

Testimony

Critical Minerals Considerations for Energy Transitions

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U.S. House of Representatives
Committee on Energy & Commerce
Subcommittee on Environment and Climate Change
Hearing on “Building a 100 Percent Clean Economy: Opportunities for an Equitable, Low-Carbon Recovery”

September 16, 2020

Summary

When it comes to the subject of this hearing, we can all agree that whatever we do, especially when we use scarce public resources (tax dollars and natural endowments), we would like outcomes to be a net improvement. I am speaking to the role of critical minerals and the challenges associated with energy transitions along with consequences such as import dependency and the cluster of environment, social and governance (ESG) considerations. In my view, with regard to security and ESG, we need to look broadly across the energy landscape to ensure that “new energies” do not compromise gains achieved around legacy systems.

I can contribute several observations drawn from my written testimony.

- First, minerals and materials “criticality” is in the eyes of the beholder. Criticality has many connotations. One is minerals occurrence – the distribution of natural resource endowments, with what types of geologies, with what relative abundance and proximity to markets, among other things. Between 1984 and 2018, for the global economy that was in place pre-pandemic, total tonnage output of non-fuel minerals increased more than 2.5 times. We know that demand will increase for alternative energy applications and that material requirements will be higher (a logical function of lower energy densities). The challenge is not just gross tonnage but also quality. For high performance end uses and applications, the quality of raw materials matters a great deal. A significant hurdle is access for development. Ownership, terms and conditions for exploitation, economic development and industrial infrastructure to support mining and minerals processing – a number of factors impact timing and cost to deliver raw and intermediate materials that we rely upon for every aspect of life.
 - In 2018, the U.S. constituted 12 percent of global non-fuel minerals production. We are tracking 41 minerals that are essential to both legacy and alternative energy technologies and systems including new battery chemistries and designs for improved energy storage and release, advanced solar, hydrogen fuel cells and wind. We are not the dominant producer of any of the 41 minerals on our watch list, and we are among the top 10 producers for only a few (mainly basic metals). Ranking does not matter given that we are a large consumer and thus demand more than our domestic supply chains can serve.
 - Work by the USGS NMIC, published earlier this year, provides at least one version of criticality by devising risk factors for 52 minerals of interest. Of these, 39 rank high for supply risk and import dependence.
- Second, any conversation about energy choices should include security, for our nation, energy system and economy. Again, “security” can take many meanings. How we define security and the many complex interactions can influence attention to risks, uncertainties, mitigation and solutions.
 - Economic security can entail mitigation of price risk. In recent years, energy and non-fuel minerals commodities prices have converged, for many reasons but mainly because of interdependence – minerals are key inputs for energy production, from any technology and source, and energy is a key input for minerals production and processing. Both are vital for economic performance and linked to gross domestic product (GDP). Pressure on minerals prices impacts on the cost and affordability of energy, and vice versa.
 - Supply chain security is subject to myriad risks and uncertainties, about which we have been learning a great deal. Any industrial activity, including the provision of consumer products, involves many linked business segments.

Requirements include supply of raw materials, shipping, transformation, distribution and end use. Numerous sources of risk and uncertainty, including natural hazards and “acts of God” can create supply chain disruptions. Supply chains for energy and minerals are large and dominate bulk shipping. For example, already, global shipments of lithium battery products for all end uses rival global shipments of traditional fuels in geographic extent. Behind global shipments of lithium batteries are global shipments of all of the raw material battery inputs. Supply chains for batteries and other components will continue to grow and increase in reach and complexity.

- A third is environmental security. We also are concerned about supply chains to support end of life decommissioning, recycling and disposal and all of these entail ESG risks and uncertainties. For instance, we know a great deal about waste, capture, recycling and disposal in established energy systems. We know relatively little about waste in the alternative energy streams and concerns are growing about end of life treatment of alternative energy components. We believe that we can recapture and reuse battery materials but currently less than five percent of lithium battery product is recycled. These functions and their associated supply chains are opaque and not well documented. We know that “e-waste” is growing, probably exponentially, and we know that global e-waste shipments and supply chains are expanding rapidly.
- If we add “climate” to environmental security, then we introduce a great deal more complexity. All industries, businesses, governments and even households are beginning to attempt to assess emissions. Emissions associated with life cycle processes for batteries and alternative energy applications are extremely difficult to ascertain. For example, global lithium battery manufacturing, including for electric vehicles (EVs), stands at roughly 740 gigawatt hours (GWh). Nearly 80 percent of this capacity resides in China, supported by nearly 3,000 coal-fired power plants, the backbone of China’s electric power grid. This means a potential output of carbon dioxide (CO₂) emissions that nearly equals all of those associated with the U.S. domestic oil and gas systems, based on U.S. Environmental Protection Agency (EPA) estimates. We are starting to think about sulfur hexafluoride or SF₆, an insulator for electric power switchgear. SF₆ is a small contributor to global emissions but has stronger thermal properties and is expected to increase considerably with electrification.
- Geopolitical security risk and uncertainty are prevalent across supply chains, including international sourcing and trade. We have geopolitical uncertainty within North America and political uncertainty across the states, a reflection of varying attitudes, laws and regulations. We have long experience with import dependency, and we are experiencing a reprieve for petroleum and natural gas. Given that our import dependence is high for both raw materials and alternative energy components (such as wind turbines and motors, solar photovoltaics or PV, and batteries for energy storage), a distinct tradeoff of a rapid shift away from our legacy energy systems is exposure to import dependency and associated geopolitical insecurities.
- Third, there is growing attention to ESG risks specific to mining and minerals processing. Mining and minerals processing are, and can be, conducted safely and soundly with best practice and enforcement.
 - Many countries have “informal mining” sectors where best practice and safety are limited, at best. Some governments are moving to “formalize” their artisanal

