Caiazza Comment Overlooked Impacts and Life Cycle Analysis

Summary

In this comment I address the environmental and life cycle costs and benefits discussion in the Draft Scoping Plan. In general, the Plan over-estimates benefits and under-estimates costs throughout the document and associated documentation. This extends beyond financial costs and includes environmental impacts, upstream emissions, and life-cycle emissions.

I maintain there is a major shortcoming in the analysis of the environmental impacts of the transition to net-zero electric generation by 2040. The most recent environmental impact analysis only addressed a fraction of the total number of wind turbines and area covered by solar PV installations. In addition, the environmental impacts of battery energy storage were not addressed. It is impossible to project the impacts of the environmental impacts of the dispatchable emissions-free resource that it included in the capacity projections because a specific technology has not been specified. My comments quantify the renewable energy resource difference between the most recent environment analysis and the Integration Analysis projections.

I recommend that the Department of Environmental Conservation propose thresholds for unacceptable environmental impacts. I believe that without addressing this problem that it is likely that the environmental impacts from the massive wind and solar resource developments will have far worse impacts than those that can be ascribed to climate change. For example, I project that at least 216 Bald Eagles could be killed every year when there are 9,445 MW of on-shore wind. There were 426 occupied bald eagle nest sites in New York in 2017. I am not a wildlife biologist but those numbers indicate to me that there will be major threats to the survivability of Bald Eagles in New York. The Final Scoping Plan must include proposed thresholds for unacceptable environmental impacts like this.

The Climate Act includes a mandate to consider the upstream emissions associated with the extraction, production, and transmission of fossil fuels imported into New York State. I argue that the Final Scoping Plan should address the upstream emissions of renewable technologies. While touted as "zero-emissions" the fact is that there are significant environmental, economic, and social justice impacts associated with the production of those technologies. I believe that information should be provided to help inform the state energy planning board's adoption of a state energy plan.

I included the article The Hard Math of Minerals because it gives an excellent overview of the renewable technology issues ignored in the Draft Scoping Plan. The complete article is attached as an addendum to these comments but I have included extensive excerpts from the article with my annotated comments.

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The Draft Scoping Plan does not recognize that the massive expansion in the use of wind, solar, and energy storage technologies significantly changes the material requirements. Mills explains that to produce the same energy wind turbines requires 50,000 tons of concrete and a gas turbine only 2,000 tons. Using his numbers, I project that over 7,000,000 tons of concrete will be required for just the projected on-shore wind turbines needed in the three mitigation scenarios. There are tradeoffs and consequences in this regard that the Final Scoping Plan should acknowledge.

The Draft Scoping Plan does not consider the impacts of the material requirements on the implementation plans in the mitigation scenarios. There is no consideration at all that the New York plan will be competing with other jurisdictions with similar initiatives for the necessary materials. The Final Scoping Plan has to include a backup plan if material shortages affect the deployment schedules. The Integration Analysis has optimistic cost reduction assumptions for future years but does not consider that the materials component of batteries, wind turbines, and solar panels will become increasingly important in the future. As other jurisdictions compete for those limited and difficult to obtain resources it is likely that costs will rise so much that costs will not drop and the Integration Analysis projections will be invalid. He also points out that most of the rare earth metals necessary for wind, solar, and battery resources are imported. There is language in the Draft Scoping Plan that mentions that the transition will make New York less reliant on fossil fuel produced elsewhere but these arguments ring hollow when the life cycle of the renewable energy resources are considered and we become dependent upon imports of another type.

There is another aspect of the materials requirements that should be addressed by the Climate Action Council. Mills explains that Jennifer Dunn, a pioneer in social life cycle assessment, has noted that "technologies that are designed to solve grand challenges such as climate change must consider both their environmental and social impacts to understand their true consequences. The Climate Action Council should bring this issue to the attention of the Climate Justice Working Group. I recommend that it should be addressed in the Final Scoping Plan.

Mills concludes that "based on today's physics and technology, the only path to an energy system with a material intensity lower than hydrocarbons would be one focused on nuclear fission." Given that nuclear power is also the only scalable dispatchable emissions-free generating resource the Final Scoping Plan should include a Scenario that takes advantage of those capabilities. The Climate Action Council needs to address why this approach has not been considered.

New York State policy and the Draft Scoping Plan do not address full life-cycle emissions assessments of all relevant energy technologies. I recommend that the National Renewable Energy Laboratory Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update report be used address life cycle emissions for all technologies. Excluding that information presents a one-sided picture of the tradeoffs of different generating resources. More importantly, that information could be used to inform the decision for the mitigation scenario decision or adjust the relative proportion of specific renewable technologies in the energy plan recommendations

Cumulative Environmental Impact Assessment

Consistent with 6 New York Codes, Rules and Regulations (NYCRR) §617.9(a)(7), a Generic Environmental Impact Statement is the appropriate mechanism for assessing environmental impacts related to the Climate Act. On September 17, 2020 the [Final Supplemental Generic Environmental Impact Statement (SGEIS) for the Climate Leadership and Community Protection Act] was released. It evaluated the environmental impacts associated with the incremental resources needed to comply with the Climate Act and built upon and incorporated by reference relevant material from four prior State Environmental Quality Review Act (SEQRA) analyses. Each of the analyses evaluated the environmental impact of the expected renewable energy resources needed at the time of the analysis was done. The most recent version considered the impact not only of previous New York proceedings but also the mandates in the Climate Act.

