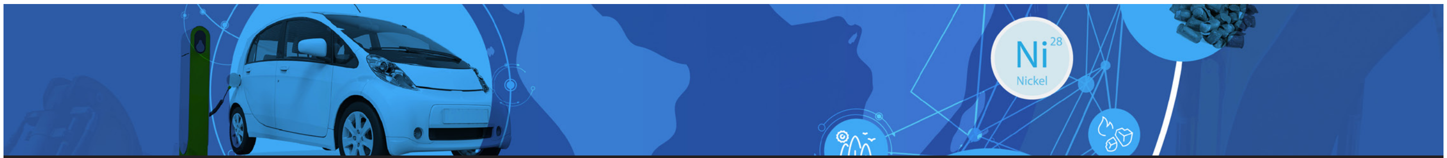
ELECTRIC POWER RESEARCH INSTITUTE

SUSTAINABILITY ASPECTS OF THE LITHIUM ION BATTERY SUPPLY CHAIN

February 2021



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INTRODUCTION

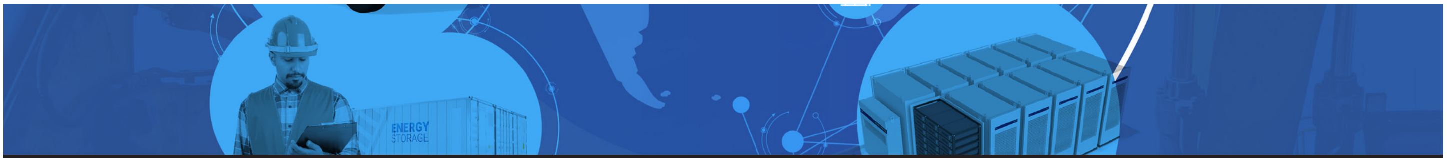
As electric vehicle sales continue to accelerate, and battery energy storage deployments continue to grow, demand for lithium ion batteries (LIBs) is projected to increase dramatically in the coming decades. Electric vehicles are projected make up 58% of passenger vehicles sales in 2040, with annual sales volumes increasing 32-fold compared to 2020 [1].[1] Stationary battery deployments are also accelerating, for both grid-scale and behind-the-meter installations, and are forecast to grow by a factor of 300 over the next twenty years [1]. The anticipated widespread deployment of LIBs is projected to be a key enabler for reducing the climate impacts of the transportation and power sectors.

As a result, demand for LIBs is expected to grow by nearly a factor of ten from 2020 to 2030 [2]. The global battery market is projected to grow to $274 billion by 2025 [3].

However, several challenging issues have been raised for the battery manufacturing industry. These include ensuring raw materials supply; upholding labor standards and human rights at all points along the supply chain; and characterizing and mitigating environmental and health impacts. The dramatic anticipated growth in LIB demand amplifies the potential impact of each of these three issues.

This report summarizes a range of resource, environmental sustainability, and labor standards topics for LIBs. It surveys current approaches to support and expand environmental and social sustainability considerations and to ensure integrity in the supply chain of this increasingly important energy storage technology.

1 Including both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).



AVAILABILITY OF RAW MATERIALS FOR MANUFACTURING LITHIUM ION BATTERIES

WHAT ARE RESOURCES AND RESERVES?

Several terms are used to describe identified quantities of minerals. Key terms are summarized here [4]:

A resource is a substance found in the natural environment that can be used for economic gain or could be used for economic gain in the future. This paper discusses certain resources which are minerals and metals used to produce batteries.

The reserve of a particular mineral is amount of the resource that can be profitably extracted and refined with today's technologies.

WILL SUFFICIENT RAW MATERIALS BE AVAILABLE TO MEET FUTURE LITHIUM ION BATTERY DEMAND?

Numerous studies have compared the known reserves for several key LIB materials to the expected future demand. Lithium and cobalt have been a focus in popular press articles. Other key materials include nickel and graphite.

These materials are sometimes described as "critical materials." The designation of a "critical material" generally denotes that the material is both economically important and carries a supply risk (Figure 1).

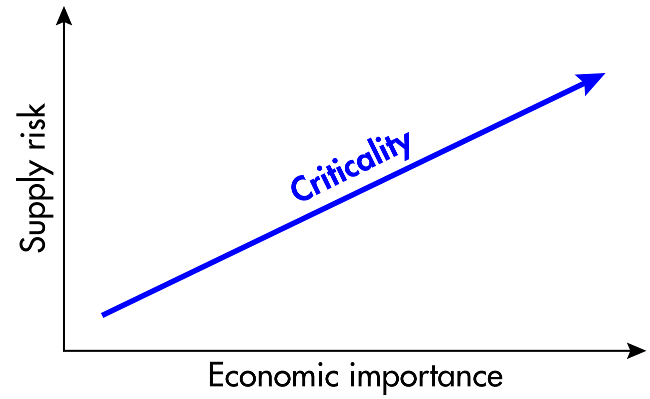


Figure 1. Criticality of raw materials in relation to economic importance and supply risk.

In a collection of three recent criticality assessments, graphite was consistently identified as a critical supply risk; cobalt was identified as critical in two out of three; and assessments of lithium varied

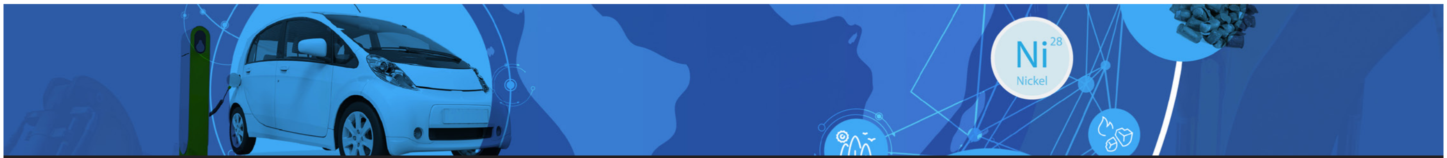
Table 1. Criticality ratings from three separate assessments for selected LIB raw materials. (Source: Mayyas et al. 2018 [5])

Element	Royal Society of Chemistry	European Commission Joint Research Center	U.S. Dept. of Energy
Lithium	Supply risk	Medium-low	Near-critical
Cobalt	Supply risk	Medium	Not critical
Nickel	Supply risk	Low	Not critical
Manganese	Supply risk	(n/a)	Not critical
Aluminum	Supply risk	(n/a)	(n/a)
Graphite	Critical supply risk	High-medium	(n/a)

Table 2. Top producing countries and reserve locations for selected LIB raw materials. (Data: USGS [6])