- miners with notable examples in Chile and Democratic Republic of Congo. Exposure for multinational mining companies is yet to be determined.
- International capacity for integrity and operating assurance need to expand. After the Vale tailings dam failure in Brazil, a distinct comment was that only 16 engineering groups worldwide are certified for tailings dam audits.
 - Communities, especially indigenous groups, are a focus for risk and uncertainty assessment and mitigation. Many existing, new and frontier minerals projects are and will be located in or proximal to indigenous lands and communities. In the U.S., we have many hard lessons from permitting and licensing that can be vetted. Achieving “social license” is demanding and even the most diligent efforts are not always successful.

With colleagues at Missouri Science & Technology, we contributed a policy brief for the upcoming G20 meeting. That brief focused on mining and minerals for energy transition with five recommendations that I will share in closing.

- Include non-fuel minerals in G20 discussions.
- G20 members should fund research to develop a uniform mineral criticality index.
- G20 member states should commit to promote transparency of critical minerals.
- G20 members should engage relevant multilateral agencies to foster technical collaborations.
- G20 members should commit to share best practices for extraction and recovery of critical minerals (an example is the Energy Resource Governance Initiative).

Background

Minerals and materials “criticality” is in the eyes of the beholder. Criticality has many connotations. One is minerals occurrence – the distribution of natural resource endowments, with what types of geologies, with what relative abundance and proximity to markets, among other things. Between 1984 and 2018, for the global economy that was in place pre-pandemic, total tonnage output of non-fuel minerals increased more than 2.5 times (based on data from the World Mining Congress, WMC, open source). We know that demand will increase for alternative energy applications and that material requirements will be comparatively higher. This is a logical function of lower energy densities.

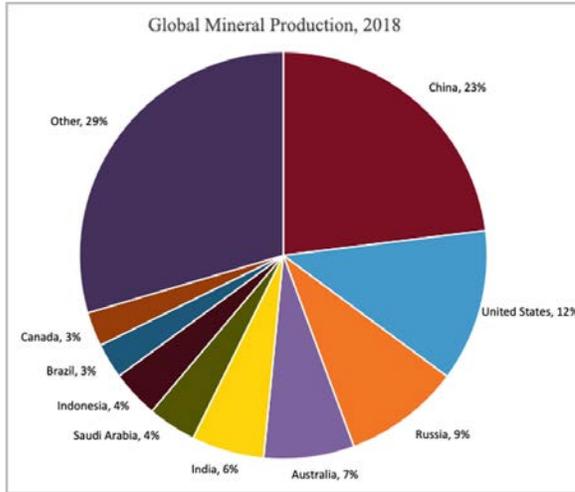
For example, even the best batteries today still cannot provide the performance of liquid fuels for vehicles. The energy density of gasoline is still 100 times higher than that of the best lithium battery designs.¹ In 2016, Argonne National Laboratory estimated that pure battery EVs (BEVs) could be at par with equivalent ICE vehicles by 2045.² Reduced vehicle weight and enhanced aerodynamic design would further increase engine efficiency. However, battery energy density (watt-hours per kilogram or W-h/kg) must advance along with motor power density (kilowatts per kilogram or kW/kg). Each metric will need to be

¹ Schlachter, Fred. 2012. “Has the Battery Bubble Burst?” APS News 21, no. 8, August/September. <https://www.aps.org/publications/apsnews/201208/backpage.cfm/>.