According to the 2020 SGEIS report:

> Exhibit 2-5 summarizes the current renewable energy generation in New York, in addition to the offshore wind and distributed solar procurement goals, and the estimate of utility-scale solar capacity required to meet the meet the 70 by 30 goal. This SGEIS is evaluating a range of utility-scale solar that can maximize the competitive outcome, including up to an incremental 6,300 MW of utility-scale solar. Procurement of 5,800 MW of offshore wind by 2030 represents a portion of the 9,000 MW by 2035 procurement goal. Distributed solar capacity by 2030 is expected to exceed the 6,000 MW by 2025 procurement goal by an additional 3,000 MW and would reduce the amount of installed capacity procured through Tier 1.

Exhibit 2-5 Expected Renewable Capacity

Renewable Energy Source	Contribution to 70 by 30 Capacity (MW)	Total New Capacity Under Proposed Action	Capacity Analyzed in Prior SEQRA Analyses (MW)	Incremental Increase Analyzed in this SGEIS
Existing and Contracted[1]	8,000	N/A	N/A	N/A
Utility-Scale Solar	11,100	9,000 – 13,200[2]	6,865	2,100 – 6,300
Utility-Scale Onshore Wind	1,900	1,900	5,905	N/A
Offshore Wind	5,800	9,000	4,200	4,800
Distributed Solar	6,000[3]	6,000	3,000	6,000
Total CLCPA-Eligible Renewables	**32,800**	**25,900 - 30,100**	**19,970**	**12,900 - 17,100**

Source: NYSERDA. 2019. Clean Energy Standard Annual Progress Report: 2018 Compliance Year Final. December 2019. Accessed April 24, 2020. https://www.nyserda.ny.gov/-/media/Files/Programs/Clean-Energy-Standard/2019/Case-15-E00302-CES-2018-Annual-Progress-Report.pdf.

Notes:

[1] Includes constructed and contracted utility-scale solar, distributed solar, onshore wind, hydropower, and imported renewable energy.

[2] The 2016 SEIS analyzed approximately 2,700 to 6,900 MW of utility-scale solar capacity that could meet the 50 by 30 goal based on varying market conditions. This SGEIS assumes a similar range for utility-scale solar applied to the preliminary modeling from NYSERDA.

[3] An additional 3,000 MW of distributed solar is included under Existing and Contracted.

Key:

CLCPA = Climate Leadership and Community Protection Act
MW = megawatt
N/A = not applicable

The problem is that the original expectations of renewable capacity for the Climate Act falls far short of the renewable capacity requirements in the Draft Scoping Plan for 2050. Table 1 compares the capacity (MW) in the IA-Tech Supplement Annex 2 Emissions Key Drivers spreadsheet the SGEIS Exhibit 2-5 expected renewable capacity. The integrated analysis does not differentiate between distributed solar and utility-scale solar so I list the totals. The table shows that the environmental impact statements done to date considered renewable resource capacities far less than what the integration analysis expects will be needed: between 20% and 40% more onshore wind, about twice as much offshore wind, and over three times as much distributed and utility-scale solar. In addition, no previous analysis considered the environmental impacts of massive energy storage facilities or the “zero-carbon firm resource” that the integrated analysis presumes will be provided by hydrogen resources. Moreover, these are just the generating resources. There will also be significant environmental impacts associated with the transmission system additions and upgrades necessary to get these additional renewable resources into the grid.

Table 1: Comparison of Cumulative Environmental Impact Statement Renewable Resources

	Onshore Wind	Offshore Wind	Total Solar	Battery Storage	Zero-Carbon Firm Resource
Prior EIS	5,905	4,200	9,865		
2020 FSGEIS	7,805	9,000	19,200		
Integration Analysis					
Reference Case	3,787	9,000	19,956	8,225	0
Scenario 1	9,888	17,912	62,463	22,869	22,869
Scenario 2	9,445	16,393	64,621	21,465	21,465
Scenario 3	10,154	19,278	60,604	19,212	19,212
Scenario 4	11,052	18,310	65,210	22,956	22,956

There is no question that the integrated analysis renewable resources should be addressed in another environmental impact statement. Considering the number of turbines and area covered by solar panels environmental impacts that may be acceptable for a limited number of facilities clearly could be issues with the larger numbers projected. Assuming onshore wind uses 3.3 MW turbines (average turbine size in the Article Ten queue in 2020), offshore wind uses 15 MW turbines per [Empire Wind website], and that solar projects in the Article Ten queue in 2020 averaged 9.3 acres of equipment area per MW I calculated the quantity of turbines and area covered for the FEIS and Draft Scoping Plan in Table 2. The Draft Scoping Plan calls for at least 497 more onshore wind turbines, 493 more offshore wind turbines and 602 more square miles covered with solar equipment.