Material	Measure	Australia	Chile	Argentina	China	Bolivia	Democratic Republic of the Congo	Russia	Canada	Philippines	New Caledonia	India	Brazil	Turkey
Lithium	% Global Production	41	34	16	6	*								
	% Global Reserves	4	19	5	8	22								
Cobalt	% Global Production	4			6		54	5	4					
	% Global Reserves	14			1		49	4	4					
Nickel	% Global Production	9						11	11	22	11			
	% Global Reserves	24						10	4	6	9			
Graphite	% Global Production				65							14	6	3
	% Global Reserves				22							3	29	36

*Currently a negligible exporter



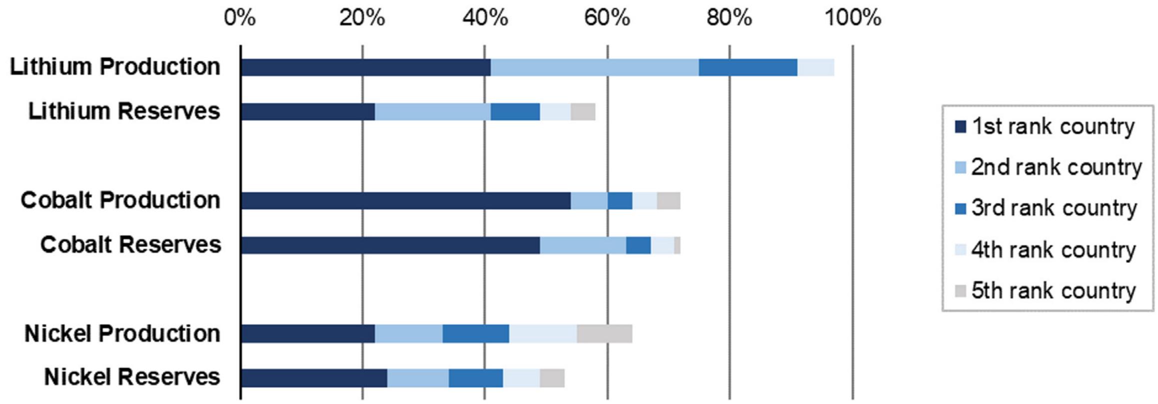


Figure 2. Concentration of global production and reserves for selected lithium ion battery materials: Share of top five countries (Data: USGS [6])

WHAT IS A "CRITICAL MINERAL"?

The United States Department of the Interior describes critical minerals as [7]:

- Those that "are vital to the Nation's security and economic prosperity."
- Where "dependency of the United States on foreign sources creates a strategic vulnerability for both its economy and military to adverse foreign government action, natural disaster, and other events that can disrupt supply of these key minerals."

The currently published list of critical minerals contains several key LIB raw materials, including:

- cobalt
- graphite
- lithium
- aluminum
- magnesium

The United States Geological Survey (USGS) developed a draft list of critical minerals using the Mineral Criticality Screening Tool, a quantitative methodology for identifying and ranking mineral commodities developed by the National Science and Technology Council. USGS applied two assessments to evaluate which minerals to include in the draft list of critical minerals [8]:

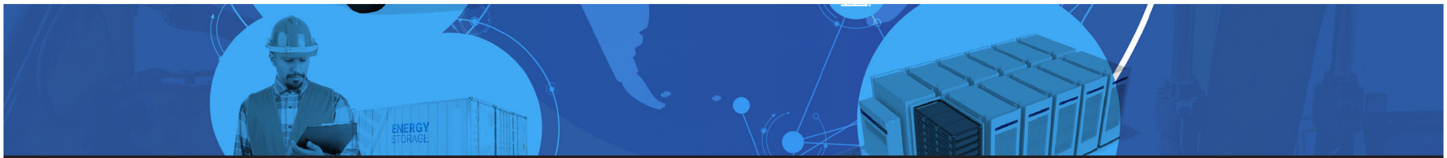
1. The Hirfindal-Hirschmann index, which measures country concentration of production; and
2. The USGS net import reliance metric based on USGS's annual Mineral Commodities Summaries.

(Table 1). These materials vary widely in the locations of their production and reserves, and in the degree of concentration in their supply chains (Figure 2 and Table 2).

Lithium

Lithium demand is forecast to grow by a factor of six to nine by 2030 in order to meet the significant increase in LIB demand described above [2,9].

Assessments of the adequacy of lithium supply involve several key uncertainties. In particular, multiple analysts have highlighted uncertainty in the size of global lithium reserves: recent estimates vary by a factor of three (ranging from 19 to 64 million tonnes [10]). Other key uncertainties include the rate of lithium recovery from recycling and the actual rate of electric vehicle production (which will be the strongest factor determining demand for lithium).



While acknowledging these uncertainties, a range of assessments conclude that global lithium reserves are likely adequate to meet forecast demand. For instance:

- "[E]ven very aggressive penetration of electric vehicles into the automotive market [is]unlikely to strain lithium resources out to the year 2050." [11]
- "[E]ven with a rapid and widespread adoption of electric vehicles powered by lithium-ion batteries, lithium resources are sufficient to support demand until at least the end of this century." [12]
- "[T]his study did not identify a potential resource constraint related to lithium for LIBs." [10]
- "[I]t is plausible that lithium supply will meet increasing lithium demand over the coming decades to 2050." [13]

Lithium production and reserves are geographically diversified, reducing the risk of supply constraints and price volatility. Three different countries (Australia, Chile, and Argentina) each provide more that 10% of global supply.

In addition, lithium reserves are still being explored and identified. For instance, although Bolivia is currently a negligible lithium exporter, it holds one of the world's leading lithium reserves, and is therefore positioned to become a critical supplier in the global market [14]. Argentina currently accounts for 16% of global supply, but recent analysis suggests that it could become a leading supplier [15].

However, an equally important potential constraint is whether production of refined lithium can increase quickly enough to keep pace with growing LIB demand. Notably, during the period 2010–2014, LIB manufacturing grew by 73%, but production of lithium precursor grew by only 28% [16]. This implies that there may be short-term disruptions in the market due to the mismatch in growth rates of supply and demand, even though there is adequate long-term supply.

Cobalt

Cobalt has a key role as a component of the battery cathode in some widely used types of LIBs. (Other types of LIBs use cobalt-free cathode materials; see "Low-cobalt battery chemistries" section below.) Cobalt-containing LIB chemistries such as nickel-manganese-cobalt (NMC) are widely expected to be used in the growing number of EVs produced. As a result, cobalt supply will need to increase by a factor of two to three by 2030 in order to meet project battery demand [2,17].