² Vijayagopal, Ram. 2016. “Comparing the Powertrain Energy and Power Densities of Electric and Gasoline Vehicles.” Presentation at Powertrain Strategies for the 21st Century, University of Michigan Transportation Research Institute, July 20, 2016. <http://www.umtri.umich.edu/powertrain-strategies-21st-century-1>. Vijayagopal, Ram, Kevin Gallagher, Daeheung Lee, and Aymeric Rousseau. 2016. “Comparing the Powertrain Energy Densities of Electric and Gasoline Vehicles.” SAE Technical Paper 2016-01-0903. <https://doi.org/10.4271/2016-01-0903/>

roughly doubled, from 135 to 320 W-h/kg and 8.6 to 16 kW/kg, respectively. (See Appendix for emerging research on mass balance challenges for vehicles.)

The challenge is not just gross tonnage but also quality. For high performance end uses and applications, the quality of raw materials matters a great deal. A significant hurdle is access for development. Ownership, terms and conditions for exploitation, economic development and industrial infrastructure to support mining and minerals processing – a number of factors impact timing and cost to deliver raw and intermediate materials that we rely upon for every aspect of life.



In 2018, the U.S. constituted 12 percent of global non-fuel minerals production (based on data from WMC). We are tracking 41 minerals that are essential to both legacy and alternative energy technologies and systems including new battery chemistries and designs for improved energy storage and release, advanced solar, hydrogen fuel cells and wind. We are not the dominant producer of any of the 41 minerals on our watch list, and we are among the top 10 producers for only a few (mainly basic metals). Notable among these are rare earths (REE group, distant 3rd), lead (4th),

zinc (4th), palladium (platinum group, 4th), platinum and rhodium (platinum group, 5th), copper (5th), selenium (6th), lithium (7th), silver 10th. Ranking does not matter given that we are a large consumer and thus demand more than our domestic supply chains can serve.

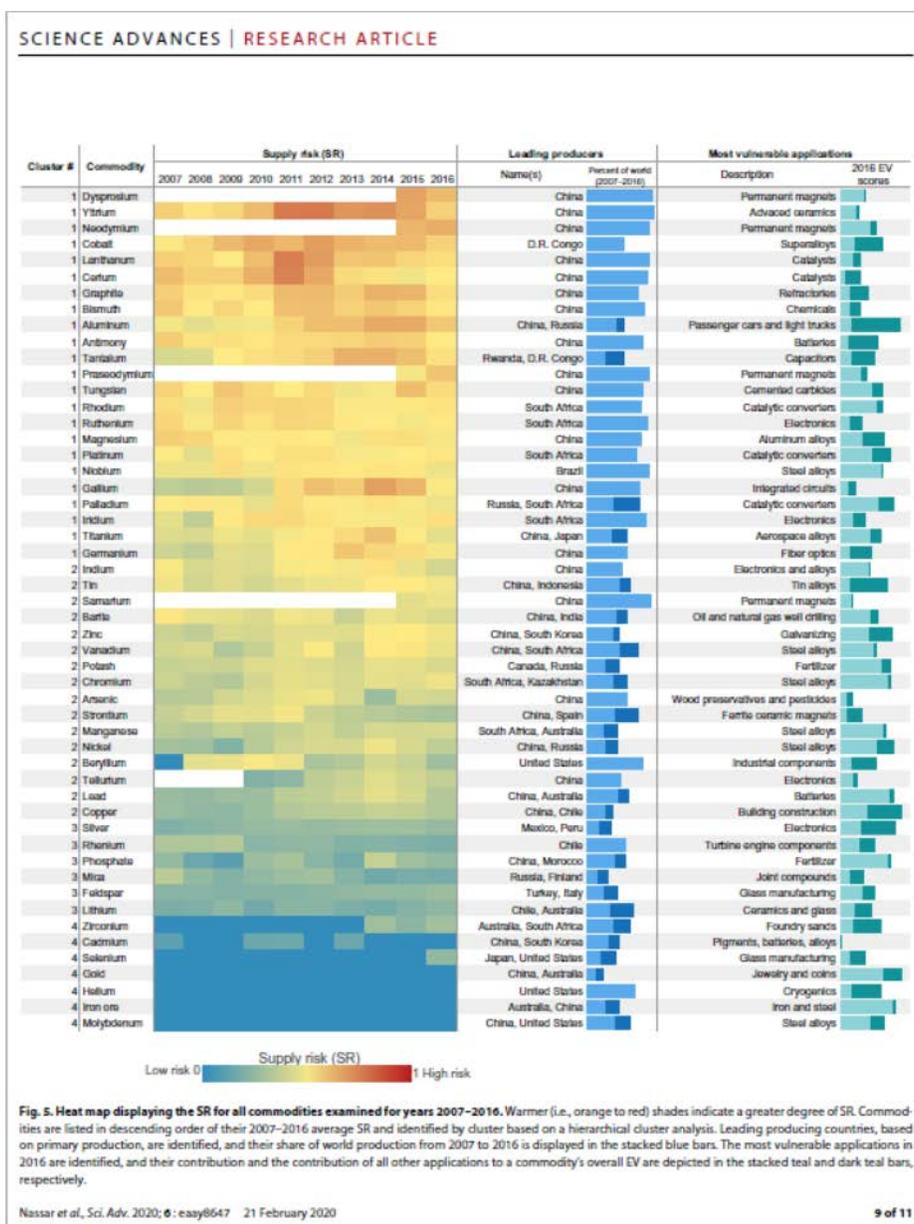
Battery Chemistries			
Element	Dominant Producer	Mkt Shr	US Risk
Iron	Australia	37%	4
Lithium	Australia	61%	3
Niobium	Brazil	90%	1
Copper	Chile	28%	2
Aluminum	China	57%	1
Cadmium	China	35%	4
Fluorspar	China	51%	
Graphite	China	60%	1
Lead	China	44%	2
Phosphorus (Phosphates)	China	40%	3
Rare Earths	China	73%	1
Silicon	China	65%	
Titanium	China	26%	1
Vanadium	China	54%	2
Zinc	China	33%	2
Cobalt	DRC	71%	1
Nickel	Indonesia	24%	2
Silver	Mexico	26%	3
Magnesium	South Africa	28%	1
Manganese	South Africa	29%	2
Potash	Canada	32%	2
Sulfur	China	22%	