Table 2: Number of Wind Turbines and Solar Equipment Areal Distribution for FEIS and Draft Scoping Plan

	Onshore Turbines	Offshore Turbines	Solar sq miles
Prior EIS	1,789	280	143
2020 FSGEIS	2,365	600	279
Reference Case	1,147	600	290
Scenario 1	2,996	1,194	908
Scenario 2	2,862	1,093	939
Scenario 3	3,077	1,285	881
Scenario 4	3,349	1,221	948

Increase above FEIS	Onshore Turbines	Offshore Turbines	Solar sq miles
Scenario 1	631	594	629
Scenario 2	497	493	660
Scenario 3	712	685	602
Scenario 4	984	621	669

The Climate Action Council should require the Department of Environmental Conservation to propose thresholds for unacceptable environmental impacts. For example, I am worried about eagles. If you had told me 30 years ago that I would ever see a Bald Eagle from my home I would have been doubtful. Now that has occurred and I am not willing to chance that environmental victory. Because there are a limited number of eagles and their reproduction rates are low, I imagine that wildlife biologists could develop a criterion on the acceptable annual rate of state-wide eagle deaths from wind turbines.

Previously I considered the avian impact of the Bluestone Wind Project in Broome County New York to show impacts for a single facility. It will have up to 33 turbines and have a capability of up to 124 MW covering 5,652 acres. The "Cumulative Impacts Assessment" Appendix UU, which is document #752 on the NYSDPS-DMM-Matter Master website case #16-F-0559 in the Article 10 application for the facility provides data on eagle impacts. Over the 30-year expected lifetime of the facility the analysis estimates that 85 Bald Eagles and 21 federally protected Eastern Golden Eagles will be killed. A first-order approximation[1] is to scale those numbers to the total capacity projected for the Draft Scoping Plan. Table 3 shows that this approximation suggests that at least 216 Bald Eagles could be killed every year when there are 9,445 MW of on-shore wind. There were 426 occupied bald eagle nest sites in New York in 2017. I am not a wildlife biologist but those numbers indicate to me that there will be major threats to the survivability of Bald Eagles in New York. The Final Scoping Plan must include proposed thresholds for unacceptable environmental impacts like this.

Table 3: First-Order Approximation Pro-Rated Cumulative Eagle Deaths

Cumulative impacts	Bald	Golden	Death Rate
Bluestone MW	124	124	
Bluestone deaths	85	21	Per 30-years
Scenario 1	226	56	Per year
Scenario 2	216	53	Per year
Scenario 3	232	57	Per year
Scenario 4	253	62	Per year

Inconsistent Upstream Emissions

On December 30,2021 the New York State Department of Environmental Conservation (DEC) released "New York's first-ever, statewide greenhouse gas emissions report compliant with state's climate law". In an article on my blog, I described this greenhouse gas (GHG) inventory. There is an inconsistency in the Draft Scoping Plan's emissions inventory for fossil fuels and other "zero-emissions" technologies.

Appendix A in the December 2021 statewide greenhouse gas emissions report explains that the emission calculations "reflect greenhouse gas emissions associated with the extraction, production, and transmission of fossil fuels imported into New York State". In other words: "upstream" emissions. The article explained that upstream emissions are included to increase the societal benefits for the emission reduction programs needed to meet the https://climate.ny.gov/Climate Act targets.

The point of this comment is that alternative renewable technologies have upstream emissions that bely the claim that they have "zero" emissions. In fact, there are significant environmental, economic, and social justice impacts that are ignored in the Draft Scoping Plan. In The Hard Math of Minerals, Mark

[1] Before dismissing this projection as overly simplistic note that the results of the Active Transportation benefits analysis should be considered "a first-order approximation of the benefits of increased active Transportation" (Appendix G Section II page 25).

P. Mills (Mills, Mark P. "The Hard Math of Minerals." *Issues in Science and Technology* [January 27, 2022]) describes those impacts. The complete article is attached in an addendum to these comments but I have included extensive excerpts from the article with my annotated comments

Mills writes:

> Today's plans to decarbonize global energy systems center on a massive expansion in the use of solar, wind, and battery technologies, with the goal of these becoming the dominant means to power society. But scaling up these energy sources entails a radically heavier materials footprint than is associated with fossil fuels, paradoxical though it may seem. The unavoidable scale of materials demand will have significant impacts on commodities markets and prices, as well as on the environment. Most policy formulations fail to account for these implications. The country is long overdue for thoughtful and realistic planning that honestly acknowledges the tradeoffs and consequences arising from the materials needed to accelerate what is being called the energy transition.