Production of cobalt is not as responsive to demand as some other commodities, because cobalt is generally a secondary byproduct from the production of a different primary metal (mainly nickel; secondarily, copper and platinum). Only 6% of cobalt production is as a primary product [18]. As a result, supply shortages and price fluctuations are more likely for cobalt than for some other commodities.

Production of cobalt ore is highly concentrated in the Democratic Republic of the Congo, which produces about half of global supply. Refining of cobalt is also highly geographically concentrated: over half of cobalt is refined in China. Global trade in cobalt ore is strongly dominated by shipments from DRC to China, which account for 40% of global trade [19].[2] While China has consumed most of its refined cobalt production domestically in recent years, it is also a dominant supplier to the United States. Notably, China has recently shown willingness to use trade relationships as leverage for its diplomatic aims [20], and has signaled the possibility of export restrictions on strategic rare earth elements of which it is the dominant supplier [21].

Nickel

Global nickel supply and reserves are fairly diversified geographically (Table 2 and Figure 2). Most nickel is used to manufacture stainless steel. However, the highly refined nickel used in LIB manufacturing (class 1, with 99.8% or higher nickel content) is mainly produced in Australia, Canada, Russia, and Finland [22]. In addition to the production and reserves locations detailed above, a cobalt and nickel mine is in development in Indonesia for the purpose of supplying these materials for battery production.

Demand for class 1 nickel for batteries is forecast to increase by a factor of 15 to 25 by 2030. This is forecast to contribute to total nickel demand increase (including both high-purity class 1 nickel and lower-purity grades) for 1.5- to two-fold over the same period [2,23].

WHAT INITIATIVES ARE UNDERWAY TO ENSURE ADEQUATE RAW MATERIAL SUPPLIES?

Low-cobalt battery chemistries

One approach to reducing the supply risk of a critical material is to remove it from the battery altogether. This may be a viable approach specifically for cobalt, as a range of different cathode compositions

2 When considering trade flows of at least US$10 million.

have been developed for LIBs with widely varying cobalt loadings (Table 3). For instance, the cobalt loading of more recently developed NMC-811 blend is about 70% lower than the widely deployed NMC-111 blend.

In addition, lithium iron phosphate (abbreviated as "LFP"[3]) is an entirely cobalt-free cathode chemistry that is seeing early commercialization. A fully cobalt-free cathode chemistry avoids any exposure to the potential price volatility and supply chain security concerns that result from the very high concentration of cobalt extraction (in the DRC) and refining (in China).

Table 3. Cobalt content for selected lithium ion battery cathode chemistries.

Cathode chemistry	Description	Cobalt content (g/kWh) [19]	Specific Energy Density (Wh/kg) [24]
LCO	lithium cobalt oxide	959	150–200
NCA	nickel cobalt aluminum oxide	143	200–260
NMC-111	nickel manganese cobalt oxide	394	
NMC-622	nickel manganese cobalt oxide	214	150–220
NMC-811	nickel manganese cobalt oxide	111	
LFP	lithium iron phosphate	0	90–120

Battery recycling

The prospect of recovering raw materials from recycled batteries has attracted attention as a possible approach to alleviate material supply constraints. This path faces economic challenges in the short-term. Given the very large expected demand for LIBs, recycling is unlikely to significantly affect the supply/demand balance for all key raw materials but could potentially increase and geographically diversify the available supply.

Integrated modeling frameworks that quantify the supply chain impacts of LIB recycling have been developed by various academic analysts [10,25] as well as the U.S. Department of Energy (DOE). DOE's Lithium Ion Battery Recycling Analysis (LIBRA) project is working "to explore issues related to the global and regional impacts of the interlinking supply chains associated with battery manufacturing and recycling" [26].

Battery recycling may help alleviate supply constraints somewhat, particularly if it provides geographic diversity in the supply of battery materials (such as through providing a larger range of countries a domestic supply of lithium, cobalt, and nickel). However, given the very large project growth in battery demand, battery recycling is unlikely to significantly reduce the primary production requirements for battery materials. For instance, one recent analysis estimates that even with a high rate of battery recycling (70%), the flow of recovered lithium from recycled batteries would meet only 11% of lithium demand in 2050 [10].

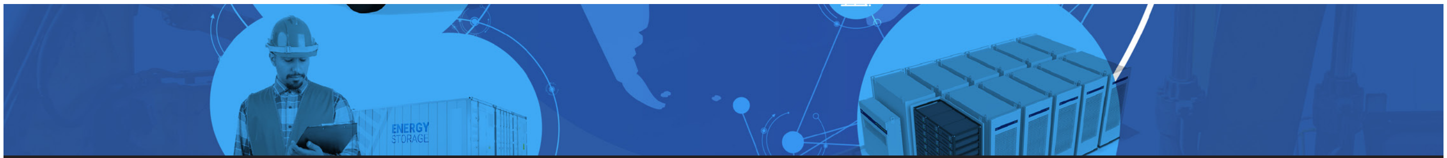
In preliminary analysis with the LIBRA tool, NREL has projected that if battery recovery reaches 95% in 2040, then the cobalt recovered from recycled batteries can supply 65% of U.S. cobalt demand for EVs [27]. However, continued scenario analysis with LIBRA and disclosure of the modeling assumptions will be necessary for more complete insight.

The high recycling rate achieved for lead-acid batteries provides a strong precedent for LIB recycling, but there are important differences: lead-acid battery recycling was implemented through regulatory requirements, which do not exist at this time for LIBs. Additionally, whereas the chemistry and product design are highly standardized for lead acid batteries—lowering the cost of disassembly—LIB design and chemistry is not standardized today. LIB recycling is generally not economically favorable currently, and the long-term business case for battery recyclers is widely viewed as dependent on policy support [2].

Significant efforts are underway to develop economically viable LIB recycling processes. For instance, DOE has initiated the ReCell program to develop more energy efficient recycling processes and increase the recovery of key materials from recycled batteries [28]. Similarly, the $5.5 million Recycling Prize aims to accelerate disruptive solutions to meet battery recycling needs [29]. Unfortunately, cost data for LIB recycling is generally not available from commercial recyclers at this time.

Notably, reducing the cobalt content of LIBs—another approach to address material supply, environmental, social and cost issues, as described above—may further impair the business case for LIB recycling. This is because cobalt is the most economically valuable material in a typical LIB. Batteries with less cobalt will provide less economic value to the recycler per battery processed, and a smaller amount of cobalt in each cell also may be more difficult to recover.

3 "LFP" is an acronym of the chemical symbols for lithium (Li), iron (Fe), and phosphorous (P).