Advanced Solar			
Element	Dominant Producer	Mkt Shr	US Risk
Copper	Chile	28%	2
Cadmium	China	35%	4
Lead	China	44%	2
Phosphorus (Phosphates)	China	40%	3
Silicon	China	65%	
Titanium	China	26%	1
Zinc	China	33%	2
Oxygen			
Sulfur	China	22%	
Arsenic	China	46%	2
Gallium	China	94%	1
Germanium	China	89%	1
Indium	China	47%	2
Tellurium	China	74%	2
Tin	China	28%	2
Bromine	Israel	43%	
Selenium	Japan/China	51%	4
Carbon			
Chlorine			
Hydrogen			
Iodine	Chile	65%	
Nitrogen			

Wind - REE group, U.S. Risk 1; Fuel Cells - PGM group, U.S. Risk 1. Not shown – gases and other elements for which supply in the appropriate quality is a risk consideration. Based on WMC and U.S. Geological Survey (USGS)/National Minerals Information Center (NMIC) for U.S. risk weighting.

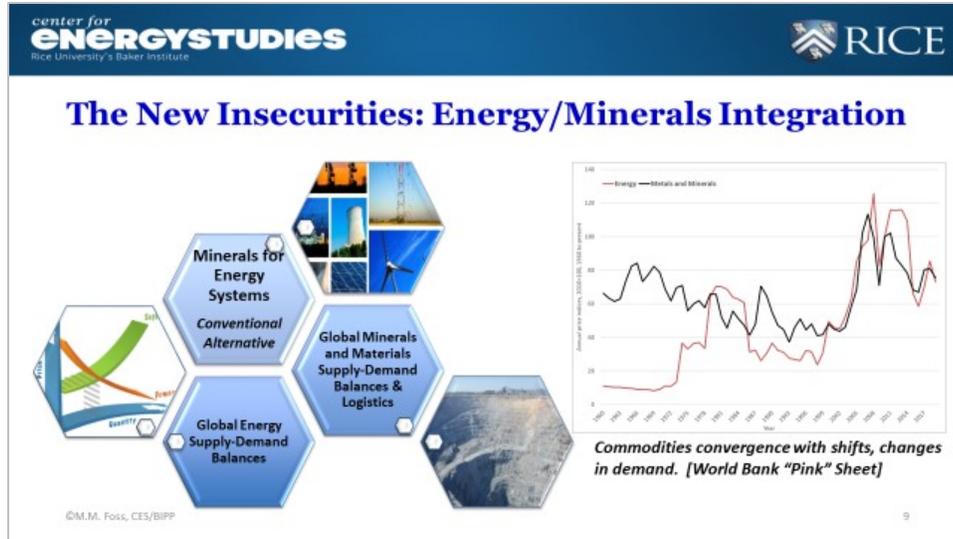
Work by the USGS NMIC, published earlier this year by the American Association for the Advancement of Science (AAAS),³ provides at least one version of criticality by devising risk factors for 52 minerals of interest. Of these, 39 rank high for supply risk and import dependence.

