse health and environmental impacts on regional population groups today against less obvious adverse impacts for the planet generally in coming years? Are you optimistic or pessimistic about the ability to maintain growth while converting to a net-zero carbon emissions economy? What is your view of *The Economist's* framing of this issue?

5. At a time when protectionism and nationalism appear to be on the increase across a number of countries around the world, how do you see free-trade and "America First" nationalism interests evolving during the early energy transition years? Do you see a period of "natural resources nationalism" impeding global access to rare earth minerals and metals needed to fuel a move to clean electrification?

6. How should the federal government deal with adversarial countries (such as China and Russia) in addressing the "common enemy" of human-caused climate change? Are there effective means of incentivizing cooperative resources trading among erstwhile adversaries? How might the U.S. best deal with friendly/neutral countries such as India and Brazil? Should the U.S. seek to continue taking the international lead in addressing climate change? And, if so, how can it do that?

Suggested readings

The World Bank, April 2023, "Falling Long-Term Growth Prospects: Trends, Expectations, and Policies." The World Bank in this report offers what it says is "the first comprehensive assessment of long-term potential output growth rates in the aftermath of the Covid-19 pandemic and the Russian invasion of Ukraine." The report characterizes these rates as the global economy's "speed limit," which would have significant implications for international commerce on renewable energy and other subjects. https://www.worldbank.org/en/news/press-release/2023/03/27/global-economy-s-speed-limit-set-to-fall-to-three-decade-low?intcid=ecr_hp_sidekick3_en_exT

Intergovernmental Panel on Climate Change (IPCC)—The Intergovernmental Panel on Climate Change, IPCC, is a project of the United Nation Environment Program and the World Meteorological Organization. For decades IPCC has been widely acknowledged as the world's most authoritative voice on climate change science. Its studies are the work of a who's who of the world's leading climatologists, and their work products reflect a comprehensive aggregation of recent years' peer-reviewed journal reports and research.www.ipcc.ch

The Economist, June 25–July 1, 2022. "The Right Way to Fix the Energy Crisis," Some of the most insightful and analytical reporting on climate change regularly appears in the print and online formats of this magazine, and this feature lives up to that viewpoint. Cover story, The Economist, June 25-July 1, 2022. www.economist.com

Resources for the Future, RFF—Global Energy Outlook, May 20, 2023. Climate change watchers each year eagerly await this annual update from a respected national think tank. RFF's report for 2023 aggregates key relevant data from several highly respected national and international sources. The result is sector-by-sector and energy source-by-energy data (wind, solar, nuclear, etc.) and projections into coming decades. www.Rff.org/geo

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