The Draft Scoping Plan certainly fails to account for these implications and I believe that the Climate Action Council has to acknowledge that there are tradeoffs and consequences to New York's net-zero transition policy.

Mills explains that:

> It has long been known that building solar and wind systems requires roughly a tenfold increase in the total tonnage of common materials—concrete, steel, glass, etc.—to deliver the same quantity of energy compared to building a natural gas or other hydrocarbon-fueled power plant. Beyond that, supplying the same quantity of energy as conventional sources with solar and wind equipment, along with other aspects of the energy transition such as using electric vehicles (EVs), entails an enormous increase in the use of specialty minerals and metals like copper, nickel, chromium, zinc, cobalt: in many instances, it's far more than a tenfold increase. As one World Bank study noted, the "technologies assumed to populate the clean energy shift … are in fact significantly MORE material intensive in their composition than current traditional fossil-fuel-based energy supply systems."

He goes on to provide some specific information about those material requirements:

> Installing so much wind and solar generation capacity worldwide has profound materials implications, not to mention land requirements, which will soon become problematic. Replacing the energy output from a single 100 megawatt (MW) natural gas-fired turbine (producing enough electricity for 75,000 homes) requires at least 20 wind turbines, each about 500 feet tall and collectively requiring some 30,000 tons of iron ore and 50,000 tons of concrete, as well as 900 tons of nonrecyclable plastics for the turbine blades. The gas turbine, by contrast, requires only about 300 tons of iron ore and some 2,000 tons of concrete. The 20 wind turbines also require 1,000 tons of specialty metals and minerals such as copper, chromium, zinc, etc., versus about 100 tons embodied in

the gas turbine. Moreover, the gas turbine is about the size of a residential house, while those 20 wind turbines require 10 square miles of land. And although a solar installation would require one-third as much land as wind, the aggregate tonnage of cement, steel, and glass used is about 150% greater than wind.

Using his material requirements for wind turbines I calculated the materials needed for the on-shore wind turbines in Table 4. These are substantial numbers that are not included in the Integration Analysis and should be addressed in the Final Scoping Plan.

Table 4: Materials Requirements for Integration Analysis On-Shore Wind Turbines per The Hard Math of Minerals

	Mills Material Requirements			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Number of Turbines	2,996	2,862	3,077	3,349
tons of iron ore	4,494,500	4,293,300	4,615,318	5,023,691
tons of concrete	7,490,833	7,155,500	7,692,197	8,372,818
tons of nonrecyclable plastics	134,835	128,799	138,460	150,711
tons of specialty metals and minerals such as copper, chromium, zinc, etc	149,817	143,110	153,844	167,456

Mills raises another upstream aspect that destroys the idea that the renewable generating and electric vehicle technologies are "zero" emissions:

> Scaling up solar, wind, and batteries also means scaling up the mining of the refined minerals they require. There is a significant environmental impact associated with the sheer tonnage of earth that must be moved and processed to produce these refined minerals. To produce one ton of a purified element, a far greater quantity of ore must be extracted and processed. Copper ores, for example, typically contain only about 0.5% by weight of the element itself: roughly 200 tons of ore are dug up, moved, crushed, and refined to produce 1 ton of copper. The rare earth element neodymium, which is used in wind turbines, requires mining from 20 to 160 tons of ore to obtain 1 ton. Cobalt (used in most batteries) occurs at a grade typically lower than 1 ton of the element per 1,500 tons of ore. The calculus of the upstream environmental footprint should also include the overburden—the necessary removal of even more tons of rocks and dirt to access a single ton of the buried mineral-bearing ore.

The Final Scoping Plan should also address these upstream emissions.

The Climate Action Council should also consider New York's net-zero transition relative to other jurisdictions:

> A recent analysis by the Wood Mackenzie consultancy found that if EVs are to account for two-thirds of all new car purchases by 2030, dozens of new mines must be opened just to meet automotive demands—each mine the size of the world's biggest in each category today. But 2030 is only eight years away and, as the IEA has reported, opening a new mine takes 16 years on average.

> Despite these and similar analyses, many countries, and many US states, are now proposing to accelerate deployment of solar, wind, and battery technologies without clear plans for overcoming the material shortfalls. One study [sponsored by the Dutch government] offered a blunt statement of reality: “Exponential growth in [global] renewable energy production capacity is not possible with present-day technologies and annual metal production.”

There is no consideration at all the New York plan will be competing with other jurisdictions with similar initiatives for the necessary materials. The Final Scoping Plan has to include a backup plan if material shortages affect the deployment schedules.