³ Nassar, Nedat T., Jamie Brainard, Andrew Gulley, Ross Manley, Grecia Matos, Graham Lederer, Laurence R. Bird, et al. 2020. “Evaluating the Mineral Commodity Supply Risk of the U.S. Manufacturing Sector.” *Science Advances* 6, no. 8 (February): eaay8647. <https://doi.org/10.1126/sciadv.aay8647/>

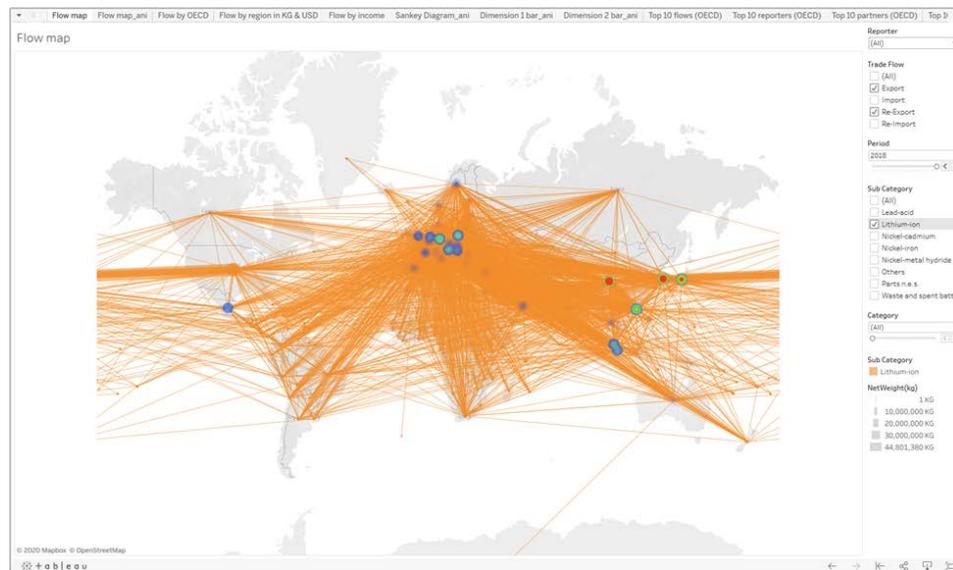


Any conversation about energy choices should include security, for our nation, energy system and economy. Again, “security” can take many meanings. How we define security and the many complex interactions can influence attention to risks, uncertainties, mitigation and solutions.

Economic security can entail mitigation of price risk. In recent years, energy and non-fuel minerals commodities prices have converged, for many reasons but mainly because of interdependence – minerals are key inputs for energy production, from any technology and source, and energy is a key input for minerals production and processing. Both are vital for economic performance and linked to gross domestic product (GDP). Pressure on minerals prices impacts on the cost and affordability of energy, and vice versa.



Supply chain security is subject to myriad risks and uncertainties, about which we have been learning a great deal. Any industrial activity, including the provision of consumer products, involves many linked business segments. Requirements include supply of raw materials, shipping, transformation, distribution and end use. Numerous sources of risk and uncertainty, including natural hazards and “acts of God” can create supply chain disruptions. Supply chains for energy and minerals are large and dominate bulk shipping. For example, already, global shipments of lithium battery products for all end uses rival global shipments of traditional fuels in geographic extent. Behind global shipments of lithium batteries are global shipments of all of the raw material battery inputs. Supply chains for batteries and other components will continue to grow and increase in reach and complexity.



CES lithium battery trade flows (Dr. Rachel Meidl and Elsie Hung, forthcoming).

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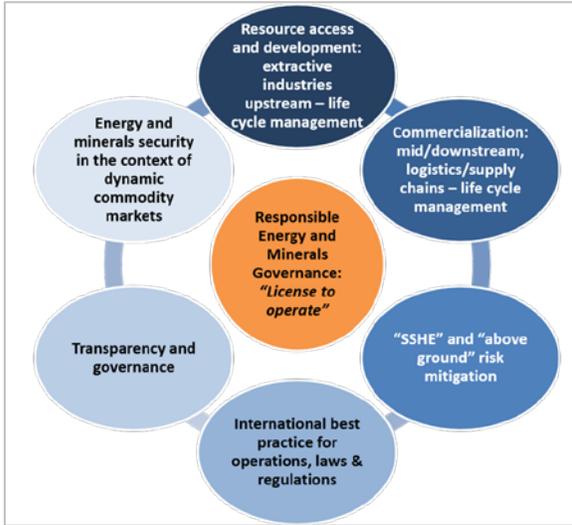
we know a great deal about waste, capture, recycling and disposal in established energy systems. We know relatively little about waste in the alternative energy streams and concerns are growing about end of life treatment of alternative energy components. We believe that we can recapture and reuse battery materials but currently less than five percent of lithium battery product is recycled. These functions and their associated supply chains are opaque and not well documented. We know that “e-waste” is growing, probably exponentially, and we know that global e-waste shipments and supply chains are expanding rapidly. (See Appendix for emerging research on waste.)

If we add “climate” to environmental security, then we introduce a great deal more complexity. All industries, businesses, governments and even households are beginning to attempt to assess emissions. Emissions associated with life cycle processes for batteries and alternative energy applications are extremely difficult to ascertain. For example, global lithium battery manufacturing, including for electric vehicles (EVs), stands at roughly 740 gigawatt hours (GWh) based on information from Wood Mackenzie. Nearly 80 percent of this capacity resides in China⁴, supported by nearly 3,000 coal-fired power plants, the backbone of China’s electric power grid. This means a potential output of carbon dioxide (CO₂) emissions that nearly equals all of those associated with the U.S. domestic oil and gas systems, based on U.S. Environmental Protection Agency (EPA) estimates. We are starting to think about sulfur hexafluoride or SF₆, an insulator for electric power switchgear. SF₆ is a small contributor to global emissions but has stronger thermal properties and is expected to increase considerably with electrification.

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Attention is growing with respect to ESG risks specific to mining and minerals processing. Mining and minerals processing are, and can be, conducted safely and soundly with best practice and enforcement. I present a summary of what we could call the extractive industries ESG cycle below.

⁴ Yergin, Daniel. 2020. “The New Geopolitics of Energy”. The Wall Street Journal, September 11. <https://www.wsj.com/articles/the-new-geopolitics-of-energy-11599836521?mod=searchresults&page=1&pos=1>

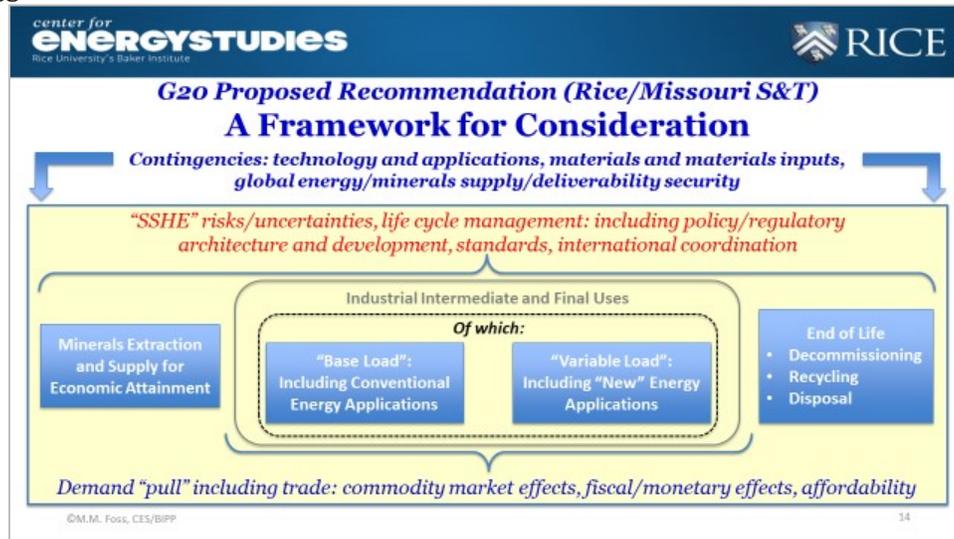


Many countries have “informal mining” sectors where best practice and safety are limited, at best. Some governments are moving to “formalize” their artisanal miners with notable examples in Chile and Democratic Republic of Congo. Exposure for multinational mining companies is yet to be determined.

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Communities, especially indigenous groups, are a focus for risk and uncertainty assessment and mitigation. Many existing, new and frontier minerals projects are and will be located in or proximal to indigenous lands and communities. In the U.S., we have many hard lessons from permitting and licensing that can be vetted. Achieving “social license” is demanding and even the most diligent efforts are not always successful. Experience with the World Bank’s “consent” process provides many lessons on this front.

With colleagues at Missouri Science & Technology,⁵ we contributed a policy brief for the upcoming G20 meeting. That brief focused on mining and minerals for energy transition. We suggested a framework for consideration, shown below.



“SSHE” refers to safety, security, health, and environment; it incorporates hazardous materials management throughout all supply chains and lifecycles. “Industrial Intermediate and Final Uses” includes energy. “Base Load” is the demand for non-fuel minerals and

⁵ Dr. Michael S. Moats, Missouri University of Science and Technology’s O’Keefe Institute; Dr. Kwame Awuah-Offei, Mining & Nuclear Engineering Department, Missouri University of Science & Technology.

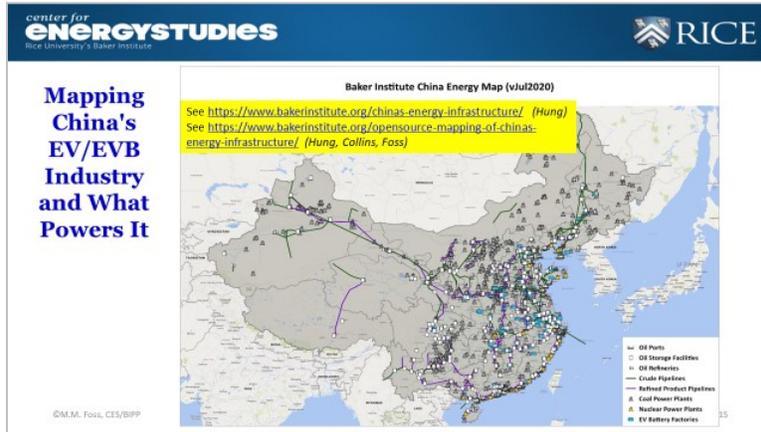
materials by all existing, legacy industrial systems, including conventional energy. “Variable Load” captures emerging applications, such as new energy systems, for which demand is highly uncertain. Supply chain logistics for “End of Life” are integrated for that stage.

With five recommendations that I share in closing.

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Appendix

2. Research on China's energy system, <https://www.bakerinstitute.org/chinas-energy-infrastructure/>, <https://www.bakerinstitute.org/opensource-mapping-of-chinas-energy-infrastructure/>



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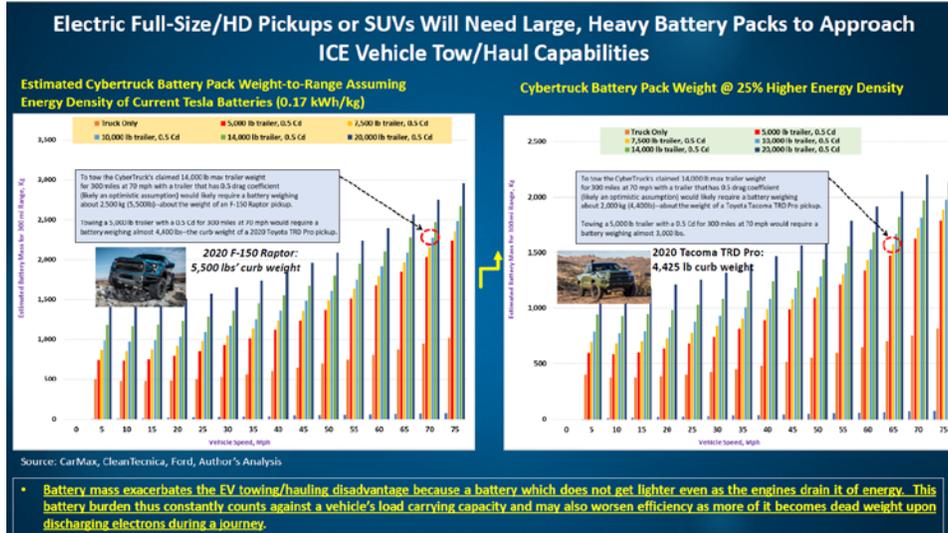
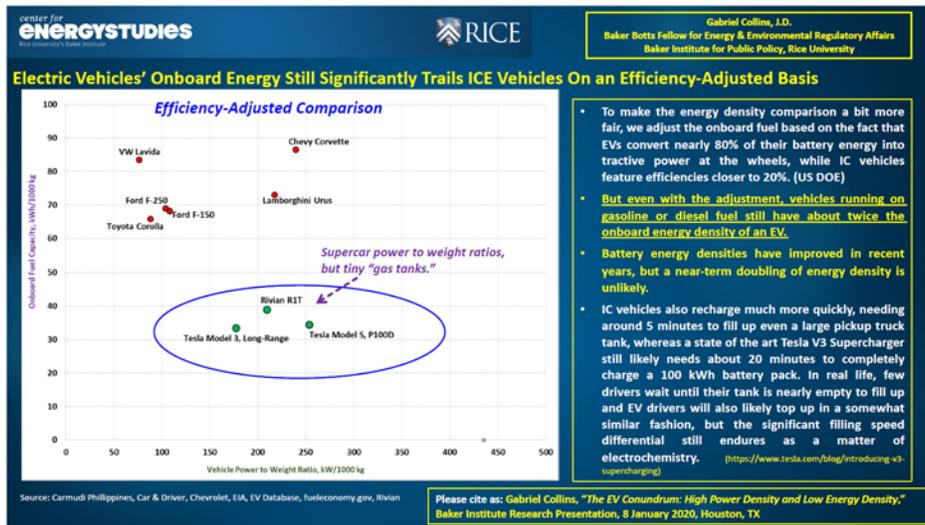
RICE

