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Testimony

Minerals & Materials Supply Chains – Considerations for Decarbonizing Transportation

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Summary – Presented Testimony

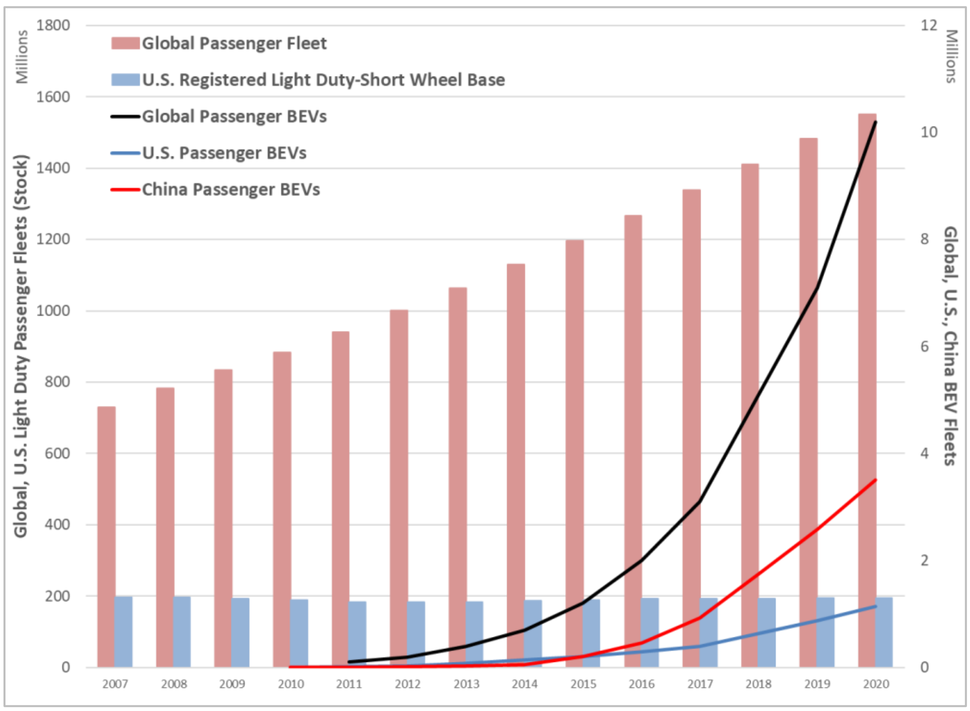
- Policy and decision makers should take an approach that is not part of conventional thinking.
    - **Materials** – all materials, regardless of source – are the first building blocks. Materials science is dynamic. The nature of innovation is serendipitous and economic and financial risks are substantial. Both are vulnerable to underlying business conditions and tax policies.
    - **Systems** require extraordinary attention and support, be they for basic infrastructure or to push sophistication into essential functions like electric power grids. A country that cannot attain public acceptance of legacy components, fuels and technologies is unlikely to be one where public acceptance of new technologies and their intrusions can easily be achieved.
    - **Data** is in a fragile state. BEVs increasingly interact with energy, telecommunications and other systems, infrastructure and data streams. Data is intellectual property (IP), with inherent value and assorted strategies for monetization. Everything from automation in transport to road maintenance and environmental controls has the potential for solutions embedded in data. A world full of BEVs is one in which data extends well beyond terabytes, creating new demands for storage with attendant energy and sustainability considerations.
- Battery costs, risks and affordability.
    - Are contingent upon regional distribution of manufacturing platforms, associated supply chains and logistics, workforce capacity and labor costs and the assortment of contextual factors that are responsible for comparative advantages, or not, across nations and localities.
    - Large "cones of uncertainty" exist.
    - Policy makers should focus on core economic policies that support competitiveness and resilience.
    - Batteries and BEVs are materials intense. Mining and minerals processing already are a focus for ESG imperatives. Recycling can help but is a work in progress. BEV manufacturing and recycling must become "symbiotic". A worry is that environmental regulations that affect businesses engaged with hazardous materials could throttle vital new processes and approaches. A further concern is that BEVs, batteries and other components of alternative energy will add to waste volumes much more rapidly than we can build capacity for handling end of life.
    - Commodity prices already are rising sharply. A "rush to materials" for alternative energy aspirations will threaten economic and national security, could trigger inflation or even hyperinflation, create new sources of geopolitical risks and uncertainties, undermine fragile states, lead to expansion of unsustainable industries and a host of other consequences. Expectations for minerals price increases are now baked into every trading position as well as into nearly every minerals expansion or new venture. They are not, however, baked into forecasts of battery costs.
    - Electricity prices are at least as unreliable as other commodities. Many government policies to support BEVs in other countries entail measures to soften the cost of recharging. U.S. residential costs have climbed persistently even while the key marginal fuel for power generation – natural gas – has been historically low. When it comes to expanding recharging, a distinct consumer issue is whether non-BEV owning or using customers will pay an oversize share of costs.
- Hydrocarbons and petrochemicals are vital raw materials.
    - Our Texas freezageddon provided an illustration of how plastics costs can soar with constraints.

    - Global oil and gas operations are leveraged by sale of petroleum and natural gas fuels, keeping costs of materials affordable.
    - Plastics are crucial for BEVs – more than half of vehicle content but only 10% of weight.
    - Advanced polymers are essential for advanced vehicles and batteries.
    - Advanced plastics recycling is underway and would benefit from more strategic thinking about supply chains and circular economies.
    - Bioplastics are under development for automotive use but availability and affordability of BEVs – any vehicle type for that matter – will continue to hinge on hydrocarbons-based materials sourced from U.S. and global oil and gas operations.
- Executive Order 14017, America's Supply Chains, should include hydrocarbons as critical minerals; add end of life management and associated logistics. Interactions are pervasive – diverse industry participants share concerns. Supply chain preparedness and resilience would benefit from the building blocks of materials first, systems and data.
- Finally, to China's role.
    - China dominates production of many critical and basic minerals and now also dominates trade flows, with some expanding as much as ten times 2001-2019.
    - China's coal dominated electric power capacity is key to its battery manufacturing.
    - China also dominates trade in LIB products.
    - China's strength in LIB manufacturing and supply chains is well documented by DOE CEMAC.
    - A "rush to materials" to counter China's influence and secure alternative energy supply chains would exacerbate global tensions on many fronts.

Full Testimony – Background: Pushing on Strings

A search has been underway for levers to accelerate an assortment of technologies that, in many views, could be used to address myriad energy, environmental, economic and hard security concerns. Battery electric vehicles (BEVs) have been iconic in this regard, as salves for everything from urban air quality to sensitivities around supply and pricing of petroleum fuels. Growth rates in BEV production, sales and fleets are enticing. However they remain a very small portion of the overall global stock of passenger vehicles (Figure 1), a luxury good in most countries and locales. Poorer countries that aspire to electric transport must first build more robust and reliable electric power systems – electricity must be available in some form and BEVs are demanding. Wealthier countries face a vast assortment of challenges to accelerating expansion of BEV fleets and displacing traditional internal combustion engine (ICE) vehicle designs.

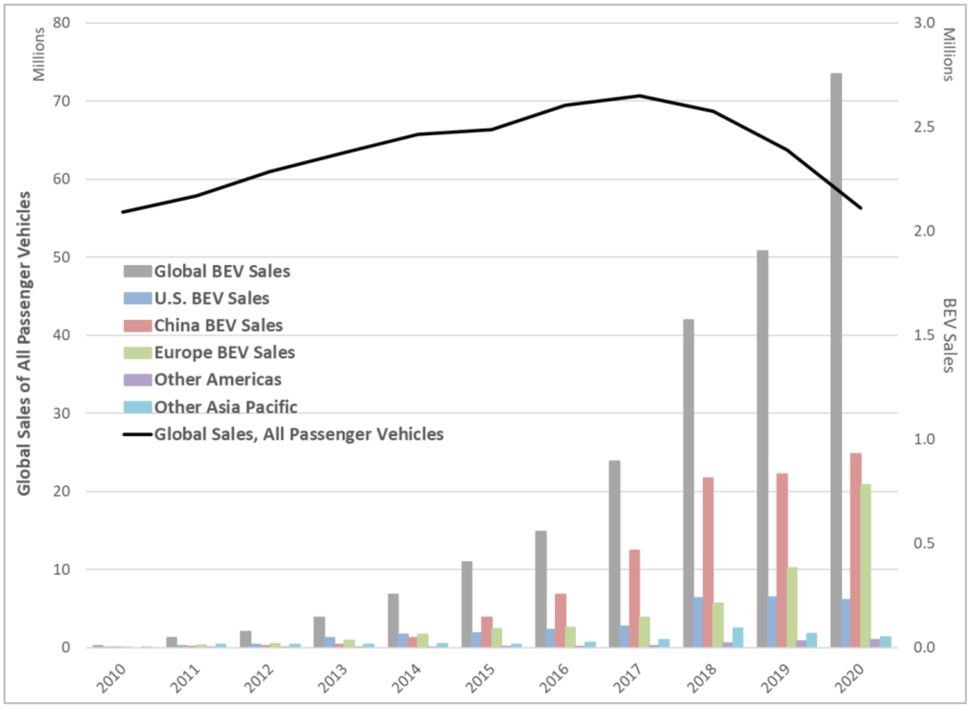
Figure 1. Scale of Global and Regional Vehicle Markets



Sources: Various including International Energy Agency's (IEA's) 2021 Global BEVs Outlook, https://www.iea.org/reports/global-ev-outlook-2021; U.S. Department of Transportation's Bureau of Transportation Statistics, https://www.bts.gov/; and other sources as compiled by Statista (accessed via Rice University).