Diversifying/Developing raw materials sources

A range of efforts are underway to develop new production sources for critical materials, including sources in locations that are close to expected major markets. The shift in locale will provide additional economic and environmental benefits due to reduction of complexity and transportation in supply chain steps.

For instance, four lithium mining projects are underway in Europe, in Spain, Austria, Czech Republic, and Poland [30]. These are anticipated to meet up to 80% of European battery sector lithium demand by 2025 [3]. Lithium exploration is also underway in California and Australia [31].

The European Commission is working on a raw materials alliance, similar to the public-private European Battery Alliance model, to focus on removing bottlenecks in critical raw materials supply chains for the EU battery industry. The European Commission has also announced plans for EU sustainable battery rules in late 2020, with the aim of challenge China's dominance of the global battery market [3].

Additionally, the Critical Raw Materials for Electric Vehicles (CRM4EV) taskforce of the International Energy Agency (IEA) was begun in 2018, with the purpose of assessing the impacts of EV on critical raw materials [32]. Participants include countries, national mining centers, mining companies, and research organizations.

ENVIRONMENTAL AND SOCIAL ASPECTS OF THE LITHIUM ION BATTERY SUPPLY CHAIN

HUMAN RIGHTS/LABOR ISSUES

Labor standards/Worker protection

The key LIB raw materials described above—lithium, cobalt, nickel, and graphite—are sourced partly from countries where higher poverty rates, weaker labor standards, and weaker overall regulatory enforcement leave mining workers more vulnerable to exploitative working conditions. In particular, cobalt production is uniquely concentrated in a single country—the Democratic Republic of the Congo (DRC)—that is particularly impacted by political instability and armed conflict. The resulting economic insecurity and social dislocation in the DRC is likely to further increase workers' vulnerability to working conditions that would be considered unethical in the developed countries that purchase finished LIBs. As a result, exploitative labor practices are particularly a concern in the cobalt supply chain.

Although the majority of cobalt produced in the DRC comes from large mining companies, a significant fraction (estimated at 15–30%) comes from informal small-scale mines (often referred to as "artisanal mining"), where basic international human rights expectations are often not implemented or enforced. "Severe social risks" that have been well documented in the DRC's artisanal mining industry include [2]:

- hazardous working conditions, including unstable tunnels prone to collapse;
- potentially various forms of forced labor, including child labor; and
- exposure to fine dusts and particulates and toxic materials.

Child labor is another significant issue in the DRC mining sector. It is estimated that 40,000 children work in artisanal mines in the DRC [33].

Community public health impacts

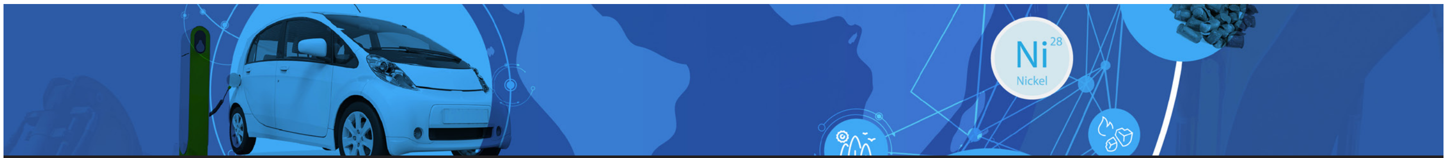
Various reporting has documented harmful health impacts of mining operations on local communities, such as respiratory and dermatological issues in the DRC [34]. Local communities are reported to be exposed to contaminated dust. Similarly, large areas within the mining region of Zambia are reportedly contaminated with cobalt, copper and other metal residues that present risks to public health [35].

ENVIRONMENTAL IMPACT OF MATERIALS EXTRACTION AND MANUFACTURING

Mine site pollution/runoff

The extraction and refining processes that produce the critical metals discussed above often use hydrochloric acid and other toxic substances. Recent reporting describes spills or runoff that have killed wildlife and degraded nearby ecosystems in diverse locations. Examples include:

- Norilsk, in Russia near the Arctic Circle, is the site of a nickel plant that produces cobalt as a by-product. Contamination reported in 2016, affecting local indigenous communities and their livelihoods, was attributed to impacts from the plant [36].
- Acid mine drainage from copper and cobalt extraction in Zam-



bia is allegedly compromising water quality in some regions and affecting local aquatic systems [37].

- Near the town of Tagong, in Tibet, multiple toxic spills occurred from the nearby Ganzizhou Rongda lithium mine during the period from 2013-2016, killing fish in the nearby Liqi river [38].

Water consumption in water-stressed regions

Lithium mining can consume large quantities of water. One common method for extracting lithium from geological deposits is "solution mining": pumping large quantities of water underground to dissolve the mineral salt, collecting the mineral solution at the surface, and then allowing the water to evaporate in order to collect the solid lithium salts.

However, a very large share of estimated lithium reserves (and current lithium production) are located in arid regions, such as the Atacama Desert in Chile and western Australia. (Note that although Argentina is listed as medium water stress at a country-wide level, its Puna highland desert of Salta and Jujuy, near the "lithium triangle", is classified as "extreme risk" for water stress. [39])

Table 4. Water stress ratings of top lithium-producing countries. (Sources: World Resources Institute [40].)

Jurisdiction	% Global mined production	% Global reserves	2010 Country-level water stress ratings	2040 Projected country-level water stress rating
Australia	41%	4%	High	High
Chile	24%	19%	Medium	Extremely high
Argentina	16%	5%	Medium	Medium
China	6%	8%		High
Bolivia	[just starting]	22%	Low	Low

High industrial water consumption in water-stressed regions has impacted local communities. Examples include:

- Lithium mining in the high-altitude Atacama Desert in Chile reportedly diverts scarce water resources away from local communities. Extraction of lithium has allegedly caused some water related conflicts among local communities.
- Communities in Argentina's Salar de Hombre Muerto region assert that lithium operations have contaminated streams used for humans, livestock and crop irrigation [41].
- Water consumption from large-scale mining is reported to have impacted local communities even in countries rated as low overall water stress, such as Bolivia.

Greenhouse gas emissions during battery manufacturing

LIB manufacturing (i.e., the production phase of the life cycle) involves a series of individual processes that produce greenhouse gas (GHG) emissions. These include:

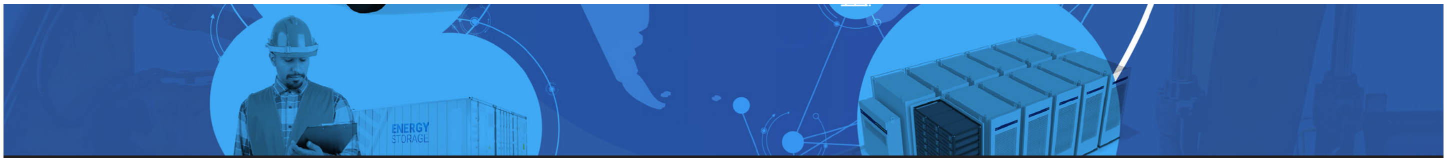
- production of anode and cathode materials;
- production of electrolyte, cell separator, current collectors;
- production of materials used in cell, pack and module housings; and
- process heat and electricity for various stages of assembly.

Studies of various LIB chemistries indicate that production of cell materials and other battery components (such as module housings and battery management systems) account for 50–75% of GHG impacts, with process electricity and heat accounting for the rest [42,43].

There is broad consensus across a range of studies that there is little difference among difference LIB cathode chemistries in the GHG impact of producing one kWh of energy storage capacity. The emissions impacts and energy requirements of producing the refined metals required for different battery chemistries (such as cobalt, nickel, manganese, and iron) do indeed vary widely [44]. However, as the cathode materials account for only 10–20% of total emissions for battery production, and other materials requirements are fairly standardized for all LIB chemistries, there is little resulting variation in total GHG impact for the entire battery cell [42].

Developing more energy efficient manufacturing processes is a key opportunity for reducing GHG emissions of battery manufacturing. Providing process electricity with lower emissions is another opportunity. Longer-lived batteries (capable of performing more charge-discharge cycles) would also correspond to lower GHG emissions, because the same manufacturing-related GHG emissions for a single battery would enable more energy to be stored over the lifetime of the battery.

The emissions intensity of electricity consumed at earlier steps in the supply chain is another factor in the overall GHG emissions of LIB production, particularly in China, where about half of global cobalt production is refined. Concerns about high electricity-related GHG



emissions have reportedly resulted in production stoppages and prompted more stringent emissions-related policies and procedures [45].

INITIATIVES TO SUPPORT SUSTAINABILITY IMPROVEMENTS

Several approaches already exist, or are being developed now, that have the potential to improve sustainability across the LIB supply chain. A common theme across these different activities is collective action—involving various combinations of manufacturers (vehicle manufacturers in particular), supply chain partners, non-governmental organizations, civil society groups, and others. These initiatives provide some previously missing key elements to address environmental and social responsibility challenges: clearly defined standards of good practice; determining the compliance of individual suppliers; and communicating this information to manufacturers and, potentially, the end consumers.

Taken together, these initiatives open the possibility that markets and consumers, when provided with transparent and trusted compliance data, can exert influence through their purchasing decisions to select more environmentally and ethically sounds supply chains.

Table 5. Comparison of selected national critical materials strategies. (Adapted from Wilson and Martinus 2020 [46]).

Action	European Union	United States	Japan	India
Economy-wide assessment surveys to identify supply risks for critical materials	✓	✓	✓	✓
Technical improvements across the value chain, including process efficiency, recycling and substitutes	✓	✓	✓	✓
Develop reserves of critical materials to help manage supply interruptions		✓	✓	
Support new producers to enter the market through packages combining investment and offtake contracts			✓	
Diplomatic efforts to improve value chain security, such as building relationships new suppliers	✓	✓	✓	✓
Develop methods to assess and report sustainability along the entire supply chain	✓			

Several governments have recognized the supply risk for these critical materials and have undertaken a range of initiatives in response (Table 5).

Standards or guidelines development

A foundational element for reducing the possibility of worker exploitation and environmental harm is to establish clear performance standards against which supply chain partners can be evaluated (such as mine operators, refiners, and battery cell manufacturers). Several existing standards that apply to key battery materials are listed in Table 6.[4] These documents define and communicate a standard; separately, auditing frameworks define a procedure by which a supplier will be evaluated against the standard. Auditing frameworks are discussed in the next section.

The Organization for Economic Co-operation and Development (OECD) Due Diligence Guidance for Responsible Mineral Supply Chains [47]—or "OECD Guidance"—is a well-established and widely referenced framework "to help companies respect human rights and avoid contributing to conflict through their mineral purchasing decisions and practices" [48]. It was first adopted in 2011 and is intended for use by any company that may source minerals or metals from conflict-affected and high-risk areas. The OECD Guidance is intended to be applicable worldwide and for all mineral supply chains. It is referenced by a range of entities worldwide, including European Union regulations, a United Nations Security Council resolution, the U.S. Securities and Exchange Commission,

HOW THE OECD GUIDANCE IS IMPLEMENTED

The OECD outlines five steps for companies to take to implement the OECD Due Diligence Guidance for Responsible Mineral Supply Chains:

1. Establish strong company management systems
2. Identify and assess risk in the supply chain
3. Design and implement a strategy to respond to identified risks
4. Carry out independent third-party audit of supply chain due diligence
5. Report annually on supply chain due diligence

4 Various other existing standards, not included in this brief, apply to metals used in other industries such as jewelry or electronics.

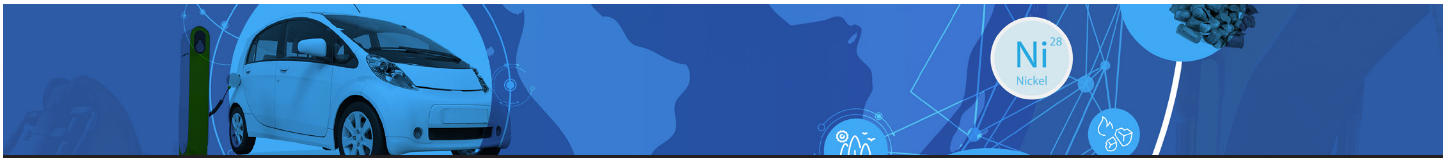


Table 6. Selected published guidelines for responsible mining that apply to key battery materials.

Name	Published by	Referenced by	Materials Covered	Scope			
				Labor Standards	Environmental	Disposal/ Recycling	Raw Materials Provenance
The OECD Due Diligence Guidance for Responsible Mineral Supply Chains	OECD	Responsible Minerals Assurance Process; Cobalt Industry Responsible Assessment Framework [49]; U.S. Securities and Exchange Commission; Chinese Due Diligence Guidelines; others	All mineral supply chains	Y	N	N	Y
Standard for Responsible Mining	Initiative for Responsible Mining Assurance (IRMA)	Anglo-American (multinational mining company); civil society groups	All mined materials	Y	Y	N	N
Chinese Due Diligence Guidelines for Responsible Minerals Supply Chains	China Chamber of Commerce of Metals, Minerals & Chemicals Importers & Exporters		All mineral resources; Initial focus on non-battery materials (Sn, Ta, W, Au)	Y	Y	N	N

and international assemblies. The OECD Guidance is a highly relevant standard for cobalt and nickel used in the LIB supply chain.

The Chinese Due Diligence Guidelines for Responsible Minerals Supply Chains were adopted in 2015 and based on the OECD Guidance. Although the Chinese guidelines are not initially focused on critical LIB materials (i.e., cobalt, nickel, copper, aluminum), their adoption is noteworthy because of China's dominance in (1) the global cobalt supply chain (with approximately 50% of global cobalt refining), and (2) as a large consumer of LIBs whose procurement standards are likely to be globally influential.

The IRMA Standard for Responsible Mining is among the most of these detailed documents. It includes particularly detailed requirements for both environmental and social responsibility. An excerpt from the Water Management section illustrates the level of specificity:

"4.2.4 – Monitoring and Adaptive Management. The operating company shall develop and document a program to monitor changes in water quantity and quality. As part of the program the operating company shall:

a. Establish a sufficient number of monitoring locations at appropriate sites to provide reliable data on changes to water quantity and the physical, chemical and biological conditions of surface waters, natural springs/seeps and groundwater (hereafter referred to as water characteristics);

b. Sample on a frequent enough basis to account for seasonal fluctuations, storm events and extreme events that may cause changes in water characteristics." [50]

The IRMA Standard Environmental Responsibility Requirements includes similarly detailed sections on:

- Waste and management
- Water management
- Air quality
- Noise and vibration
- Greenhouse gas emissions
- Biodiversity, ecosystem services, and protected areas
- Cyanide management
- Mercury management

The IRMA Standard's Social Responsibility Requirements include sections on:

- Fair labor and terms of work
- Occupational health and safety
- Community health and safety
- Mining and conflict-affected or high-risk areas
- Security arrangements
- Artisanal and small-scale mining

- Cultural heritage

The IRMA Standard also includes sections on "Business Integrity" and "Planning for Positive Legacies" [50].

Audit or standards verification activities

An audit or verification framework is the mechanism for evaluating whether supply chain partners are meeting a specified guideline or standard. Table 7 collates information on several of these verification frameworks which are operating or nearing operational status.

One robust example is the Responsible Minerals Assurance Process (RMAP) framework for third-party assessment. The program "employs a risk-based approach to validate smelters' company-level management processes for responsible mineral procurement" [51]. RMAP focuses specifically on smelters/refiners, because this stage of the minerals supply chain is relatively concentrated, with a relatively small number of refining operations serving the global market. RMAP standards are aligned with the OECD Guidance.

Assessments for RMAP conformance are conducted by third-party Responsible Materials Institute-approved auditors. RMAP promotes transparency in the cobalt supply chain by publicly listing these smelters and refiners that participate in its validation process.

Individual corporate sustainability policies

Many electric vehicle and/or battery manufacturers have published corporate sustainability statements or policies that include environmental and labor standards considerations (Table 8). Several distinct motivations have been advanced for manufacturers to pursue responsible sourcing and certification in the battery supply chain, in a recent elicitation involving a range of stakeholders (EV OEMs, mining industry associations, standards groups, research institutes) [52]. These include:

- Meeting investors' and insurers' expectations;
- Reputation and consumer expectations;
- Market advantage from demonstrating good practices; and
- Improving sustainability and transparency in the supply chain.

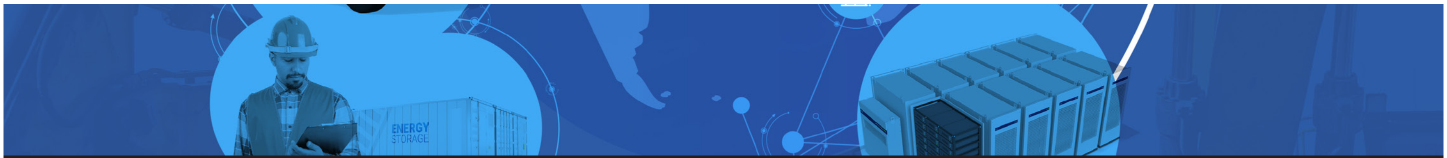
A key consideration is that some companies specifically endorse or participate in certain of the standards and/or audit frameworks discussed in the preceding sections. Importantly, this feature aligns the individual corporate policy with standardized frameworks that (in some cases) are supported by other stakeholders (including the mining industry, civil society groups, and local community advocates). Importantly, this participation also connects the individual corporate policy with transparent reporting platforms that are included in some of the frameworks (such as RMAP). These features increase the likelihood of broad industry adherence across the supply chain.

Table 7. Selected frameworks to implement guidelines for responsible mining.

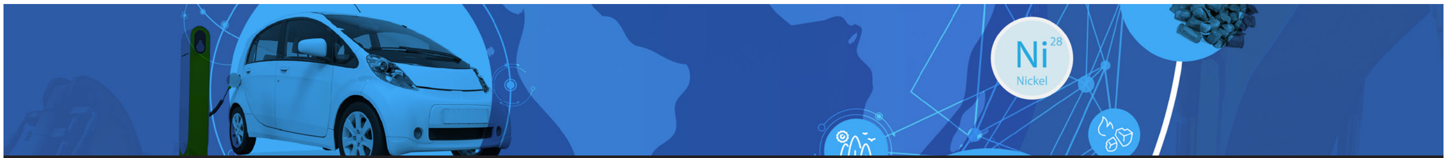
Name	Type of Initiative	Operated by	Participation	Mandatory or Voluntary	Materials Covered	Scope			
						Labor Standards	Environmental	Disposal/ Recycling	Raw Materials Provenance
Responsible Minerals Assurance Process (RMAP)	Third-party assessment of smelter/refiner management systems and sourcing practices to validate conformance with OECD and RMAP standards	Responsible Minerals Initiative	Cobalt smelters: • 7 conforming • 22 participating • 62 eligible	Vol.	Co, Au, Ta, Sn, W	Y	N	N	N
Battery Passport	Data sharing (digital platform) of battery composition and features	Global Battery Alliance/World Economic Forum	Seeking participation from battery original equipment manufacturers (OEMs)	Vol.	n/a	Y	Y	Y	Y
Cobalt Industry Responsible Assessment Framework (CIRAF)	Reporting framework and management tool	Cobalt Institute		Vol.	Co	Y	Y	N	N
Responsible Sourcing Requirements	Defined and consistent implementation of existing labor and environmental standards	London Metal Exchange	All traders on the London Metal Exchange	Man.	Many	Y	Y	N	N

Table 8. Illustrative excerpts from corporate sustainability policies, with examples of references to third-party audit/reporting frameworks.

Company	Labor standards	Environmental standards	Subscribe to third-party audit framework?
Toyota [53]	"Child Labor: Do not use child labor. The minimum age for employment shall be 15 years of age, the legal minimum age for employment, or the age for completing compulsory education, whichever is greatest under the local applicable laws and regulations. "Forced labor: Do not use forced labor. Ensure that all work is voluntary and employees are free to leave work or terminate their employment. • Do not require employees, who must work in a legal status, to surrender passports, government-issued identifications, or work permits as a condition of employment."	"Environment: … Establish an Environmental Management System (EMS) that can promote environmental preservation activities and continuously improve them, in addition to comply with applicable environmental laws and regulations in each country… (Refer to the Green Purchasing Guidelines of each region/country)."	Not at the corporate level [53]
General Motors	"We put in place several reporting mechanisms and have strong anti-retaliation policies." "GM has a zero-tolerance policy against the use of child labor as stated in our Supplier Code of Conduct and Conflict Minerals Policy. GM prohibits abusive treatment to employees and corrupt business practices in our supply base. As stated in this policy, we 'seek to avoid inadvertent adverse economic impact attributable to conflict mineral due diligence activities.'"[54]	"[W]e plan to have one-on-one strategic discussions with targeted suppliers about their emissions results and initiatives to decrease emissions, energy and water usage. These will enhance collaboration between GM and its supply base for further reductions." "[W]e have engaged our supply chain by inviting a group of suppliers, around 300 in 2019, to participate in the CDP [55] Supply Chain climate change and water programs. We have recently developed a goal to have 100 percent of strategic suppliers participate in CDP reporting by 2022." [54]	Uses the Cobalt Reporting Template with key suppliers Determines whether cobalt suppliers meet RMI's industry specification for a legitimate cobalt refiner Performing outreach to nonconformant cobalt refiners to encourage them to go through the RMAP for cobalt. Analyzes Conflict Minerals Reporting Template submissions from suppliers [54]
BMW	"The BMW Group does not tolerate child labor of any kind.[…]. Their dignity must be respected, and their health and safety protected. In accordance with ILO Core Conventions, the BMW Group adheres to minimum employment ages and fully rejects child labor, in particular all worst forms of child labor." "The BMW Group does not tolerate forced or compulsory labor of any kind. In accordance with ILO Core Labor Standards, the BMW Group opposes the use of forced or unlawful compulsory labor of any kind in its business activities." [56]	"Having already lowered emissions per vehicle produced by more than 70 percent since 2006, the BMW Group now aims to reduce its emissions (Scope 1 + 2 - Link) by a further 80 percent from 2019 levels by 2030.[…]" [57]	Expects each raw material supplier to implement IRMA certification. [52]



Company	Labor standards	Environmental standards	Subscribe to third-party audit framework?
Samsung SDI	"...developed and published Migrant Worker Guidelines in cooperation with Business for Social Responsibility (BSR) that includes commitment to eradicate forced labor, excessive commissions for employment and any discriminatory treatment which may occur while migrant workers are working in foreign locations."… "Samsung Electronics enacted the Child Labor Prohibition Policy describing our strong will to prevent child labor in partnership with The Centre for Child Rights and Corporate Social Responsibility (CCR CSR), a social enterprise established by Save the Children Sweden. Child Labor Prohibition Policy is based on the 'UN Convention on the Rights of the Child', 'UNICEF Children's Rights and Business Principles', and 'ILO Convention'." [58]		"[W]e encourage suppliers to partner with smelters certified by the RMAP (Responsible Minerals Assurance Process), and require uncertified smelters in our supply chain to become certified by the RMAP." [59]
Volkswagen Group	"We affirm our commitment to the relevant international conventions and declarations, in particular the International Human Rights Charter and the core labour standards of the International Labour Organisation (ILO).* We structure our business operations in line with the UN Guiding Principles for "Business and Human Rights" (UNGP). The ten principles of the UN Global Compact are crucial guiding pillars for the activities of our Group." [60]	"We are committed to the 2° goal of the Paris Climate Agreement. We intend to become a CO_2 neutral company by 2050." "By 2025, we plan to have reduced the production-related environmental externalities (CO_2, energy, water, waste, volatile organic compounds) by 45% per vehicle compared to 2010." "By 2025, the share of battery electric vehicles in our model portfolio will be between 20 and 25%. The share of electric vehicles in the Group fleet is to rise to at least 40% by 2030." [61]	n/d
General Electric	"Our Supplier Integrity Guide (SIG) governs all facets of our relationships with suppliers, and includes specific prohibitions against forced, prison, or indentured labor, and prohibitions against subjecting workers to any form of compulsion, coercion, or human trafficking." [62]	"GE supports policies that: • Reduce greenhouse gas emissions, while also ensuring a reliable, safe energy supply; • Encourage early adoption of cleaner technologies and energy efficiency; • Reflect national and local circumstances; and • Set realistic timelines for reduction efforts with periodic reviews as knowledge of the science evolves and technology improves." [63]	"In connection with our due diligence, we utilize and rely on information made available through the Responsible Minerals Assurance Process ("RMAP") administered by RMI, concerning independent third-party audits of smelters and refiners to assess smelter and refiner due diligence and to identify countries of origin." [64]



Centralized verification of materials provenance

Although several standards and frameworks relevant to the LIB supply chain exist or are emerging, no single framework has yet emerged as a central standard. There is a risk that fragmented and overlapping systems will persist, increasing overall reporting and compliance costs for industries within the supply chain, and limiting the ability to easily compare assessments.

In response to this fragmentation, the Global Battery Alliance has proposed the Battery Passport initiative, with the overall aim of enabling "greater trust and transparency in the exchange of material along supply chain" [65]. The Global Battery Alliance is a public-private partnership whose members include key corporate stakeholders as well as non-governmental organizations (NGOs), agencies, and industry associations. Notable industry members include automakers (Audi, BMW, Honda, Renault; Volkswagen, Volvo); battery manufacturers (LG Chem, NEC, Saft); battery recyclers (Umicore); and mining conglomerates (Anglo-American, Glencore, Eurasian Resources Group) [66].

The Battery Passport envisions a common and secure data infrastructure that is recognized and trusted by many stakeholders along the battery supply chain. The Battery Passport is envisioned to encompass the entire battery life cycle, including raw materials extraction and refining; battery manufacturing; product use; and remanufacturing/recovery/recycling at end of life.

The Battery Passport concept proposes blockchain as a "shared and trusted ledger" to immutably record key data in a manner that would be commonly accessible to every downstream stakeholder, including battery and auto OEMs. This data is envisioned to include:

- Provenance of raw materials
- Emissions footprints and other environmental impacts
- Proof of compliance with human rights policies

The Battery Passport initiative aims to introduce "Battery Passport 1.0" in 2021 (covering a subset of battery data including materials provenance and GHG disclosure). The Global Battery Alliance notes that CEO-level support from key stakeholders will be crucial to developing the platform. A graphite producer recently initiated a pilot project to align with the Battery Passport guidelines by mapping and documenting social and governance factors, GHG footprint, and other factors along the graphite supply chain [67].

Collaborative industry initiatives

Collaborative initiatives have also been created within specific industries. Ten major automakers have formed Drive Sustainability [68], a partnership to influence the sustainability of the automotive supply chain. Drive Sustainability developed a "Raw Materials Observatory" to identify risks and opportunities for collective industry action and published an extensive assessment of 37 raw materials essential to the automotive and electronics industries [14]. Members of the Drive Sustainability partnership include BMW Group, Daimler AG, Ford, Honda, Jaguar Land Rover, Scania CV AB, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.

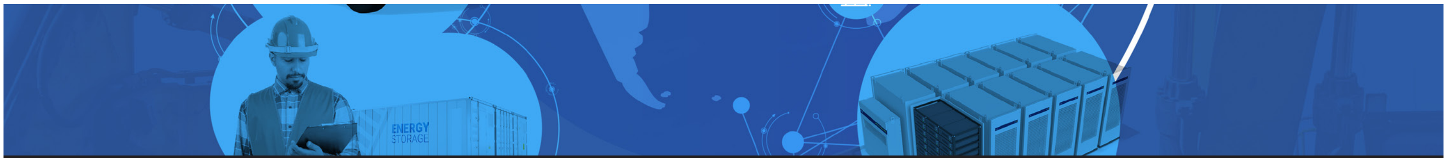
Direct sourcing of raw materials by EV manufacturers

At least one major automaker, BMW, has taken the step of procuring battery materials directly, and then providing those shipments to its battery supplier, in order to ensure compliance with its corporate sustainability objectives [69]. This approach may eliminate the risks associated with ambiguous provenance or questionable assurance of compliance with particular standard for environmental and social impacts [14].

SUMMARY

Lithium ion batteries (LIBs) are a key technology for decarbonizing the transport sector and for transitioning to a low-emissions power system. Numerous assessments have examined whether global reserves and supply chains for key LIB raw materials will be adequate to meet the expected growth in demand for LIBs in the coming decades. Global lithium reserves are widely expected to be adequate to meet demand from growing EV production, although short-term supply challenges and price volatility could arise if production growth lags demand. Cobalt and graphite are also critical materials with potential vulnerability to supply interruptions, due largely to the extreme geographic concentration of their supply chains in just two countries.

For some raw materials used in manufacturing LIBs, serious concerns of exploitative labor practices and environmental degradation have been documented. A range of auditing and reporting frameworks have been developed in order to improve transparency about these issues along the LIB supply chain. This improved transparency is intended to help end users incorporate environmentally and ethi-



cally informed sourcing into their purchasing decisions. Manufacturers are also beginning to take voluntary action, both individually and through industry consortia, with concrete and potentially impactful steps toward robust environmental and social responsibility assessment and reporting along the battery supply chain. Participation in these efforts is expected to increase in the future, as the early adopters are likely to experience customer preference, and competitors may subsequently become more inclined to take action themselves.

Continued research and collaboration can further outline specific approaches for end users to fully utilize these emerging auditing frameworks, industry collaborations, and other approaches. This survey of approaches provides a foundation to develop further guidance for electricity companies to align their stationary battery procurements and EV programs with their own corporate sustainability policies.

ABBREVIATIONS

EV	electric vehicle
DOE	Department of Energy
DRC	Democratic Republic of the Congo
GHG	greenhouse gas
ILO	International Labor Organization
IRMA	Initiative for Responsible Mining Assurance
LIB	lithium ion battery
LFP	lithium iron phosphate
NMC	nickel manganese cobalt
OECD	Organization for Economic Co-operation and Development
OEM	original equipment manufacturer
RMAP	Responsible Minerals Assurance Program
RMI	Responsible Minerals Initiative
USGS	United States Geological Survey

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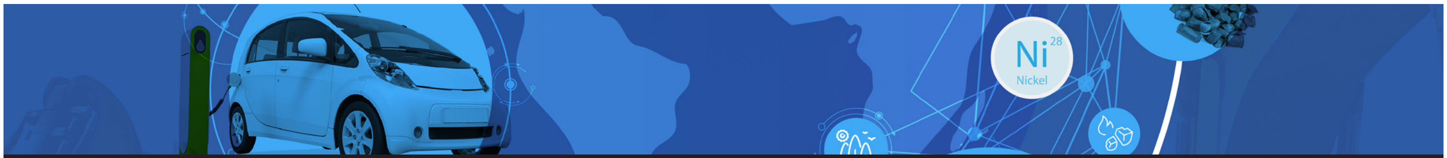

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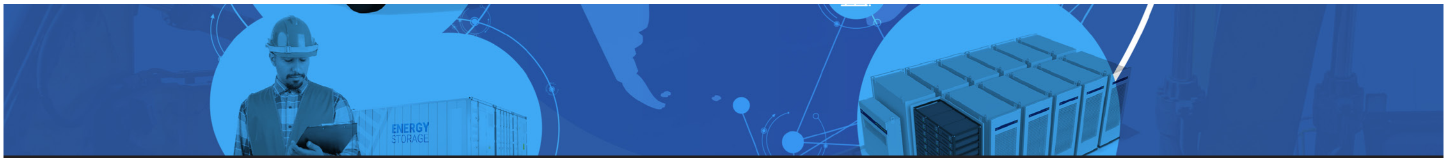

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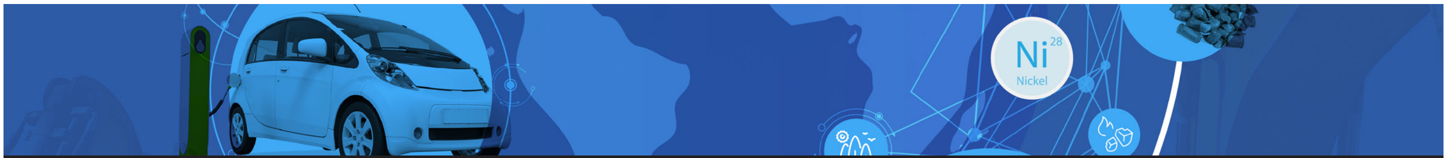

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Environmental Aspects of Fueled Distributed Generation and Energy Storage

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