The Integration Analysis has very optimistic cost reduction assumptions for future years. Mills points out that those projections are unlikely to verify because of the material issues:

> Another area of concern for these new technologies is their future cost, which will be inseparable from the velocity and scale of their entry into the market. Today, future plans for solar, wind, and battery technologies assume costs will continue to fall significantly, as they have over the last decade. But the implications of record-breaking demands for mineral commodities suggest the reverse is more likely.

He provides specific examples for batteries, wind and solar system costs that are available in the Addendum.

Mills goes on to point that there are flaws in arguments that could reduce these concerns. He explains that while recycling is a worthy aspiration, “myriad practical and economic factors impede getting close to that goal in general, not just with solar, wind, and batteries.” He also points out that in general, and as will be the case in New York, the massive buildout of solar, wind and batteries will be so large compared to the availability of materials from retired facilities that means that even if the recycling issues are resolved it won’t be a factor for many years.

I think that the Climate Action Council needs to address another issue raided by Mills in the Final Scoping Plan:

> Beyond economics, there are also the practical and geopolitical challenges arising from realignments of energy material supply chains. For example, the United States today [is dependent on imports] for 100% of some 17 critical minerals and, for 28 others, net imports account for more than half of existing domestic demand. Assembling batteries or solar hardware in the United States won’t change the underlying dependencies any more than assembling automobiles domestically would if the key components and all the fuel were imported.

There is language in the Draft Scoping Plan that mentions that the transition will make New York less reliant on fossil fuel produced elsewhere but these arguments ring hollow when the life cycle of the renewable energy resources are considered.

Mills concludes his paper with another issue that is relevant in the context of the Climate Act. There is a strong social justice emphasis regarding implementation in the Draft Scoping Plan but it only addresses New York.

> Finally, there are the social and moral implications associated with a radical shift in the types and locations of environmental impacts that comes from replacing drilling (for fossil fuels) with a massive expansion in mining, much of which will occur in emerging markets and fragile ecosystems. For example, Australia's Institute for Sustainable Futures noted in its analysis that the global gold rush for minerals to meet ambitious transition plans could take miners into "some remote wilderness areas [that] have maintained high biodiversity because they haven't yet been disturbed."

More importantly, there is no explicit recognition of the social and humanitarian consequences of New York's net-zero transition. Mills explains:

> Meanwhile, little attention has been afforded the social and humanitarian implications of this shift. Jennifer Dunn, a pioneer in social life cycle assessment (S-LCA) and associate director of the Center for Engineering Sustainability and Resilience at Northwestern University's McCormick School of Engineering, has noted that "technologies that are designed to solve grand challenges such as climate change must consider both their environmental and social impacts to understand their true consequences." As Dunn and her collaborators observe in a recent analysis focused on cobalt as a case study, while *environmental* life cycle assessment is a "mature widely-used tool," social and humanitarian considerations remain nascent and "the lack of regionally or locally specific data and guidance for collecting them are significant barriers to robust and effective S-LCA."

The Climate Action Council should bring this issue to the attention of the Climate Justice Working Group. I recommend that it should be addressed in the Final Scoping Plan.

The Mills article discusses potential ways to address this problem and concludes a longer deployment period is probably needed. Ultimately though he concludes that "based on today's physics and technology, the only path to an energy system with a material intensity lower than hydrocarbons would be one focused on nuclear fission." Given that nuclear power is also the only scalable dispatchable emissions-free generating resource the Final Scoping Plan should include a Scenario that takes advantage of those capabilities. The Climate Action Council needs to address why this approach has not been considered.

Renewable Life Cycle Analysis

In my opinion one of the shortcomings of the Draft Scoping Plan is that it does not emphasize the mandate to "inform the state energy planning board's adoption of a state energy plan in accordance with section 6-104 of the energy law" contained in § 75-0103 (11). In order to do that properly the state energy planning board has to understand all the factors affecting energy supply and not get a one-sided description of the factors involved.

As shown above, New York's statewide greenhouse gas emissions report includes upstream emissions associated with the extraction, production, and transmission of fossil fuels imported into New York State. However, it does not address the full life-cycle emissions that would add the decommissioning effects. I recommend that the National Renewable Energy Laboratory Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update report be used to provide the upstream emissions associated with the wind, solar and energy storage technologies and address life cycle emissions for all technologies. Excluding that information presents a one-sided picture of the tradeoffs of different generating resources. More importantly, that information could be used to inform the decision for the mitigation scenario decision or adjust the relative proportion of specific renewable technologies in the energy plan recommendations.

I prepared this comment because the Draft Scoping Plan over-estimates benefits and under-estimates costs. In this comment I address the environmental and life cycle costs and benefits discussion in the Draft Scoping Plan. I have written extensively on implementation of the Climate Act because I believe the ambitions for a zero-emissions economy outstrip available renewable technology such that it will adversely affect reliability and affordability, risk safety, affect lifestyles, will have worse impacts on the environment than the purported effects of climate change in New York, and cannot measurably affect global warming when implemented. The opinions expressed in this document do not reflect the position of any of my previous employers or any other company I have been associated with, these comments are mine alone.