Some of these challenges are battery manufacturing and associated supply chains; costs of raw materials (including many that are not usually considered in analysis), labor and other inputs; access to and costs of recharging along with all of the associated complexities; other variables such as consumer behavior and competing alternatives; and many more. Depending upon information sources and how one looks at these things and the implications for vehicle production and sales (**Error! Not a valid bookmark self-reference.**), transitioning the U.S. and global fleets could take a mere 150 years, or much longer.

Figure 2. Only "XXX" Years to Go



Sources: Various including IEA's 2021 Global BEVs Outlook, https://www.iea.org/reports/global-ev-outlook-2021; U.S. Department of Transportation's Bureau of Transportation Statistics, https://www.bts.gov/; and other sources as compiled by Statista (accessed via Rice University).

Devilish Details

I suggest that policy and decision makers take an approach that is not part of conventional thinking. **Materials** – all materials, regardless of source – are the first building block. Materials are in a dynamic state as bench science dips into ever more adventurous endeavors, down to the atomic scale and to include "smart materials" that can be used to achieve extraordinary performance in applications. Achieving better understanding realistic time frames to "proof of concept" is vital. The nature of innovation is serendipitous and – of great consequence in light of pandemic recovery – economic and financial risks are substantial. Both are vulnerable to underlying business conditions and tax policies. **Systems** require extraordinary attention and support, be they for basic infrastructure or to push sophistication into essential functions like electric power grids. **A country that cannot attain public acceptance of legacy components, fuels and technologies is unlikely to be one where public acceptance of new technologies and their intrusions can easily be achieved.** This is true no matter the lip service to "leap frogging".[1] **Data** is in a fragile state. Legacy technologies already are lagging in data security. By their very nature, existing BEV models and, even more, new designs under development raise the bar on "hardening". This is especially true as BEVs increasingly interact with energy, telecommunications and other systems, infrastructure and data streams. Data is intellectual property (IP), with inherent value and assorted strategies for monetization. Everything from

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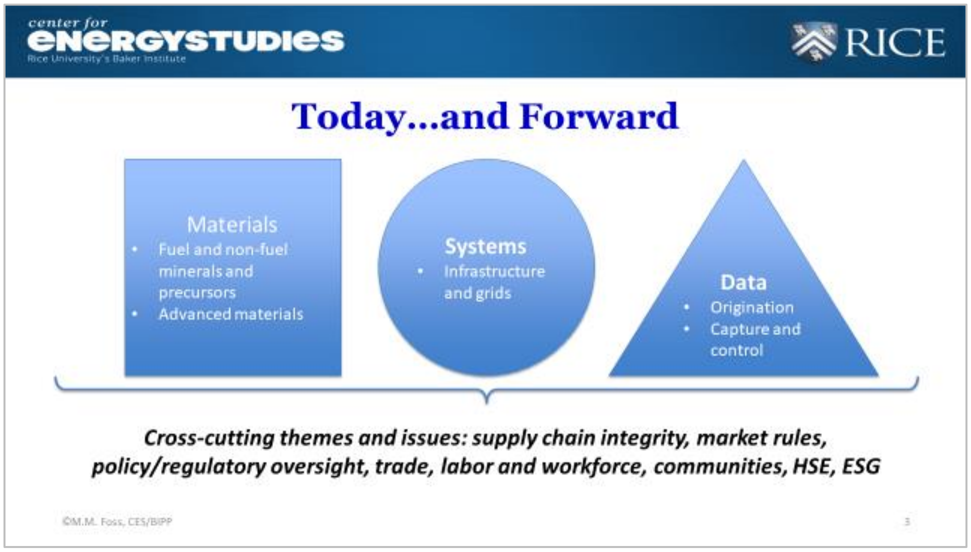
[1] Many political leaders of U.S. states desire to promote BEVs but also want bans on mining and minerals processing in their states. See https://www.americanexperiment.org/looming-nickel-shortage-threatens-to-slam-the-brakes-on-governor-walzs-electric-vehicle-mandates/ and https://www.reuters.com/article/us-usa-mining-polymet-mining/minnesota-court-orders-fresh-review-of-polymet-mine-permits-idUSKBN2CF2KK.

automation in transport to road maintenance and environmental controls has the potential for solutions embedded in harvesting, managing, controlling, protecting and ultimately effective utilization of data. A world full of BEVs is one in which data extends well beyond terabytes, creating new demands for storage and the attendant energy and sustainability considerations.

Figure 3. Building Blocks for Policy and Decision Makers



Against that backdrop, I focus on four aspects for the hearing today.

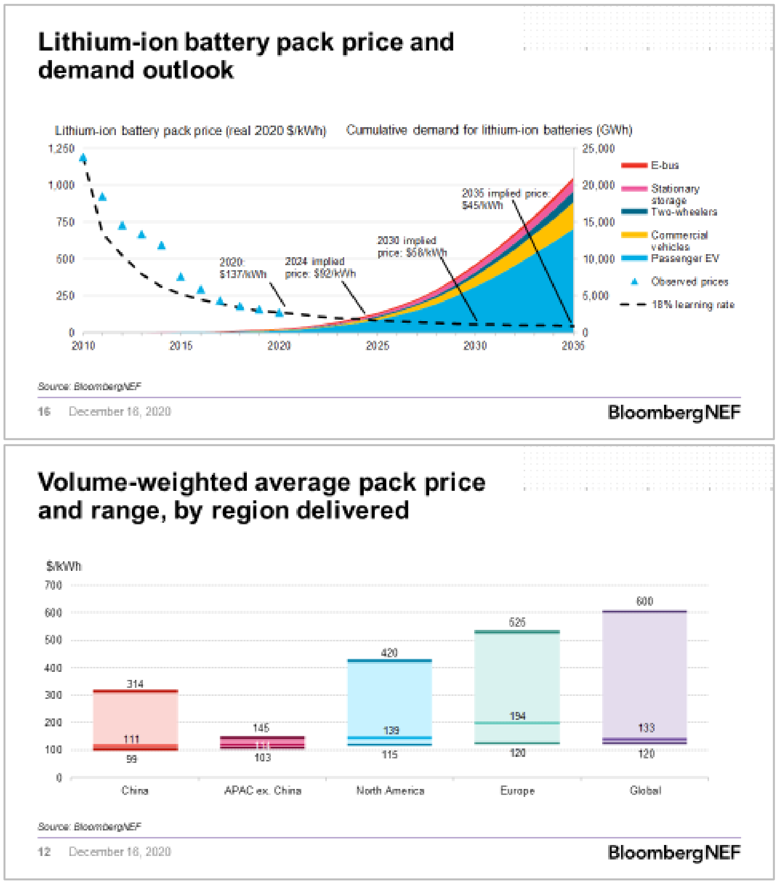
- Battery costs, risks and affordability.
- Hydrocarbons and petrochemicals, vital raw materials.
- Executive Order 14017.
- China's role.

Battery Costs, Risks and Affordability

The widespread view is, and has been, that BEVs make sense because battery costs have declined and will continue to do so. In the most assertive views, batteries for BEVs not only can reach the magical $100 per kilowatthour (KWh) "stretch" goal but could even come close to zero! That is the implicit conclusion from the top panel of Figure 4 below. Most automotive original equipment manufacturers (OEMs) and their vendors will say, at least privately, that such a vision is critical, vital, to making BEVs affordable. Anything less is usually considered a deal breaker. Batteries are one-third to one-half of the cost of a BEV, depending upon design and model and so not an inconsequential feature. A great deal more goes into making affordable cars, of course, than the collection of battery metals that are capturing high profile attention. Driving down battery costs has become the mantra for achieving sufficient headroom to accommodate costs of other inputs and all of those associated risks and uncertainties.