China's Inventory

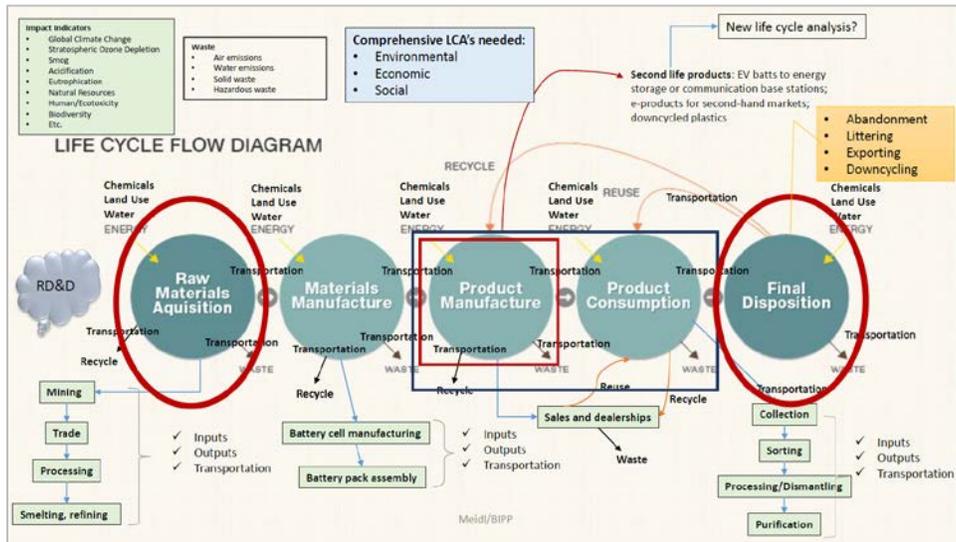
	EV battery factories	Nuclear Power Plants	Coal Power Plants
In number of units			
Total units	186	114	2,956
Operating	177	47	2677
Under construction	8	14	170
Permitted			70
Announced	1	53	39
% of est. coordinates	7.6%	5.3%	1.6%
In GW			
Total capacity	89.3(GWh)*	95	1,145
Operating	85.4(GWh)*	45	997
Under construction	3.9(GWh)*	14	95
Permitted			34
Announced	0.5(GWh)*	36	20
Avg. age for operating units (yrs)	9	8	13
Capacity captured (CEC, 2020)		93%	96%

©M.J.M. Foss, CES/BIPP *China Electricity Council for 2019 data
<https://www.cec.org.cn/zhongguo-dianli-gongye-jingji-zhanqing-bao/2020-01-21/287090.html>

1. **Emerging research on EV mass balance challenges**, Gabriel Collins, J.D., Baker Botts Fellow in Energy & Environmental Regulatory Affairs, <https://www.bakerinstitute.org/media/files/files/e315e1b0/collins-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-28-january-2020.pdf>, <https://www.bakerinstitute.org/media/files/files/c44ec012/ces-collins-pp-ev-conundrum.pdf>



2. **Research on waste and waste management, including hazardous materials, Dr. Rachel Meidl, Fellow in Energy & Environment, keynote speaker for the 2020 MIT Applied Energy Symposium**



Glaring Blind Spot: Quantifying and Understanding True Costs

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- ▶ Life cycle assessments (LCA) do not account for **social impacts**
- ▶ LCAs do not account for full range of **environmental impacts**
- ▶ LCAs do not account for **economic impacts**
- ▶ LCAs misconstrued due to **limited boundaries**, i.e. product manufacturing process vs. evaluating entire life cycle (raw materials extraction to actual disposal method)
- ▶ Emerging technologies difficult to assess due to lack of data, analytic tools, uncertainty, no scaled end-of-life management technologies

Metrics, such as mining, processing, smelting, trade, transportation, and wastes and the social, econ, and env costs are currently unaccounted for when determining the sustainability of the energy transition to renewables

End-of-Life of Lithium Batteries

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- ▶ <5% of lithium ion batteries are recycled
- ▶ By 2030, China battery waste >2 million tons/yr; >10 million tons/yr globally
- ▶ Majority are landfilled
- ▶ Recycling too costly
- ▶ Labor-and energy intensive
- ▶ Technical constraints
- ▶ Focus has been on charge capacity and battery longevity

Meich Jacoby/CAEN

End-of-Life of Solar Panels

center for ENERGY STUDIES

- ▶ ~250,000 metric tonnes of solar panel waste globally (2016)
- ▶ 78 million metric tonnes by 2050
- ▶ Recycling costs more than economic value of materials recovered
- ▶ At end-of-life, solar panels exported, landfilled, or incinerated
- ▶ No national or globally harmonized international regulations for managing solar panels at end-of-life



Lithium Battery Industry Parallels E-waste

E-waste	Lithium Batteries
• Rapid technology development and deployment	✓
• Lack of developed or fragmented waste management technologies	✓
• Complex transportation networks/logistics	✓
• Old/obsolete technologies	✓
• Overlapping and conflicting disposal/recycling policies domestically and internationally	✓
• Dearth of recycling opportunities	✓
• EOL for e-waste difficult to assess—lack of data, processes poorly understood w/in LCA context—this has led to disregard of EOL considerations	✓