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[The Hard Math of Minerals]

By [Mark P. Mills]

Mills, Mark P. "The Hard Math of Minerals." *Issues in Science and Technology* (January 27, 2022).

Today's plans to decarbonize global energy systems, which center on a massive expansion in the use of solar, wind, and battery technologies, need to better account for the high environmental and economic costs of materials and minerals.

The great twentieth-century physicist Richard Feynman once said that "it is important to realize that in physics today, we have no knowledge what energy is." But we do know one unequivocal fact: delivering useful energy services to society has always been about materials.

Today's plans to decarbonize global energy systems center on a massive expansion in the use of solar, wind, and battery technologies, with the goal of these becoming the dominant means to power society. But scaling up these energy sources entails a radically heavier materials footprint than is associated with fossil fuels, paradoxical though it may seem. The unavoidable scale of materials demand will have significant impacts on commodities markets and prices, as well as on the environment. Most policy formulations fail to account for these implications. The country is long overdue for thoughtful and realistic planning that honestly acknowledges the tradeoffs and consequences arising from the materials needed to accelerate what is being called the energy transition.

It has long been known that building solar and wind systems requires roughly a [tenfold increase in the total tonnage] of common materials—concrete, steel, glass, etc.—to deliver the same quantity of energy compared to building a natural gas or other hydrocarbon-fueled power plant. Beyond that, supplying the same quantity of energy as conventional sources with solar and wind equipment, along with other aspects of the energy transition such as using electric vehicles (EVs), entails [an enormous increase in the use of specialty minerals and metals] like copper, nickel, chromium, zinc, cobalt: in many instances, it's far more than a tenfold increase. As [one World Bank study noted], the "technologies assumed to populate the clean energy shift … are in fact significantly MORE material intensive in their composition than current traditional fossil-fuel-based energy supply systems."

Today, the material intensity of solar and wind systems and EVs is still of minimal consequence because those technologies account for only a few percentage points of the global energy system. But the material demands will become hard to ignore if the world's economies all simultaneously pursue similarly ambitious policies to displace the fossil fuels that currently supply over [80% of all energy]. The [vision plan from the International Energy Agency] (IEA), which has been adopted and even exceeded by some policymakers, has solar and wind providing some 60% of net new global energy supply over the coming two decades.

The country is long overdue for thoughtful and realistic planning that honestly acknowledges the tradeoffs and consequences arising from the materials needed to accelerate what is being called the energy transition.

Installing so much wind and solar generation capacity worldwide has profound materials implications, not to mention land requirements, which will soon become problematic. Replacing the energy output from a single 100 megawatt (MW) natural gas-fired turbine (producing enough electricity for 75,000 homes) requires at least 20 wind turbines, each about 500 feet tall and collectively requiring some 30,000 tons of iron ore and 50,000 tons of concrete, as well as 900 tons of nonrecyclable plastics for the turbine blades. The gas turbine, by contrast, requires only about 300 tons of iron ore and some 2,000 tons of concrete. The 20 wind turbines also require 1,000 tons of specialty metals and minerals such as copper, chromium, zinc, etc., versus about 100 tons embodied in the gas turbine. Moreover, the gas turbine is about the size of a residential house, while those 20 wind turbines require 10 square miles of land. And although a solar installation would require one-third as much land as wind, the aggregate tonnage of cement, steel, and glass used is about 150% greater than wind.

And if solar and wind are to become the primary sources of power, then utility-scale electricity storage and additional generating capacity will be required to meet demand and to produce excess energy to be stored. Thus, replacing a 100 MW gas turbine would necessitate at least 200 MW of solar or wind capacity, more than doubling the hardware and materials requirements—along with yet more materials associated with building about 10,000 tons of batteries for energy storage.

Scaling up solar, wind, and batteries also means scaling up the mining of the refined minerals they require. There is a significant environmental impact associated with the sheer tonnage of earth that must be moved and processed to produce these refined minerals. To produce one ton of a purified element, a far greater quantity of ore must be extracted and processed. Copper ores, for example, typically contain only about 0.5% by weight of the element itself: roughly 200 tons of ore are dug up, moved, crushed, and refined to produce 1 ton of copper. The rare earth element neodymium, which is used in wind turbines, requires mining from 20 to 160 tons of ore to obtain 1 ton. Cobalt (used in most batteries) occurs at a grade typically lower than 1 ton of the element per 1,500 tons of ore. The calculus of the upstream environmental footprint should also include the overburden—the necessary removal of even more tons of rocks and dirt to access a single ton of the buried mineral-bearing ore.
The energy transition, as it's being conceived today, will create a need for tens of gigatons of materials for solar and wind generation, grid storage, and car batteries. The IEA terms this a "shift from a fuel-intensive to a material-intensive energy system." The agency estimates that an energy plan more ambitious than implied by the 2015 Paris Agreement, but one that remains far short of eliminating the use of fossil fuels, would increase demand for minerals such as lithium, graphite, nickel, and cobalt rare earths by 4,200%, 2,500%, 1,900% and 700%, respectively, by 2040.