Many of these are inherent in the regional distribution of manufacturing platforms, associated supply chains and logistics, workforce capacity and labor costs and the assortment of contextual factors that are responsible for comparative advantages, or not, across nations and localities. The bottom panel of Figure 4 provide a quick snapshot of variations in battery cost, which can be extensive in both scope and in the "cone of uncertainty" around the full set of factors. The higher the cost of manufacturing locations, the greater the pressure to seek interventions, including through policy and/or regulatory actions. Would a better approach be to tear apart cost structures, assess competitiveness and build more resilient platforms? Time, attention and scarce resources devoted to overhauling and simplifying tax codes, addressing labor markets and productivity along with workforce education and training, reviewing laws and rules for IP, devising creative strategies for de-risking and funding research and development (R&D), implementing sensible market rules for energy and other goods and services – these and more would build for overall economic growth and performance.

Figure 4. Battery Costs



Sources: BNEF analysis accessed via license and used with permission.

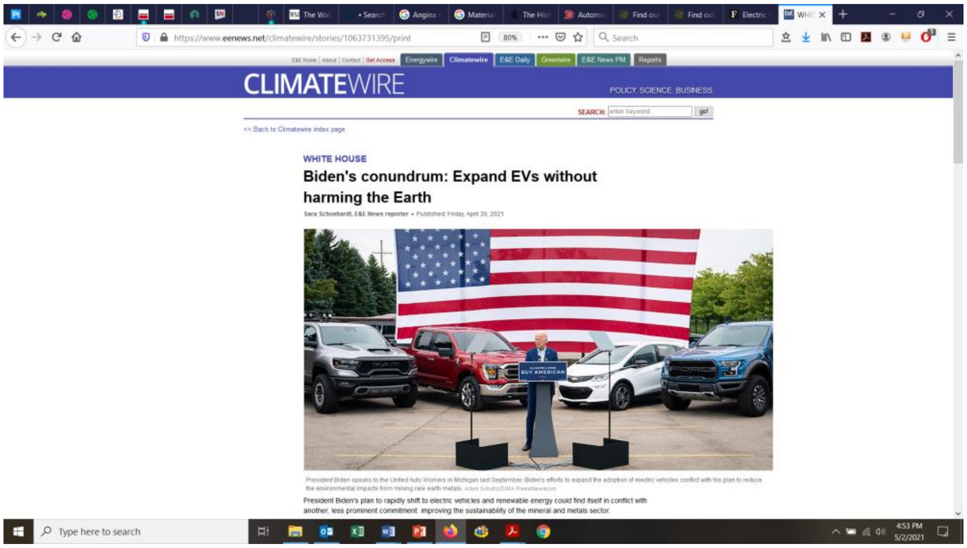
Materials Intensity

No matter the analysis or source, BEVs, and all other alternative energy technology, is materials intense. Almost daily, new research and evidence attests to the materials demands of the technologies that we hope will carry us into a sustainable future. In the past week, insights from the IEA are added to the mix. As noted (Figure 5):

> *"According to the International Energy Agency's 2020 Global BEV Outlook, the material demand for batteries in BEVs sold in 2019 was estimated at about 19 kilotons for cobalt, 17 kt for lithium, 22 kt for manganese and 65 kt for nickel.*
>
> *Under a projected scenario that incorporates existing government policies — where demand for BEV batteries increases from 170 gigawatt-hours today to 1.5 terawatt-hours by 2030 — demand for cobalt would expand to about 180 kt per year in 2030, lithium to around 185 kt/year, manganese to 177 kt/year and Class I nickel to 925 kt/year.*

If projected demand is in line with the goals of the Paris climate agreement and includes a target where BEVs make up 30% of global sales, material demand would more than double."[2]

Figure 5. The EV Sustainability Conundrum



https://www.eenews.net/climatewire/stories/1063731395/print

In previous testimony[3], I focused on some of the mining minerals processing environment, social, governance (ESG) concerns and imperatives. The widespread view is that recycling can address much of the tension around battery raw materials. In our surveying thus far, recyclers face their own, not insignificant hurdles for locating, certifying, building logistics for and achieving financial success of the new capacity that so many envision. The chicken-egg dilemma surrounding volumes of feedstock for recovery are such that one OEM representative commented that manufacturing and recycling simply must become "symbiotic". A great worry is environmental regulations that affect businesses engaged with hazardous materials, impacting development of vital new processes and approaches before they can even be pilot tested or, much less, commercialized. Considerable R&D is underway on recycling – which is highly contingent on battery chemistries – along with thinking about how to best to build this essential function of materials and manufacturing supply chains. A distinct possibility, considering the very rapid escalation of electronic waste (e-waste)[4] is that **BEVs, batteries and other components of alternative energy schemes will add to waste volumes much more rapidly than we can build capacity for handling end of life.**

Commodity Markets and Prices

Many views are that increases in costs of materials can be accommodated in battery manufacturing and affordability. **Absolutely no research or outlooks accommodate the sheer extent of a worldwide policy push to vastly accelerate, in short time frames, BEVs, batteries,**

[2] Excerpted from https://www.eenews.net/climatewire/2021/04/30/stories/1063731395 (accessed via subscription).

[3] See my testimony, https://energycommerce.house.gov/committee-activity/hearings/hearing-on-building-a-100-percent-clean-economy-opportunities-for-an-0.

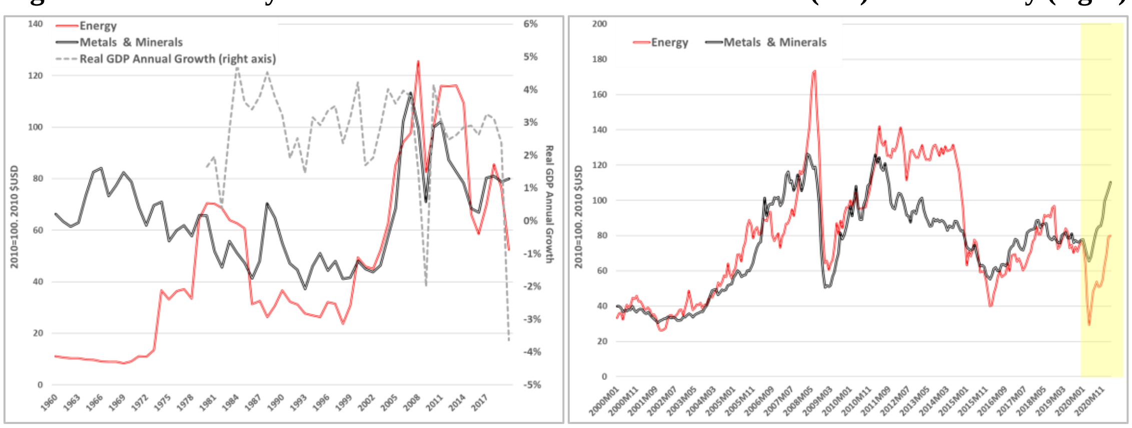
[4] See http://ewastemonitor.info/.

wind and solar, power grids and any number of other technologies and devices. While researchers and analysts typically construct scenarios that capture forward pathways that are not "business as usual", "BAU" is generally the underlying assumption for the extractives industry and processing businesses. To a large extent, this is because lack of data and, worse, lack of transparency around closely held, proprietary businesses and operations, including battery manufacturing. However, history has demonstrated that more often than not, these businesses and industries – a great number of which are controlled and/or owned by sovereign governments – are anything but BAU. **A "rush to materials" for alternative energy aspirations will threaten economic and national security, could trigger inflation or even hyperinflation, create new sources of geopolitical risks and uncertainties, undermine fragile states, lead to expansion of unsustainable industries and a host of other consequences.**

I raised all of these possibilities in previous testimony.[5] I pointed to the history of the battery minerals of interest as typical "cartel commodities", those which are often subject to attempts by producing governments to control exports, control ownership and/or exert changes to fiscal terms (taxes, royalties and other methods for capturing economic rents). Even where fiscal regimes should be reviewed and where producing governments have not had the best deals, righting the ship can destabilize mining properties and industries. Since my testimony in September 2020, countries from Indonesia to Zambia have taken or are contemplating taking actions that will have negative consequences for materials supplies. Even sophisticated countries like Chile are looking to extract more from their established mining industries to close pandemic economic gaps. Broad awareness of these threats does exist, but is largely confined to the extractives industry community. As well, change is slow. Programs that target ESG for sustainable mining and minerals processing have a very long way to go.

We already have evidence of price pressures on commodities that will affect the gamut of industrial and consumer products (Figure 6). Recent reporting notes the broad impact of latent demand on energy, minerals and agriculture, across the board, and also recognizes the impact of expectations regarding the "rush to materials" as governments promote alternative energy policies and strategies. **These expectations are now baked into every trading position as well as into nearly every minerals expansion or new venture. They are not, however, baked into forecasts of battery costs.**

Figure 6. Commodity Index Trends – Annual with Global GDP (left) and Monthly (right)

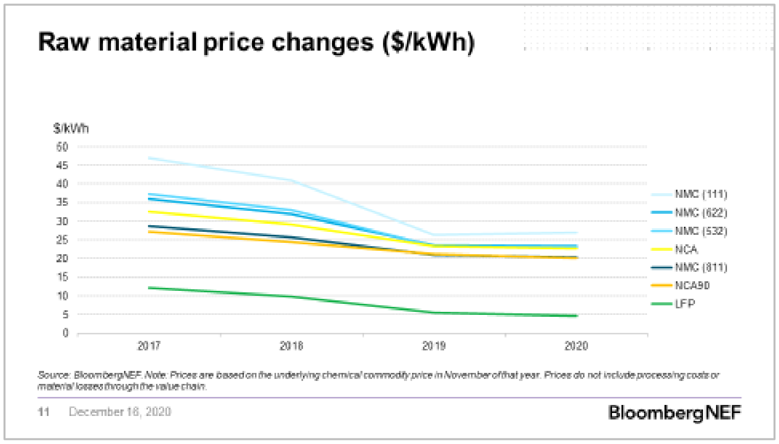


Source: Commodity price charts compiled by M. Michot Foss using IMF World Economic Outlook data for GDP and World Bank Pink Sheet for commodities.

[5] See footnote 3.

When compared to a typical projection of battery materials cost patterns (Figure 7) the fragility of assertions and assumptions regarding future trajectories should come into full debate.

Figure 7. Historical Price Changes for Battery Raw Materials



BNEF analysis on raw materials price changes accessed via license and used with permission.

Electricity Prices

Another argument put forward to promote BEVs is "cheapness" of electric power for recharging. Below is typical treatment, profiling a widely quoted study.[6]

> *"As of 2020 in the United States, the total cost of ownership of electric cars is less than comparable ICE cars, due to the lower cost of fueling and maintenance, more than making up for the higher initial cost…. Several national and local governments have established BEV incentives to reduce the purchase price of electric cars and other plug-ins…. According to a study done in 2018, examining only fuel costs, the average fueling cost of an electric vehicle in the United States is $485 per year, as opposed to an ICE cars' $1,117 per year. Estimated gasoline costs varied from $993 in Alabama to $1,509 in Hawaii. Electric costs varied from $372 in Washington to $1,106 in Hawaii."*

Electricity prices are at least as unreliable as other commodities. Many government policies to support BEVs in other countries entail at least some measures to soften the cost of recharging. In countries where EVs of various types have grown fastest, administered electricity pricing is often in the mix. The latter bears numerous implications for investment in electric power systems.

For several years, a puzzle for U.S. electric power has been why residential costs have climbed persistently even while the key marginal fuel for power generation – natural gas – has been historically low (Figure 8). A number of analysts – including the U.S. Energy Information Administration (EIA) – have suggested that rising costs are linked to pursuit of wind and solar. Although these generation sources are pegged as inexpensive, pricing of dispatched electricity is an artifact of federal subsidy support. Production tax credits (PTCs) for wind make up the difference between low prices in the wholesale market and realized price project developers need for "bankability". Investment tax credits (ITCs) for solar help to buy down the cost of grid-based installations. These intermittent generation sources consume system services to integrate them with grids, enabling grids to function with reliability (hopefully).

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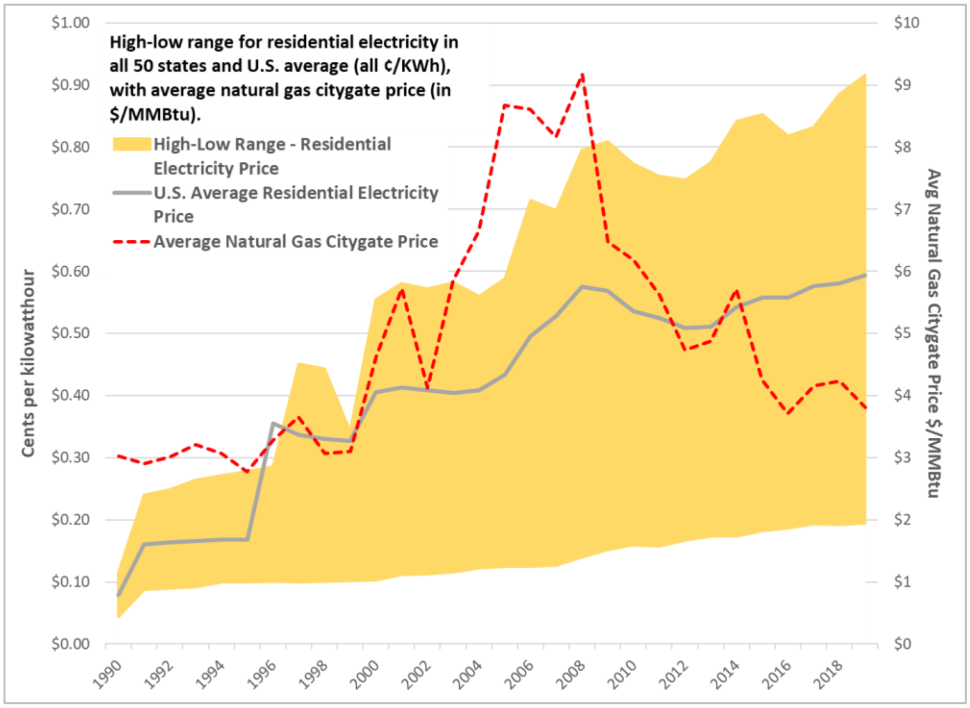
[6] See https://www.wikiwand.com/en/Electric_car#/Economics, https://www.energysage.com/electric-vehicles/advantages-of-evs/do-electric-cars-save-money/, or any number of links and sources.

Figure 8. U.S. Residential Electric Power Prices



Source: compiled by M. Michot Foss using U.S. Energy Information Administration data. High cost states are: RI, MA, CT, NY, NH, CA, ME, HI, NJ, MI, MD, DE, PA, (DC), IL.

Wind and solar resources are often thought of as "free" but, in fact, considerable expense is entailed in capturing and utilizing them. Beyond wind turbines and solar photovoltaics (PV) the cost of backup – usually natural gas generation – and/or alternative storage – usually grid-scale stationary batteries – are rarely, if ever, included in price quotes to customers. Yet all of these costs for system integration, backup, storage and so on are incurred and must be paid with allocation always, eventually to the customer. Residential customers in locations that are still operated by regulated utilities or where market restructuring has not been deep or where states/municipalities are promoting alternative energy are most likely to be affected. All customers, but residential users in particular, are subject to transfer of costs through their "wires" charges. Much of the thinking about BEV recharging incorporates assumptions of cost transfer to electric power customers in order to amortize the enormous costs of expanding capacity. "Free" BEV recharging is anything but. A distinct consumer issue is whether non-BEV owning or using customers will pay an oversize share of such endeavors.[7]

[7] Several sources and links for electric power research are in the appendix. Much of what I describe centers on the growing debate surrounding use of "levelized cost of electricity" (LCOE) as an appropriate measure. For previous related work under my direction, see https://www.beg.utexas.edu/files/cee/legacy/2016/CEE_Snapshot-Retail_Electricity_Price_Mar16.pdf, https://www.beg.utexas.edu/files/cee/legacy/2017/CEE_Research_Note-What_Future_for_Electricity_Markets-Mar17.pdf, https://www.beg.utexas.edu/files/energyecon/CEE_Research_Note_Competitiveness_Generation_Apr18.pdf and https://store.beg.utexas.edu/special-books/3777-us0007-net-social-cost-of-electricity.html.

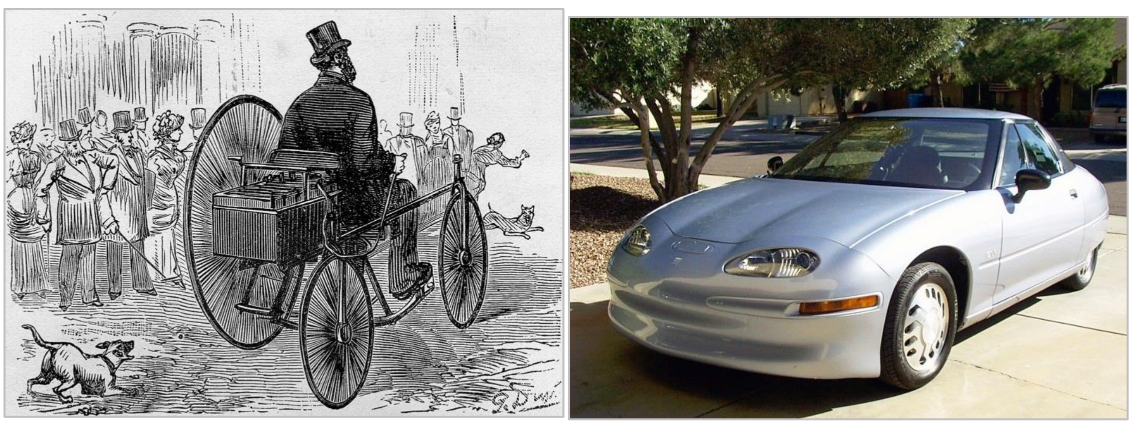
Cost of Hydrocarbons for Plastics (and Fuels)

A sidebar to our February deep freeze in Texas has been disruption to petrochemicals output and broad impacts on plastics supply chains.[8] The soaring cost of petrochemicals is a good analogy for what could happen to the other, larger portion of BEV materials requirements. **Any, all policy actions and mandates against oil and gas production and processing will be felt not only in cost of fuels – the intended effect – but also in the cost of critical materials – a widely unintended and never considered effect.**

Hydrocarbons and Petrochemicals

It is doubtful that a modern BEV customer would ever be content to motor around on an implement that was simply a collection of metals. (The same holds true for cyclists and their gear.) The rest of the story (Figure 9) is that modern vehicles have long owed a good portion of their substantial improvement in performance and fuel economy to "light weighting" as auto makers substituted plastics for heavier metal components. Expectations are that BEVs and other transportation technologies of the future will hinge on continued ability to incorporate light weight, durable, strong, safe composites throughout vehicle designs. This means that policy and decision makers simply must attend to hydrocarbons supplies and hydrocarbons based materials for the foreseeable future, perhaps forever.

Figure 9. The Rest of the BEV Materials Story



Left: Gustave Trouvé's personal electric vehicle (1881), world's first full-scale electric car to be publicly presented. Right: The General Motors BEV1, one of the cars introduced due to a California Air Resources Board (CARB) mandate, had a range of 260 km (160 miles) with NiMH batteries in 1999. https://www.wikiwand.com/en/Electric_car

IEA estimates that petrochemicals account for about 14% of global oil demand and 8% of global natural gas consumption.[9] This means that the enormous cost for drilling, producing and shipping feedstock is born largely by the revenues derived from sales of refined petroleum and natural gas fuels. ***In other words, the vast global uses and benefits of petroleum and natural gas for energy leverages the cost and affordability of materials derived from petrochemicals.*** This reality is largely, if not totally, ignored in the race to electrify transport. Automakers and customers will benefit most from less expensive oil and gas for materials. ***But the lower cost of petroleum and natural gas fuels competes head on with desires to shift away from these vital***

[8] See https://www.wsj.com/articles/one-week-texas-freeze-seen-triggering-monthslong-plastics-shortage-11615973401 (subscription required).

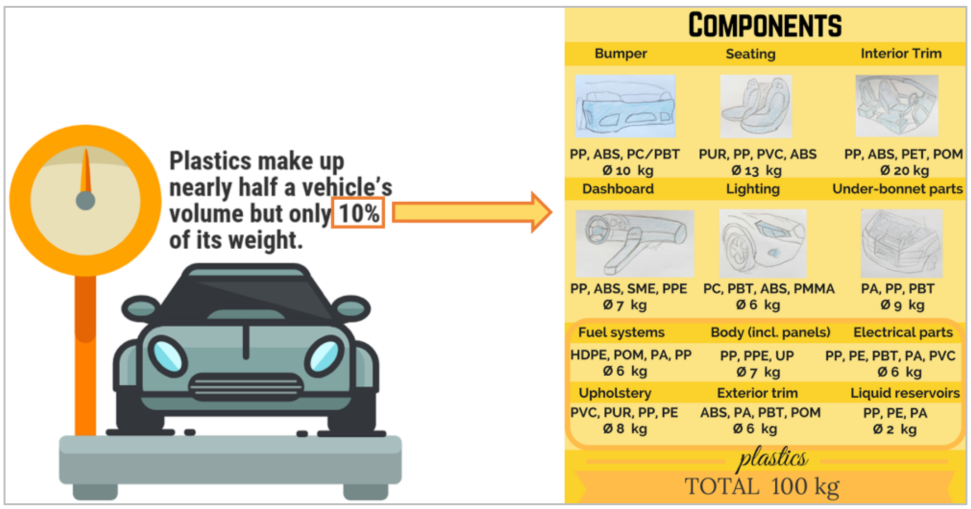
[9] See https://www.iea.org/reports/the-future-of-petrochemicals.

resources. Likewise, the many solutions proposed that target fossil fuel consumption will only serve to increase the cost of materials that are essential for substitutes, be they wind turbine blades or BEVs. Bans and moratoria on drilling, carbon taxes, opposition to oil and gas infrastructure and other options have the ultimate aim of making hydrocarbons scarce and expensive (note that "expensive" translates to "higher price" which has the contrary effect of luring investors). All of these considerations makes a "materials first" approach to policy making more than sensible.

When it comes to the specifics of plastics for autos, one analysts notes that:

> *"The overall plastic weight per car will not change significantly with BEV's. However, there will be a slight increase in weight in total. There are currently 10 000 parts made out of plastic in an average car and these use ca. 39 different polymers. Out of the 39, 6 are used the most, i.e. polypropylene, polyurethane, polyamides, polyethylenes, acryle-butadien-sytrenes, and polyvinylchloride."*[10]

Figure 10. Plastics Components for Autos



Source: https://www.innovativeautomation.com/the-history-importance-and-use-of-plastics-in-automobiles/ and https://www.findoutaboutplastics.com/2019/04/high-performance-polymers-in.html

Moreover:

> *Also in electrification, light weighting together with fuel economy will continue to be a megatrend. The rule of thumb says that for every 10% of weight reduction, fuel economy improves by ca. 6-8%. This additionally drives the consumption of plastics in automotive.*
>
> *Today, in hybrid and full BEV's, material selection tends to be much more differentiated, since applications need to fulfill specific requirements. The one-fits-all approach is no longer working in a similar sense. Standards from other industries such as electronics influence now material selection in automotive. As a result, a "wedding" between e.g. consumer electronics and automotive standards may take place.*

High performance materials, akin to and, in fact, drawn from state of the art polymers for electronics will be integrated for controls, thermal management, safety, dielectric properties and

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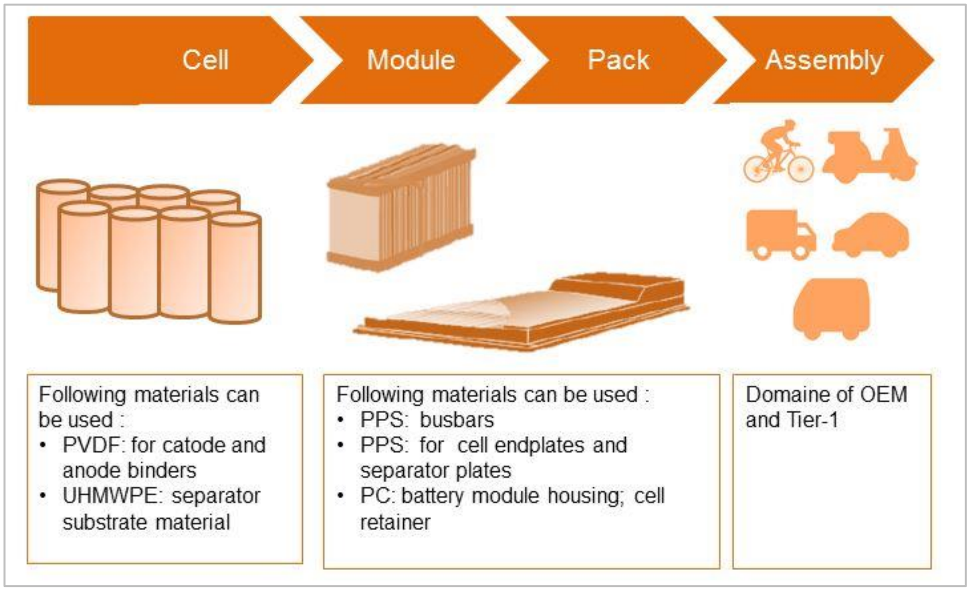
[10] See https://www.innovativeautomation.com/the-history-importance-and-use-of-plastics-in-automobiles/.

myriad other applications. Battery cells and packs incorporate and will incorporate polymers, adhesives, coating and more. Vehicles of the future will reflect the focus on materials and advances in materials – there is no choice. Figure 11 summarizes the potential plastic materials for cells, module, and pack.

Figure 11. Battery Plastics



Source: https://www.findoutaboutplastics.com/2019/04/high-performance-polymers-in.html.

"Plastics" invokes any number of images, mental or otherwise, regarding waste. The chemicals industry is pursuing a number of options for waste reduction, substitutes and other solutions. Recycling is advancing rapidly but, as with battery recycling, nascent technologies and processes need to be cultivated.[11] Can some auto plastics components be derived from bio sources? Plenty of thinking and research are underway regarding development of bioplastics for automotive uses. Bioplastics are estimated to account for about 1% of total global plastics production (roughly 368 million tonnes).[12] While much of that output is targeted for consumer goods and packaging of all sorts, autos are increasingly a target for application. **Until that nut is cracked, availability and affordability of BEVs – any vehicle type for that matter – will continue to hinge on hydrocarbons-based materials sourced from U.S. and global oil and gas operations.**

EO 14017 – America's Supply Chains

The executive order on supply chains has the side benefit of educating many on the challenges ahead, especially when it comes to how best to source materials at home. A number of issues exist, relative to points in my testimony.

- EO 14017 focuses on minerals, with emphasis on those deemed "critical". The vital, ongoing operations of the domestic oil and gas industry are ignored. Indeed, other executive orders

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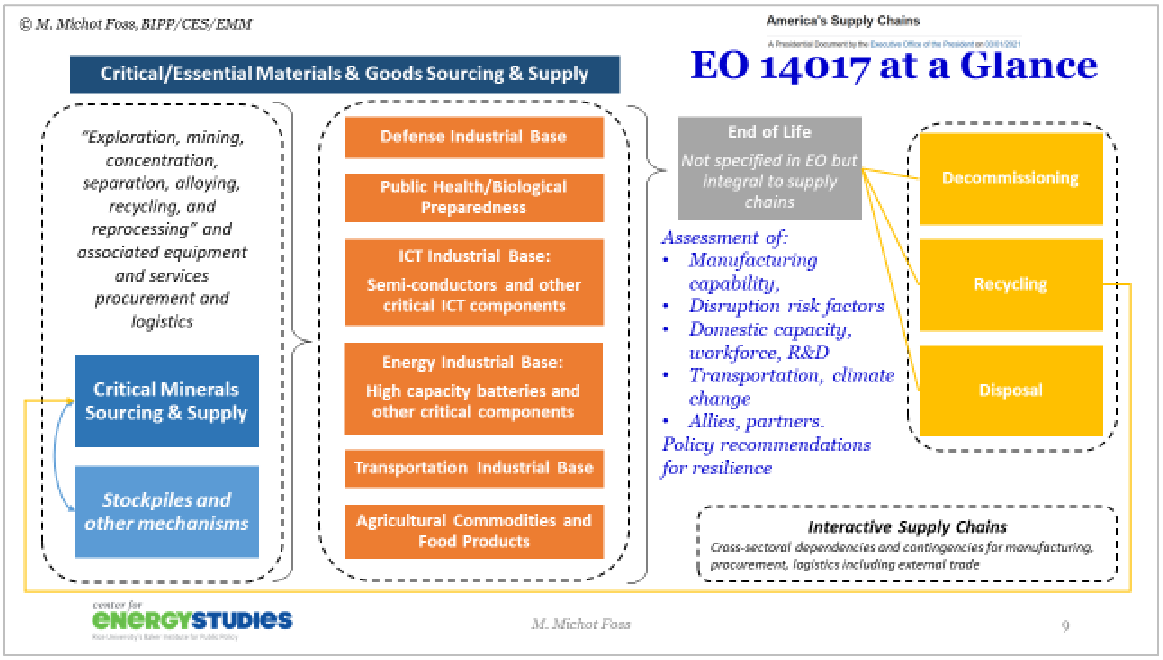
[11] My colleague Dr. Rachel Meidl points out that much of the issue on plastics waste is poor conceptualization of the need, https://blog.bakerinstitute.org/2021/04/19/smart-policy-and-innovative-technologies-like-advanced-recycling-will-deliver-on-climate-and-sustainability-goals/.

[12] See https://docs.european-bioplastics.org/conference/Report_Bioplastics_Market_Data_2020_short_version.pdf.

serve to threaten oil and gas resource development and supply, thus my view that **hydrocarbons should be designated as critical minerals**.

- **End of life** and the complicated supply chains associated with decommissioning, recycling and disposal are excluded.
- When it comes to interactions, we are exploring semiconductor industry priorities. Industry participants **share concerns about raw materials supplies that extend beyond their own needs** because of how these impact their key customer groups – such as auto manufacturers.
- Overall, **supply chain preparedness and resilience**, including both defense and non-defense needs, would benefit from the building block approach of materials first, systems and data.

Figure 12. Representation of EO 14017



Source: compiled by M. Michot Foss based on EO 14017.

All China All the Time

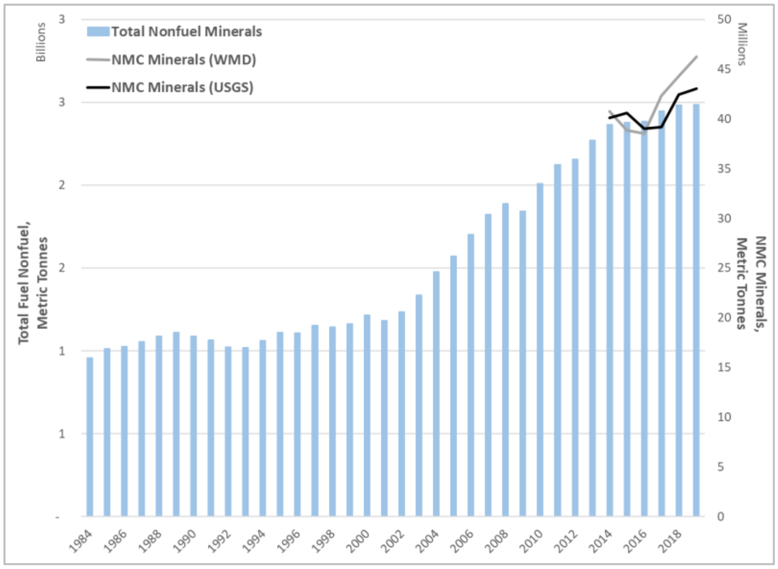
Since my previous testimony[13], a number of organizations and resources have emerged with a focus on China's role. Our own research demonstrates the following.

- Lithium ion battery (LIB) minerals are, for now, a relatively small part of the global nonfuel minerals pie. Figure 13 illustrates state of knowledge on minerals output using the main lithium nickel, manganese, cobalt chemistry (NMC).
- An image of our world map of minerals production is captured in Figure 14. I add phosphates for the lithium iron phosphate, LFP battery that is in use by, and promoted by, BYD, a prominent Chinese producer. LFP offers safety advantages over other LIB designs and longer life cycle. Drawbacks are low energy density and conductivity. Some makers add carbon for improvements. Given the influence of Chinese capacity and progress around the LFP chemistry, it bears watching, as do other advanced battery designs such as solid state.
- Our data and mapping continue to reinforce China's impressive build out of energy infrastructure but also that battery making is only as "clean" as supporting power systems.

[13] See previous footnote 2.

To our thinking, **China's EVB capacity is highly advantaged by the enormous installed base of coal-fired electric power generation** (EVB sites are proximal to these facilities).

Figure 13. Worldwide Production of Nonfuel and NMC Minerals



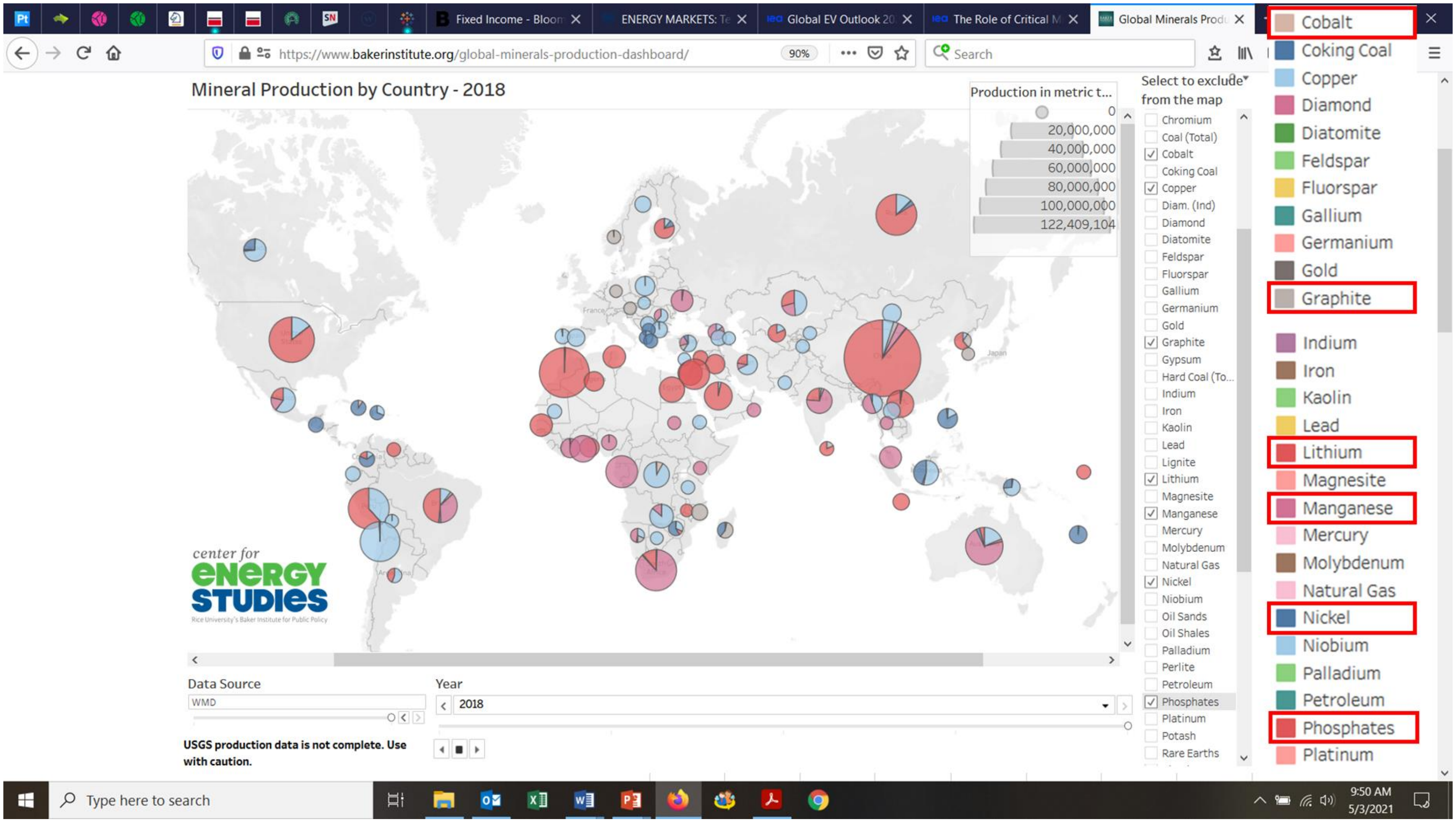
Source: CES dataset based on U.S. Geological Survey (USGS) and World Mining Data (World Mining Congress), https://www.world-mining-data.info/?World_Mining_Data.

Table 1. China's Energy System

		BEV Battery Factories	Nuclear Power Plants	Coal Power Plants
Units by Status	**Total**	**248**	**175**	**3,096**
	Operating	217	49	2,753
	Under construction	22	17	180
	Permitted			85
	Announced	9	58	78
Capacity	2020 Installed Capacity (GW)		51	1,080
Capacity by Status	**Total (GWh/GW)**	**1,083 GWh**	**106 GW**	**1,215 GW**
	Operating	559	48	1,033
	Under construction	325	16	92
	Permitted			43
	Announced	89	43	47
By Age	Average age for operating units (yrs)	9	9	14
	Map captured (*CEC, 2020)		93%	96%

Source: https://www.bakerinstitute.org/chinas-energy-infrastructure/ for map, methodology, sources and updates.
**Note – CEC is China Electric Council.*

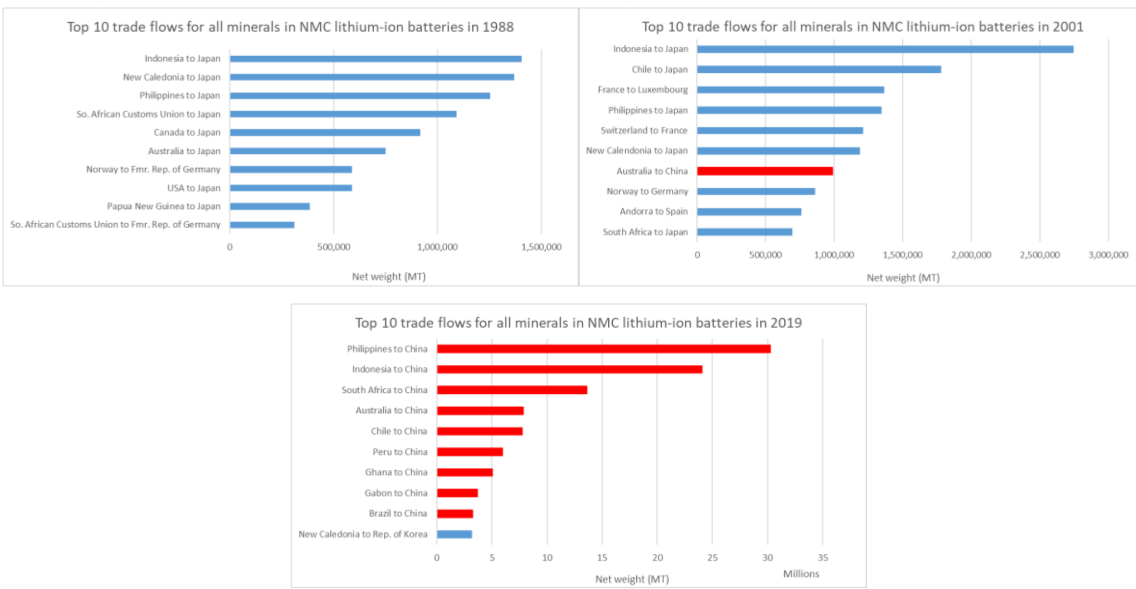
Figure 14. Worldwide Production of NMC Battery Minerals, Copper and Phosphates



From: CES Energy, Minerals & Materials program, https://www.bakerinstitute.org/global-minerals-production-dashboard/.

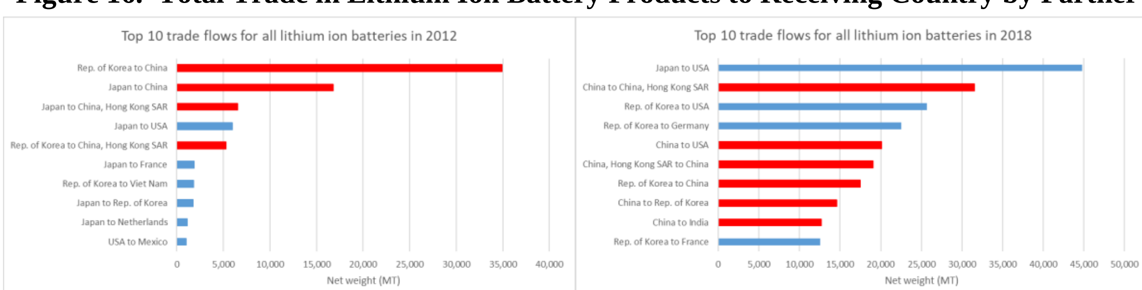
- China's command of LIB and BEV raw materials supply chains is the bottom line. China's outbound investment has enlarged global supply, a good outcome in general. **Chinese participation abroad as well as escalation of domestic production are the main factors prodding rapid growth in nonfuel minerals supply since 2000** (previous Figure 13). China's investment style and associated implications bear more detailed analysis, which we and others are undertaking.
- The rapid evolution of minerals trade routes to China is astounding, by any measure. Figure 15 shows, in three panels, the first prominent flow, Australia to China (mainly copper, manganese and lithium). **By 2019, China dominates all minerals trade flows. In addition, even more notable and astounding, is that trade volumes for these minerals ballooned up to ten times between 2001 and 2019.**
- A similar story holds for trade in LIBs (Figure 16). Volumes include all LIB products, for consumer goods as well as EVBs. **Even where other countries manufacture components, trade flows revert back to China for finishing and shipment to importing markets.**

Figure 15. Total Minerals Trade to Receiving Country by Partner (metric tonnes)



Source: extracted from background data for CES visualizations, https://www.bakerinstitute.org/global-minerals-trade-dashboard/.

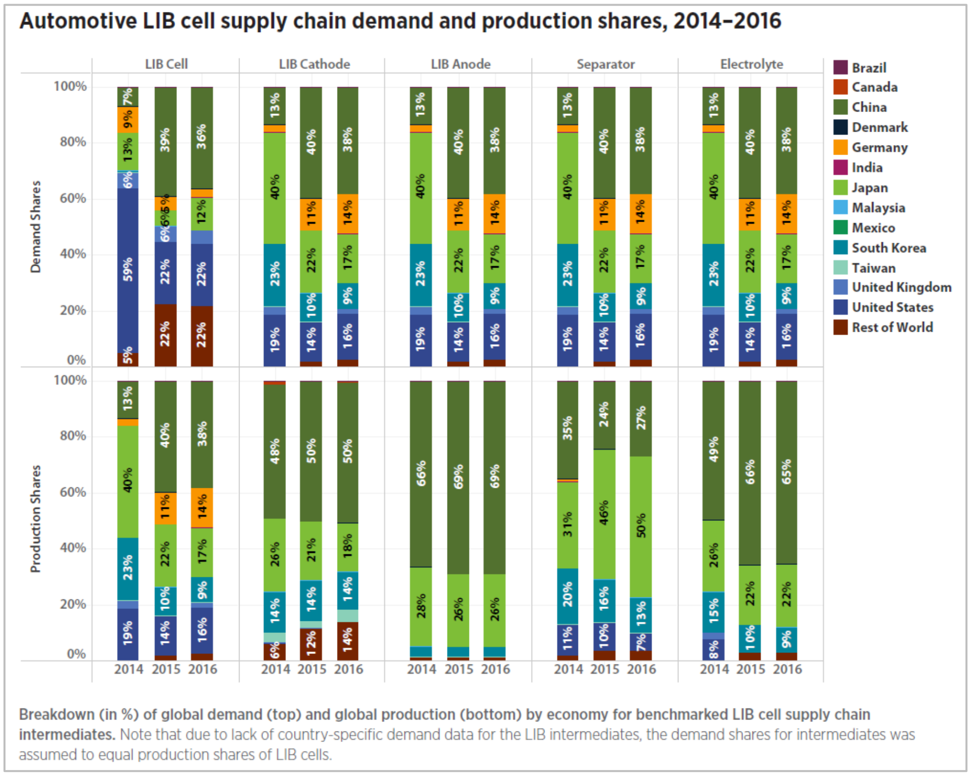
Figure 16. Total Trade in Lithium Ion Battery Products to Receiving Country by Partner



Sources: UN COMTRADE data as compiled by E. Hung, depicted by M. Michot Foss, CES (forthcoming).

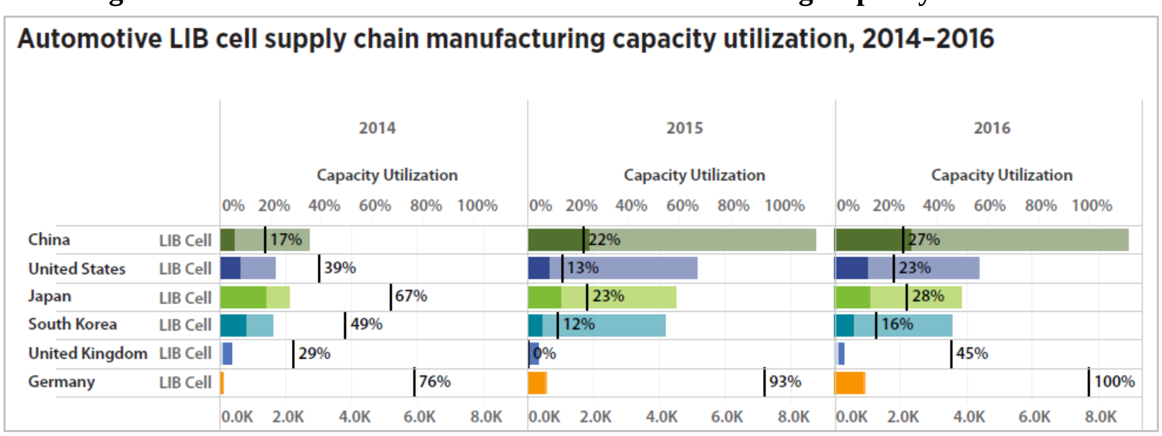
Beyond our own work and documentation, good signals on China's position come from the periodic benchmarking of components such as wind, solar and batteries undertaken by DOE's CEMAC (Clean Energy Manufacturing Analysis Center). Figure 17and Figure 18 vividly illustrate the strengthening of Chinese competence and influence on LIB supply chains and manufacturing. The effect of large slugs of Chinese capacity have negatively affected other plants and countries. Slack capacity in various locations might help with production output if supply chains can be secured. A more pronounced impact is the flurry of announcements for new plants outside of China as competitors seek to balance the playing field. The test for new facilities will be supply chain sourcing, including domestic content where that is an imperative. Although not popular in today's energy narrative, new facilities in countries like Germany and France will benefit from zero emissions nuclear power.

Figure 17. CEMAC Analysis of LIB Supply Chains



Source: https://www.nrel.gov/docs/fy21osti/78037.pdf.

Figure 18. CEMAC Review of Global LIB Manufacturing Capacity Utilization



Source: https://www.nrel.gov/docs/fy21osti/78037.pdf.

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Appendix

Supporting research and publications of interest from the Baker Institute's Center for Energy Studies

Michelle Michot Foss, Ph.D., Fellow in Energy, Minerals & Materials

- Testimony before the U.S. House Energy & Commerce Committee-Subcomittee on Environment & Climate Change, "Building a 100% Clean Economy
- Upcoming Testimony before the U.S. House Energy & Commerce Committee-Subcomittee on Energy, "The CLEAN Future Act: Driving Decarbonization of the Transportation Sector" (May 5)
- Minerals and Materials for Energy: We Need to Change Thinking – Recommendations for the New Administration
- Chinese Firms Position for an Energy Transition Copper Supercycle
- The "criticality" of minerals for energy transitions. Hydrocarbons? Yes, hydrocarbons.
- Framing Energy & Minerals for Future Pathways, with Michael S. Moats and Kwame Awuah-Offei, Missouri S&T – G20 Policy Brief
- Energy in Transition – Presentation to World Federation of Science-Erice 2019
- Battery Materials Value Chains – Verma, et.al., BEG/CEE The University of Texas at Austin

Rachel A. Meidl, Lp.D., CHMM, Fellow in Energy & Environment

- Waste Management and the Energy Transition –Recommendations for the New Administration
- Measuring the True Cost of Sustainability: A Case Study in a Green Energy Approach
- Recommendations for Realizing the Full Potential of Nanotechnology as the Energy Sector Transitions - Recommendations for the New Administration and Full Report
- Smart policy and innovative technologies, like advanced recycling, will deliver on climate and sustainability goals
- Banning Carbon Nanotubes Would Be Scientifically Unjustified and Damaging to Innovation
- Policy Considerations for Energy Infrastructure Resilience
- Hurricane Risk Assessment of Petroleum Infrastructure
- The Future of Plastics Sustainability: Advanced Recycling – Recommendations for the New Administration
- A G20 Circular Carbon Economy: Policies and Practices to Foster Circularity in Plastics – G20 Policy Brief

Gabriel Collins, JD

- Dua, et.al., "A Cost-Effective Pathway to a Low-Emissions Transportation Future," Policy Brief 2, September 2020, G20 Policy Brief
- "Ford vs. Tesla: What Does a Transformational Automobile Scale-up Look Like?," Issue Brief no. 02.14.20
- "Want an Electric Pickup to Tow Like a Ford F-250? You'll Need a Battery That Weighs As Much As An F-150 Raptor" – Presentation

- "The BEV Conundrum: High Power Density and Low Energy Density" - Presentation
- "Low-Speed Electric Vehicles: An Underappreciated Threat to Gasoline Demand in China and Global Oil Prices?," Issue brief no. 05.15.19
- Hold the Line Through 2035: A Strategy to Offset China's Revisionist Actions and Sustain a Rules-based Order in the Asia-Pacific – with Andrew S. Erikson

Specific Contributions on Electric Power

- Michelle Michot Foss CEE/BEG legacy, The University of Texas at Austin – papers, presentations on electric power, 2005-2018 including the guides to electric power in Texas and Mexico, competitiveness of renewables
- Julie A. Cohn, Ph.D., Nonresident Scholar, Center for Energy Studies, Olivera Jankovska, M.Sc., Nonresident Fellow, Center for Energy Studies and Kenneth B. Medlock III, Ph.D., James A. Baker, III, and Susan G. Baker Fellow in Energy and Resource Economics, and Senior Director, Center for Energy Studies https://www.bakerinstitute.org/research/grids-renewables/ recommendations for the new Administration
- Peter Hartley, Ph.D., George A. Peterkin Professor of Economics, Rice University; Baker Institute Rice Faculty Scholar, Center for Energy Studies, Jim Krane, Ph.D., Wallace S. Wilson Fellow for Energy Studies, Center for Energy Studies, Michael Maher, Ph.D., Senior Program Advisor, Center for Energy Studies and Kenneth B. Medlock III, Ph.D., https://blog.bakerinstitute.org/2021/04/09/lets-mess-with-texas-power-market-and-make-it-stronger/
- Mark Finley, Fellow in Energy and Global Oil, http://blog.bakerinstitute.org/2021/02/25/for-energy-security-power-is-the-new-oil/
- Olivera Jankovska and Julie Cohn, https://www.bakerinstitute.org/research/texas-crez-lines-how-stakeholders-shape-major-energy-infrastructure-projects/
- Peter Hartley, Kenneth B. Medlock III and Olivera Jankovska, https://www.bakerinstitute.org/research/electricity-reform-and-retail-pricing-texas/
- Ted Temzelides, Baker Institute Rice Faculty Scholar, George and Cynthia Mitchell Professor in Sustainable Development and Lee E. Ohanian, Does Subsidizing Renewables Work? https://www.bakerinstitute.org/research/my-kingdom-renewable-energy-source/.
- Forthcoming research by Robert Idel, Levelized Full System Costs of Electricity, The Energy Journal.