Can the world meet the minerals and mining demands of these collective goals? The IEA report is not alone in pointing out that the required mining and processing infrastructure capacities don't yet exist to meet the demand for essentially every category of mineral necessary for the transition path.

The energy transition, as it's being conceived today, will create a need for tens of gigatons of materials for solar and wind generation, grid storage, and car batteries.

In a recent report from the Geological Survey of Finland, researchers considered the minerals implications for achieving a so-called full transition; that is, using solar and wind to electrify all ground transport as well as to produce hydrogen for both aviation and chemical processes. They found the resulting demand for nearly every necessary mineral, including common ones such as copper, nickel, graphite, and lithium, would exceed not just existing and planned global production capabilities, but also known global *reserves* of those minerals.

A recent analysis by the Wood Mackenzie consultancy found that if EVs are to account for two-thirds of all new car purchases by 2030, dozens of new mines must be opened just to meet automotive demands—each mine the size of the world's biggest in each category today. But 2030 is only eight years away and, as the IEA has reported, opening a new mine takes 16 years on average.

Despite these and similar analyses, many countries, and many US states, are now proposing to accelerate deployment of solar, wind, and battery technologies without clear plans for overcoming the material shortfalls. One study sponsored by the Dutch government offered a blunt statement of reality: "Exponential growth in [global] renewable energy production capacity is not possible with present-day technologies and annual metal production."

Another area of concern for these new technologies is their future cost, which will be inseparable from the velocity and scale of their entry into the market. Today, future plans for solar, wind, and battery technologies assume costs will continue to fall significantly, as they have over the last decade. But the implications of record-breaking demands for mineral commodities suggest the reverse is more likely.

Many countries, and many US states, are now proposing to accelerate deployment of solar, wind, and battery technologies without clear plans for overcoming the material shortfalls.

Consider batteries, which underpin hopes to displace fossil fuels both in transportation and in enabling solar- and wind-dominated grids. Numerous estimates (exact data are proprietary) suggest that commodity materials comprise 60 to 70% of the cost to produce a battery. Thus, modest increases in commodity prices can wipe out gains in the smaller share of costs associated with assembly, electronics, and labor, leading to overall higher costs. The IEA's analysis in early 2021 of "energy transition minerals" noted as much, concluding that future mineral price escalations could "eat up the anticipated" reductions in manufacturing costs expected from the "learning effects" in further scaling up battery production. In fact, 2021 saw high material costs lead to overall lithium battery prices declining by only 6%. That was a dramatic slowdown from the decadal trend, and less than half the decline rate in each of the prior two years. Although EVs comprise only 5% of the market for automobiles, the price index of EV battery metals has already increased by more than 200% over the past two years.

Commodity inflation has begun to escalate the cost to build wind and solar systems as well, slowing or reversing long-run cost declines. As with batteries, progress in manufacturing efficacy has reduced solar module production costs so much that commodity inputs now make up about 70% of the overall price of modules. These inputs include not only copper, silver, and aluminum but also, in no small irony, coal. The energy-intensive fabrication of polysilicon, a key raw material in solar modules, takes place mainly in China (with its two-thirds share of all polysilicon supply) on its low-cost, coal-dominated grid. The combination of mineral commodity inflation and the jump in coal prices pushed solar module prices up nearly 50% over 2020. Wind turbine manufacturers were similarly stung by higher material costs (which make up 20% of their cost) with many now planning to sell turbines with clauses that will "pass through" commodity price hikes onto buyers.

Many analysts claim that materials demand can be greatly alleviated with recycling. The ideal is described as a circular economy achieving nearly complete reuse of materials from discarded hardware. Although a worthy aspiration, myriad practical and economic factors impede getting close to that goal in general, not just with solar, wind, and batteries. And, as one United Nations study observed: "Less than one-third of some 60 metals studied have an end-of-life recycling rate above 50% and 34 elements are below 1% recycling, yet many of them are crucial to clean technologies." Even if far greater levels of recycling were mandated, the vast quantity of solar and wind equipment required for the energy transition will for decades overwhelm any marginal additions to materials supply that could come from recycling the far smaller quantity from worn-out hardware.

Some proponents of the transition pin their hopes on innovation to reduce materials intensity through improvements to the underlying operating efficiency of the systems: higher photovoltaic conversion efficacy and battery chemistries with higher energy density, for example. But in these realms, gains of 10% or so are hard won. To have a meaningful impact on materials demands would require, rather than 10% efficiency gains, leaps of *tenfold* over existing solar, wind, and battery technologies—gains that aren't even theoretically feasible. There is, in short, no escaping the fact that the astonishing scale of global materials production needed for proposed energy transition plans will almost certainly place severe limits on aspirations for expanding the use of wind, solar, and battery systems. But even before those limits are reached, the pursuit of a materials-heavy energy infrastructure will cause economic impacts that ripple beyond energy markets, inflating the cost of nonenergy uses for the same minerals in computers, conventional manufacturing equipment, everyday consumer appliances, and more.

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Beyond economics, there are also the practical and geopolitical challenges arising from realignments of energy material supply chains. For example, the United States today is dependent on imports for 100% of some 17 critical minerals and, for 28 others, net imports account for more than half of existing domestic demand. Assembling batteries or solar hardware in the United States won't change the underlying dependencies any more than assembling automobiles domestically would if the key components and all the fuel were imported.

Finally, there are the social and moral implications associated with a radical shift in the types and locations of environmental impacts that comes from replacing drilling (for fossil fuels) with a massive expansion in mining, much of which will occur in emerging markets and fragile ecosystems. For example, Australia's Institute for Sustainable Futures noted in its analysis that the global gold rush for minerals to meet ambitious transition plans could take miners into "some remote wilderness areas [that] have maintained high biodiversity because they haven't yet been disturbed."

Meanwhile, little attention has been afforded the social and humanitarian implications of this shift. Jennifer Dunn, a pioneer in social life cycle assessment (S-LCA) and associate director of the Center for Engineering Sustainability and Resilience at Northwestern University's McCormick School of Engineering, has noted that "technologies that are designed to solve grand challenges such as climate change must consider both their environmental and social impacts to understand their true consequences." As Dunn and her collaborators observe in a recent analysis focused on cobalt as a case study, while *environmental* life cycle assessment is a "mature widely-used tool," social and humanitarian considerations remain nascent and "the lack of regionally or locally specific data and guidance for collecting them are significant barriers to robust and effective S-LCA."

Policymakers are limited in what they can do to alleviate the materials challenges arising from an overreliance on solar, wind, and battery technologies. While the long history of maintaining military stockpiles for critical minerals may seem like a precedent to emulate, stockpiles don't solve a systemic supply problem. In any case, the quantities of materials required in the energy sector are many orders of magnitude greater than for defense purposes, rendering that option economically, if not functionally, impossible—even for the security feature that stockpiles are intended to address.

The European Union has acknowledged the need for additional mining, specifically on its own continent, and has even proposed development incentives. But the few attempts thus far to open new mines in EU countries have quickly met with fierce environmental opposition. In the United States, neither Congress nor the administration has proposed anything meaningful to help expand domestic mining industries. Instead, proposals for new mines continue to be blocked.

The obvious approach for avoiding the creation of unsustainable demands for minerals is to adopt more moderate and longer-term deployment targets for solar, wind, and battery hardware. This would necessitate a far less aggressive imposition of mandates and subsidies directed at accelerating market adoption. More realistic policies could not only avoid triggering hyper-inflation in commodity markets, but they would also have the salutary benefit of a more cost-effective, natural evolution of new energy technologies.

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The downside to this approach is that it leaves a gap in aspirations for reducing the use of fossil fuels. It bears noting that over the past decade of already accelerated transition policies, hydrocarbon consumption has risen and is forecast by the IEA to continue rising for the usefully foreseeable future. To address this, policies could more productively focus on support for the expanded use of different kinds of technologies, especially those that radically improve fossil fuel efficiencies.

For the longer term, policymakers might take heed of the reality that a goal of "net-zero" will require new technologies that don't exist today. That reality points to the need for a greater focus on basic scientific research. Unfortunately, that path doesn't have a "predictor function" (to use Bill Gates's locution) and one cannot, in effect, order up elusive breakthrough technologies. One can imagine but not predict when someone will discover, for example, a low-cost, room-temperature superconductor that would make storing electricity as easy and cheap as storing petroleum, or a metamaterial that synthesizes hydrogen at a scale and cost rivaling natural gas.

Based on today's physics and technology, the only path to an energy system with a material intensity lower than hydrocarbons would be one focused on nuclear fission. In the pantheon of energy-producing machines, none is more remarkable than the nuclear reactor. Nuclear fission offers a potential hundredfold reduction in material intensity over combustion, and a thousandfold reduction over solar and wind. Here too, though, even if policies are implemented that are conducive to a nuclear renaissance, meaningful expansion will take decades longer than the rapid transition timelines popular today.

The material realities associated with solar, wind, and storage technologies do not obviate an expanded, or even a substantial, role for these energy systems. However, believing that such technologies make possible a rapid and wholesale replacement of fossil fuels ignores the underlying physics, engineering, and economics. Even more troublesome, putting so much effort and money into those technologies will lead the world down a path that won't meet targets to reduce carbon dioxide emissions, but would cause massive collateral damage to economies and the environment. If Feynman were alive today, one suspects he would repeat another of his favored aphorisms: "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled."