California Center for Jobs & the Economy | California Business Roundtable

A Closer Look At

California's Cobalt Economy

January 2019

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Executive Summary

Through a series of regulatory mandates, Executive Orders and high-profile laws, California has begun to transform its economy through energy policy. However, unlike other states and economies that rely on a more diversified energy portfolio, California's policies are leading to an over-reliance, if not complete dependence, on electrification including increasing generation from intermittent sources. This shift will require a significant investment in battery technology—currently dominated by lithium-ion—for a range of transportation and other applications, including storage technology not currently available.

These investments will put considerable strain on the existing markets for critical minerals needed to manufacture the batteries, likely contributing to currently-projected global resource shortages for battery-grade materials, which could keep costs elevated in the near future. Of greater concern, a key mineral used in the production of lithium-ion batteries, cobalt, is primarily mined in the Democratic Republic of the Congo (DRC), where reports from Amnesty International detail the use of child labor and other humanitarian and worker abuses related to "artisanal" cobalt mining. Increasing demands generated by the California policies will further increase reliance on materials from this unstable region.

Increased demand will also put additional pressures on other existing and emerging cobalt applications, including electronics like cellular phones, computers, wheelchairs, medical devices and myriad other battery-powered devices along with traditional uses for metallurgical and other chemical products. Cost increases could affect sales and production competitiveness for these products, which in turn will impact the state's employment in these industries along with collection of sales tax and other associated revenue.

Under its current climate change policies—including Executive order B-16-2012 which set a goal of 1.5 million ZEVs on California roads by 2025, and the subsequent B-48-18 which pushed the goal to 5 million by 2030—the state has made a significant shift away from its historic "technology neutral" approach to clean vehicles and has effectively moved to promotion of a specific, resource-heavy technology as the answer to its regulatory goals. This report looks at the increased demand on raw materials that are a direct result of the state's efforts to increase zero-emission vehicle (ZEV) use in California primarily through the promotion of electric vehicles and their associated battery use.

This report seeks to understand what impact this regulatory approach will have on the global supply of key minerals required to produce the batteries needed to meet the demands created by California regulations, the impact this increased demand will have on costs—both economic and human—a brief explanation of how these outcomes may impact other sectors of California's economy that rely on the same raw materials for their existing technologies, and an initial discussion of the risks that come with the current regulatory drive towards a single-source energy economy.

KEY FINDINGS:

The transformation to a single-source, battery cell energy policy will require an overreliance on overseas markets, particularly East Asia, to meet demand. Because of aggressively applied industrial policies, current battery cell production has concentrated to a high degree in the East Asia countries of China, South Korea and Japan. The resulting cost efficiencies that exist now from these supply clusters likely mean this concentration will endure and is currently on course to expand. At the same time, China-based firms are driving to secure cobalt and other battery-critical material supplies, further undercutting the ability of competitors elsewhere to compete or even enter the industry.

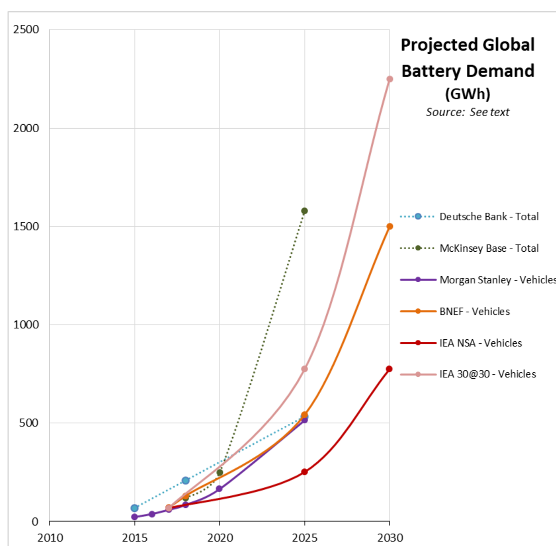
EV & Energy Storage Lithium-Ion Battery Cell Production Capacity (GWh)

	2010	2016	2017	2022
China	9	69	145	373
Asia-Pacific*	5	31	31	57
North America**	1	11	18	46
Europe	0	3	4	41
Other	0	0	0	79
Total	*15*	*114*	*198*	*596*

Source: IEA [2017]
*Notes: *Primarily Japan/South Korea;*
***Growth primarily from Tesla Gigafactory (35 GWh cells/50 GWh packs by 2020)*

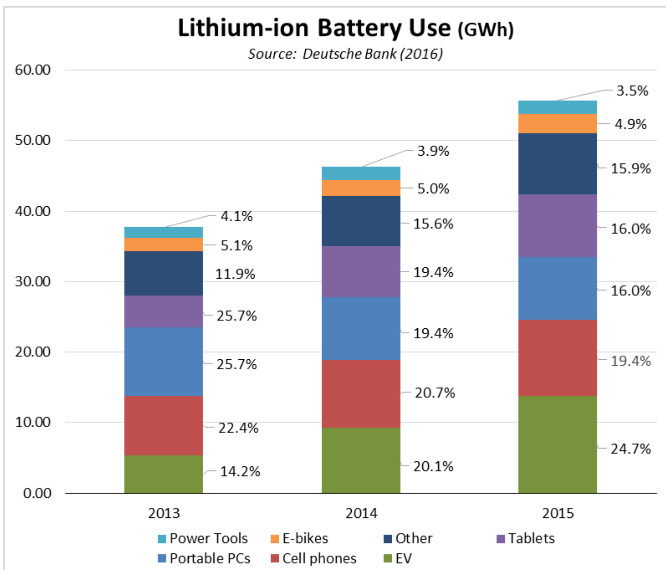
History is repeating itself. Solar panel manufacturing in both California and the United States was undermined by a rapidly growing overcapacity created by government subsidies in Asia. There are now no solar panel manufacturers in California. Given China's aggressive drive to secure preferential access to the raw materials needed to develop the battery economy we are building, it is highly unlikely California manufacturers will ever benefit from the heavy investments of public and ratepayer funds the state is now making in this new technology, despite the fact that the industrial sector pays nearly twice as much as the rest of the nation in energy prices to help subsidize the transition to the new battery economy.

Battery cell shortages are now projected by 2025. Because ZEV sales have lagged previous investment projections, the recent excess of battery capacity has contributed to declining vehicle battery prices. Moving into 2025, most analyses see tighter market conditions as battery cell demand comes more into balance with capacity, especially as cobalt constraints come into play. This shortage will come just five years before the deadline for the state's latest and most aggressive ZEV mandates and could significantly affect prices—batteries currently comprise about half of a typical ZEV cost—at a time when state policies will be heavily favoring producers of these vehicles. While other battery chemistries may come into play especially in the post-2025 timeframe to address these supply and cost



conditions, the accelerated schedules now mandated by California and other state and country ZEV policies mean in practice most producers are designing their models around the batteries available now and on the foreseeable commercial horizon.

Additional mining of cobalt will be required to meet national and California-specific ZEV mandates to not negatively impact other sectors of the economy. Cobalt is widely used throughout the economy for a range of metallurgic, chemical and non-mobility battery applications, in addition to the growing use for vehicle batteries. Growth in these competing demands alone is now projected to match current cobalt production levels, meaning the additional demand for vehicle batteries brought about by current national and sub-national policies likely will have to be met primarily through new and expansion of existing mines. Any delays in bringing this new production on line—as a result of permitting delays, changing investment assumptions, litigation, or shifting tax, regulatory, and security environments in the producing countries—will likely have a negative effect on increasingly tight supplies, increasing prices and the cost of the ZEV policies while affecting other sectors of the economy as well.



Based on currently announced expansions, The Democratic Republic of the Congo (DRC) is expected to provide 75 percent of global cobalt mine production by 2025. DRC currently accounts for 58 percent of global cobalt mine production and 49 percent of estimated reserves. Given the extreme amount of time to discover, delineate and permit new mining capacity, national and California policies will rely heavily on expanded DRC production to fulfill their goals. Based on current mine proposals, DRC's share of the market is now projected to expand to 75% by 2025.

"Artisanal mining" in the DRC provides about 20 percent of the country's current supply, or 10 percent of global supply and growing as DRC expands its production. In 2017, Amnesty International exposed artisanal mining for what it really is—as many as 40,000 child laborers, slave labor and significant abuses of worker and human rights. Reports from other organizations have detailed how foreign and rebel militias and units of the national military control much of artisanal mining in the country, along with the communities springing up around this activity.

Some companies, including Apple and Tesla, are attempting to develop tracking methods to ensure future cobalt comes from "ethical" sources. Previous efforts mandated by federal law for DRC gold, tantalum, tin and tungsten have failed and in fact have intensified the conditions that originally forced many to rely on artisanal mining in the first place. As developed countries increase their cobalt demand to produce electric vehicles for higher income buyers and $1,000 cell phones, the incentives for artisanal mining will only increase, especially in a country where two-thirds of the population lives in extreme poverty (less than $1.50 a day) and where most other income options have been destroyed by three decades of unrelenting civil unrest, civil war, and external conflict.

"The energy solutions of the future must not be built on human rights abuses."

Seema Joshi, Head of Business and Human Rights at Amnesty International

Increased demand for cobalt will also require reliance on the DRC's historically unsettled government. Civil war, foreign incursions and civil unrest have frequently led to disruptions of mining operations and global supplies. Corruption within the government and throughout the country has included the systemic looting of the national mining company, which resulted in the physical collapse of the Kamoto underground cobalt mine due to lack of funds for maintenance. Recent reports including from the [Jimmy] Carter Center have indicated redirection of mining revenues continues at high levels.

California's energy future now relies on DRC and East Asian markets for success. By now choosing winners and losers in the technology sphere and creating a single energy source future, California's future energy and, in turn, economic stability is now over-reliant on DRC and East Asia.

To put this dependence in perspective, the US reliance on OPEC oil production reached only one-third of consumption at its highest point in 1977, dropping to only 17 percent in the most recent data for 2017.

The ambitious schedule for ZEV sales—especially in China and California—leave little slack between expected cobalt demand and anticipated supply expansions. The projections anticipate periods of shortage after the 2025 timeframe even with accelerated introduction of lower-cobalt chemistry batteries, and prior to 2025 if announced mine expansions are not fully completed or if production overall is negatively affected by the recent changes to DRC mining law.

Introduction & Summary

Beginning with the California Air Resources Board (CARB) LEV I regulations, California has required some level of zero emission vehicles (ZEVs) to be offered for sale within the state since 1990. Begun primarily as an air quality measure, the ZEV policies have since been extended as a major component of the climate change program as well. First under Executive Order B-16-2012 which set a goal of 1.5 million ZEVs on California's roads by 2025 and subsequently under B-48-18 which pushed the goal to 5 million by 2030, the state has made a significant shift away from its historic "technology neutral" approach to regulation and—due to the scope and expedited compliance schedule for this program—has in effect moved to promotion of a specific technology as the answer to its regulatory goals.

Other technologies such as fuel cell vehicles remain technically viable under the current regulatory structure. The current implementation schedule, however, combined with current and proposed plans for a massive public investment in the required recharging infrastructure—financed directly by electricity ratepayers and indirectly through Cap and Trade revenues by traditional fuel vehicles and other consumers—means in effect the state has moved into the role of technology selector and staked its air quality, climate emissions, and economic future on the success of batteries.

The political and advocacy justifications behind this policy course often portray this choice as generally devoid of negative consequences if not out rightly beneficial economically due to the long anticipated but substantially unrealized creation of green and clean energy jobs within the state.[1] These conclusions, however, are possible only from a highly California-centric view of the issues. The effects within California may in fact be beneficial when viewed strictly from the potential reductions in both priority air pollutants and climate change emissions within the state's borders. But only because, as is the case with many of the state's other policies, California will function primarily as end user of the products required to achieve these results. Impacts will still occur as raw materials are produced and refined, battery cells and packs are completed, other product components are manufactured and shipped, and as final assembly takes place for final delivery to a California showroom. With few exceptions, these outcomes will occur instead in other locations for the vehicles, their power train components, and for a significant portion of the electricity required to keep them moving.

This report is the latest in a series of Center reports assessing a more complete range, including distributional factors, of the effects from the state's current policies. The focus in this instance is on the policies now driving an exponential growth in the use of battery technology.

[1] See the Center's recent analysis of this issue: California Green Jobs, An Updated Review: Phase I Estimates, May 2018.

Summary

- California vehicle policies have shifted from being standards based and technology neutral, to a de facto selection of a single solution—lithium-ion batteries—on which the state has now staked its air quality, climate emissions, and economic future. The zero emission vehicle industry was fundamentally birthed through California's regulations, originally adopted based on the state's air quality and economic goals. While the underlying CARB assumptions from the beginning were that compliance would be through electric vehicles, the regulations were crafted specifically to encourage development of a range of technologies. The shift in emphasis to the climate change goals now means the ZEV policies are driven more by the sales levels CARB believes are essential to achieve these goals, and more importantly at the accelerated schedule dictated by these policy deadlines. Rather than adjustments to reflect the state of technology, policies are now promulgated while assuming that technology will develop and prices will drop to what is needed to make the policies work. Other countries in particular China have adopted this approach as well in the national and subnational ZEV policies that are now driving investments in battery cell and vehicle production, and the materials supply chains to sustain them.

- The effect is the technology that is available now—lithium-ion batteries—has become the de facto compliance option. While new battery technologies including those using far less cobalt may offer growing contributions beginning near the end or after the current policy timeframe through 2030, the aggressive schedules envisioned in those policies—especially in China and in California—mean in practice the current lithium-ion chemistries will retain most if not all of the market. The projected raw materials use and potential related risks fall out from this structure as well.

- Battery cell production has concentrated to a high degree in the East Asia countries of China, South Korea, and Japan as a result of aggressively applied industrial policy. The resulting cost efficiencies that exist now from these supply clusters likely mean this concentration will endure and potentially expand. Increasing this trend, actions in particular by China-based firms to guarantee current and future supplies of cobalt and other battery-critical materials will limit the opportunities for comparable production to compete elsewhere.

- Considering plants that will actually be built, concentration in Asia is likely to be higher. Those planned for China have a higher probability of being built due to the high level of national and local subsidies, along with other provisions such as local content requirements that will guarantee the necessary demand. Bosch previously had intended to develop cell capacity serving the full German auto industry, but withdrew earlier last year after concluding it could not compete with lower cost Asian competitors. The long planned EU battery consortium has yet to move forward. Daimler and BMW instead have reached agreements to buy cells from China-based CATL. Rather than trying to replicate the cost efficiencies of the Asian supply chain clusters, Tesla accessed the one in Japan by entering into partnership with Panasonic to produce the cells at its Nevada Gigafactory, with Tesla handling the subsequent battery pack stage.

- The battery cell industry now appears poised to repeat the recent solar panel experience, in which a fledgling California and US industry was undermined by a rapidly growing overcapacity created by government policies and subsidies in Asia. Because electric vehicle sales have not kept pace with projections, the lithium-ion battery cell industry has operated under conditions of oversupply. Some of the battery cell price drops seen in recent years have been the result of technology and operating efficiencies, but at least some of the observed price trend is the result of oversupply, with some analysts concluding battery cell makers have been selling below the cost of production. The push to "gigafactory" level expansions in a search for cost efficiencies will continue an imbalance between demand and increments to supply, with producers keeping pressure on prices to maximize the sales they need to be a survivor. This situation will be intensified by China subsidies pushing their battery cell makers to scale, while the subsidies themselves will put these large producers in a better position to survive. Increasing this trend again will be the current drive by China-based firms to secure preferential access to cobalt and other battery critical materials, further undercutting the ability of competitors elsewhere to compete or even enter the industry.

- Industry consolidation could intensify the likelihood of battery cell shortages now generally projected for around 2025, stalling the shift to BEVs in areas other than China. Moving into 2025, most analyses see tighter market conditions as battery cell demand comes more into balance with capacity, weaker players—particularly those without access to subsidies and the battery critical raw materials—fall by the wayside, and the cobalt supply constraints discussed in this report start coming into play. The policy risk is that these conditions could arise just as consumer acceptance of ZEVs is improving, affecting in particular the more battery-intensive BEVs and potentially stalling ZEV introduction outside China at the HEV stage. This outcome is less likely to occur in China, which has taken the steps to secure battery cell capacity throughout this cycle and instituted the controls to ensure first priority for domestic consumption.

- While fulfillment of the ZEV policies still faces challenges from lagging consumer acceptance, the national and subnational policies set the base for projected vehicle sales now driving the core capacity investments. The various forecasts reviewed in this report show PEVs at 7 million to 23 million vehicles in 2025 (6% to 20% market share), and 21 million to 50 million in 2030 (13% to 42% market share). BEV sales alone—a key element of the battery cell and battery raw material estimates—range from 2 million to 4 million in 2025 (3% to 12% market share), and 16 million to 41 million in 2030 (13% to 34% market share). These numbers do not include provisions that now consist solely of announcements without the accompanying policies and actions required to achieve them, such as those from France and the UK to phase out ICE sales.

- The forecasts, however, vary over the types of vehicles they cover, affecting the associated battery demand coming from the national and subnational policies. These differences include assumptions of penetration rates for buses and other HDVs; the application of batteries to PHEVs and standard HEVs, mild HEVs, and micro HEVs to meet fuel efficiency rules and thereby extend the percentage of combustion vehicles being sold; and shifts in vehicle sales due to mobility services such as car sharing and ride hailing as a result of consumer choice and restrictions on personal vehicle ownership and use. California's most recent sales policies embodied in Executive Order B-48-18 are more in line with the higher end of the estimates, and consequently entail relatively greater exposure to the risks and impacts associated with the battery cell raw material use.

- ZEVs are not the only source of future lithium-ion battery demand. Most of the projections incorporate continued HEV uses as a result of lagging consumer acceptance, while recent studies expect increased use of mild and micro HEVs primarily for compliance with fuel efficiency rules. The current global stock of two- and three-wheelers is now estimated at 900 million vehicles, and most projections show future sales moving to electric as they are now for two-wheelers. Low-speed electric vehicles are a popular option for retirement communities in many countries and for lower income households in China, with anticipated annual sales of 1 million in that country alone. A number of other national and subnational policies are promoting potentially competing demand for energy storage necessary to handle grid problems as the various renewable energies strategies were put into place. Other growing non-transportation uses include forklifts and other heavy equipment, power tools, household equipment, consumer electronics, other consumer products, and medical applications.

- Compared to identified and likely cell battery capacity expansions, most of the demand projections indicate supplies will likely be tight leading into the 2025 goals. The level of expected battery cell capacity is sufficient to accommodate projected use under some of the earlier forecasts, but several recent ones show the capacity nearly required for vehicles alone with little left over for energy storage, consumer products, and the other growing demands. Additional investments are possible within this period, but only if there is sufficient access to the battery critical materials such as cobalt. Projections to 2030 and beyond are less relevant because they become more tautological. Sales expand if battery and therefore vehicle prices go down. Battery prices go down and additional supply goes up only if the assumed technology advances come into play.

- Forecasts of battery critical raw material demand vary widely among the studies, and depend on assumptions concerning future shifts in the core battery technologies and towards lower-cobalt chemistries, the geographical distribution of future sales, and the mix between various classes of vehicles being sold as electric models. For example, the typical BEV sold in California now requires three times as much battery-critical raw materials as the average vehicle sold in China, and considerably more if lower power mobility options being used in China are taken into account. All other things being equal, providing the same number of vehicles in the US compared to other countries will require higher relative raw materials use and consequently higher supply risks.

- Cobalt will be the battery critical material most likely to be in short supply, if not a full out constraint on fulfilling the national and subnational policy goals. Other battery critical materials have more options to be in sufficient supply but risk spot or temporary shortages as well due to other factors such as the time needed to bring new production to full scale (lithium) and potential fracturing of the market as a shift towards nickel raises prices for battery-grade supplies. With a broader geographic dispersion of deposits, the other materials also present fewer opportunities for a single country to monopolize the available supplies.

- Cobalt is widely used throughout the economy for a range of metallurgic, chemical, and non-mobility battery applications in addition to its growing use for vehicles. Taking into account growth in these demands and current level of vehicle use, the additional cobalt demand being mandated through the national and subnational policies likely will have to be met in total from new production additions to cobalt supply in order to <u>not</u> have negative supply and input price effects on other sectors of the economy.

- Democratic Republic of the Congo (DRC) currently accounts for 58% of global cobalt mine production and 49% of estimated reserves. Based on current announced expansions, DRC is expected to provide 75% of production by 2025. Given the extreme amount of time to discover, delineate, and permit new mining capacity as well as resolve the inevitable years-long litigation, fulfillment of the national and subnational policies will rely heavily on DRC production to fulfill their goals. The certainty of this new production, however, is now unsettled as a result of recent changes to DRC mining law.

- Even large increases in cobalt prices will bring little change in the total amount produced by mines. Cobalt is produced primarily as an associated product of copper and nickel mining, and expansion of cobalt is determined more by trends in world prices and consequently production levels for those two metals. For example, cobalt prices have tripled since 2016, yet production declined and reserve estimates were unchanged in 2017 due to slumping Chinese demand for copper and nickel. Even with soaring demand for batteries, most analyses do not expect cobalt production to keep pace.

- Battery recycling is not expected to be a significant factor in supply until well towards 2030. Specifically to address consumer acceptance factors, vehicle batteries are designed to have a long product life, and still retain about 70% of the recharge capacity at the end of their vehicle use. Rather than recycling, these batteries are more likely to be repurposed to energy storage, especially in rural areas and developing countries where cost is much more a consideration and space less so. The established process under which California and the US in general ship a large portion of their recycled material overseas for reprocessing or disposal in this instance simply means batteries at the end of their vehicle life will be moved to where they are the most valuable for repurposing rather than recycling. This factor further increases the reliance of the national and subnational policies on production of virgin ore, and thereby their reliance on future DRC supplies.

- Artisanal mining in the DRC is generally estimated as providing 20% of the countries supply, or 10% of global supply and growing as DRC expands its production. Following the release of reports from Amnesty International and others, artisanal mining in DRC has also become associated with 40,000 child laborers, slave labor, and worker and human rights abuses. And while companies such as Tesla and Apple are seeking to develop tracking methods to ensure future cobalt comes from "ethical" and child labor-free sources, previous efforts to do the same for DRC gold, tantalum, tin, and tungsten failed. Suddenly removing 10% of potential production or making it more difficult to access will only accelerate a supply crisis, leading in turn to higher prices that would incentivize even more artisanal mining and/or increase the potential payoff from subverting an "ethical" or child labor-free tracking system in an otherwise already corrupt environment.

- More than ample cobalt supplies outside the DRC do exist, but they are deep seabed deposits, estimated to be 5 times the size of total terrestrial resources. This source is currently not economic to mine, and development of the required technology for extraction and environmental measures would require at least 5-10 years, if ever. And while such activities would likely be vehemently opposed if proposed within or near California's jurisdiction, other nations are actively exploring this resource. In particular, China in the same Five Year Plan documents launching its current ZEV policies also includes provisions on deep seabed technology development applicable to both minerals and hydrocarbon production.

- The forecasts reviewed in this study anticipate cobalt production will be sufficient up to the 2022-25 period but with a tightening market after that if not outright shortages, even with the expedited introduction of low-cobalt chemistries assumed in these reports. This conclusion depends on all currently anticipated mine expansions being completed on time, and some level of stability within the DRC. This conclusion also relies on no further acceleration in the national and subnational goals.

- While the academic and policy studies conclude that producers will resolve these shortages by developing even lower-cobalt chemistries, producers actually in the market are instead moving to secure priority access to the available supplies. By going upstream to gain greater control over cobalt mining as well, China-based companies have moved to ensure that nation's electrical vehicle goals will be met and fulfill the climate change, energy security, and economic strategy purposes behind them. And by creating local access to the only metal that now could threaten this future, the center of the electric vehicle industry has moved from California where it was fundamentally created, to the China-based clusters designed to bolster its chances to grow and succeed.

- Recognizing the potential limiting role that could be played by cobalt, China acted early to secure its supply and ensure a predominant share of this battery-critical material would be available to those producers who choose to locate their jobs in China. As China has acted on its strategy, others—often late in the game—have been doing as well including automakers and consumer product firms, with an overall result that the limited current and likely future supplies are increasingly being locked in with long-term buyers. The opportunity for new entrants into the cell market is consequently becoming limited, with the result being to further cement cell production where it is now. While most of the projections anticipate the future is with less cobalt, current players are not acting like it is—securing the available supplies both to launch the electric vehicle industry but also to remain an industry participant over the longer run.

- The recent run up in cobalt prices brought the electric vehicle policies to many investors' attention, but also began to bring a focus to potential supply risks associated with these policies. This price behavior, however, was not new. Most of the recent reporting has focused on price spikes in the last two years. The same degree of extreme price instability can be seen in a longer period trend line, but as the result not of government regulations promoting electric vehicles but of sustained government instability in the DRC.

- With little effective control by the central government over large swathes of the nation, DRC (formerly known as Zaire) has seen an unending period of civil war, civil unrest, and foreign incursions. This situation has frequently led to disruption of mining operations and global supplies. The nation's mineral riches have also been used by the different parties to these conflicts to support their operations, including the many militia groups and national armies operating on DRC soil throughout this period, and have fed rampant corruption that has flourished in these unsettled conditions. This corruption included the systematic looting of the national mining company, Gécamines, which resulted in the actual physical collapse of the Kamoto underground cobalt mine due to the lack of funds for maintenance. The lack of effective government control has also led to widespread human rights abuses in much of the country including unending abominations committed by government forces, foreign forces, rampant militias, and even UN peacekeeper troops ostensibly sent to protect the civilian population.

- Even as global dependence on DRC is growing for the national and subnational policies, civil unrest has escalated as a result of the decision to delay presidential elections by two years. The current President finally announced his decision not to run, leaving voters to decide at the end of December 2018 between the three leading candidates allowed to run—including a current government minister widely seen as a puppet for the incumbent and the leading opposition candidate backed by Jean-Pierre Bemba, former Vice President and formerly-convicted war criminal. In a surprise move widely seen as the result of a deal with the current President, the election commission finally declared that the third candidate had won.

- The current policy reliance on promoting specific vehicle technology carries a range of risks to the California economy. These risks stem primarily from three sources: (1) uses of cobalt in the non-vehicle portions of the economy, (2) systemic risks associated with the dominant cobalt source, and (3) potential cost shifting embedded within California's current regulatory structure.

ZEV Acronyms

As indicated in the sections that follow, the terminology applicable to ZEVs has followed an ever expanding acronymical path. As a guide, some of the most commonly used terms are:

- BEV – Battery Electric Vehicle, powered solely by a plug-in battery system.
- CARB – California Air Resources Board
- EPA – US Environmental Protection Agency.
- EV – Electric Vehicle, generally used to refer to PEVs but can also allude to a wider range of vehicle types including MHVs, HEVs, and electric HDVs.
- FCEV – Fuel Cell Electric Vehicle, generally powered by hydrogen and emitting zero emissions.
- HDV – Heavy Duty Vehicle, including commercial trucks and buses.
- HEV – Hybrid Electric Vehicle, generally referring to hybrids where the battery component is recharged through the ICE power train.
- ICE – internal combustion engine (gasoline fueled vehicles).
- LCO – Lithium Cobalt Oxide Battery.
- LDV – Light Duty Vehicle, primarily passenger cars and trucks.
- LEV – Low Emission Vehicle, under CARB regulations specifying various classes of vehicles including ZEVs with emissions below the national standards set by USEPA.
- LFP – Lithium Iron Phosphate Battery.
- LIB – Lithium-ion Battery.
- LMO – Lithium Manganese Oxide Battery.
- MHV – Mild Hybrids, a form of HEV using an additional battery (moving to 40V) with regenerative braking and series drivetrain primarily to extend fuel efficiency. Some projections further subdivide into Micro Hybrids—similar vehicles equipped with a 12V battery.
- NCA – Lithium Nickel Cobalt Aluminum Battery.
- NEV – New Energy Vehicle, under China's new vehicle regulations, comprising both BEVs and PHEVs.

- NLEV – National LEV, under USEPA and Section 177 states regulations.
- NMC – Nickel Manganese Cobalt Battery.
- PEV – Plug-in Electric Vehicle, covering both BEVs and PHEVs.
- PHEV – Plug-in Hybrid Electric Vehicle, with two power trains running on electricity and conventional motor fuels.
- PZEV – Partial ZEV, under CARB regulations, generally comprising hybrid electric vehicles.
- TZEV – Transitional ZEV, under CARB regulations, generally comprising PHEVs.
- UPS – Uninterruptible power supplies.
- ZEV – Zero Emission Vehicle, generally defined as including both BEVs and PHEVs (which under CARB's ZEV regulations are eligible for full and partial, respectively, ZEV credits) along with FCEVs.

The Battery Economy

While rechargeable batteries have been around since Gaston Planté's invention of a lead-acid system in 1859, this predominant battery chemistry over the next century restricted potential applications to those able to accommodate its lower energy density, high weight, and limited product life. Even so, improvements to Planté's battery soon led to the creation of an electric car industry in the late 19th and early 20th Centuries. The limited ranges, low speeds, and cost restricted the appeal of these early models primarily to upper income households as an urban town car, and they were quickly replaced as advancements enabled mass production of affordable ICE vehicles appealing to a broader range of consumers and business applications.

Over the last 6 decades, commercialization of additional battery chemistries has led to a growing range of portable and mobility product lines, leading to lithium-ion that has enabled an expanding number of electric vehicle models and has the potential to support far more if costs continue to drop and energy capacities continue to rise as now forecast. The following discussion considers the value chain required to serve this evolving market.

Battery Production

Electric vehicles in both the immediate and likely medium terms are generally expected to rely on lithium-ion battery technology. Lithium has the best electrochemical potential among the metals and is also the lightest known metal, allowing production of batteries with much higher energy density and relatively lower weights than other battery chemistries, including those available now commercially and those likely to reach this point within the 2025 – 2030 time period encompassed in the present national and subnational electric vehicle policies. This combination of energy and weight attributes has enabled recent production of BEVs capable of the single-charge ranges of 200 – 300 miles generally considered as necessary to compete with ICE vehicles, while the shorter ranges in prior battery offerings largely limited their use in the earlier HEV models.

Total battery cost is a key element determining the price and therefore consumer acceptance for electric vehicles. Most estimates indicate batteries currently comprise 40 – 50% of the cost of BEVS, and will need to drop to 20 – 25% in order to achieve cost parity with ICE vehicles in the mid-market segment.

Battery production is composed of two primary stages:

- Battery Cells are the working components of vehicle batteries that convert chemical energy into electrical energy. These are generally produced in Asia.

- Battery Packs assemble the cells into the final vehicle battery. For example, Tesla's current 50 kWh battery is reported as containing just under 3,000 cells, with the 100 kWh battery at over 8,200. Other automakers have chosen less complex systems. Because the design of a battery is generally specific to a vehicle model, pack operations are often adjacent to the vehicle assembly. Tesla differs by having its battery operations in an adjacent state having the permit and regulatory flexibility accommodating the compressed timeframes needed to remain competitive, both in the initial build-out and in future modifications as conditions change in this rapidly evolving market. The Nevada Gigafactory also differs from being a partnership handling both stages, with Panasonic assembling the cells and Tesla the battery modules and packs.

Media accounts of battery plant announcements often mix the two. For example, through the beginning of 2018, Europe had at least 7 "gigafactory" scale battery plants planned over the next few years, but these are assembly plants focused on the pack stage and reliant on cells from Asian producers.

Cell production is based on four primary components, each of which is produced by separate specialized suppliers for either the component itself (separators, electrolyte) or the materials inputs (cathodes, anodes). Note that the cathode metals are used in a form such as hydroxides, sulfates, and carbonates, but most analyses measure demand and supply on a metal basis. Lithium, on the other hand, is more generally measured in terms of lithium carbonate equivalent (LCE) rather than the metal.

- Cathode is the positive electrode containing lithium and other metals. The chemistry used will affect a battery cell's weight, energy density, power density, safety, durability, and cost. Cobalt provides high reactivity. Nickel can increase energy density substantially, but presents safety issues that must be handled by other metals such as cobalt. Manganese is cheaper than cobalt, but dissolves slowly in electrolyte and thereby has a shorter effective life. Other materials such as aluminum are used in combination with the others to achieve a balance between the various metal attributes required for individual applications, while various monitoring and control systems in the battery pack and vehicle provide flexibility as well. Production of the cathode involves combining the selected metals in powder form with a binder and using this slurry to coat a metal foil (aluminum). Many current efforts to reduce battery cell production cost focus on this component and the mix of metals being used.

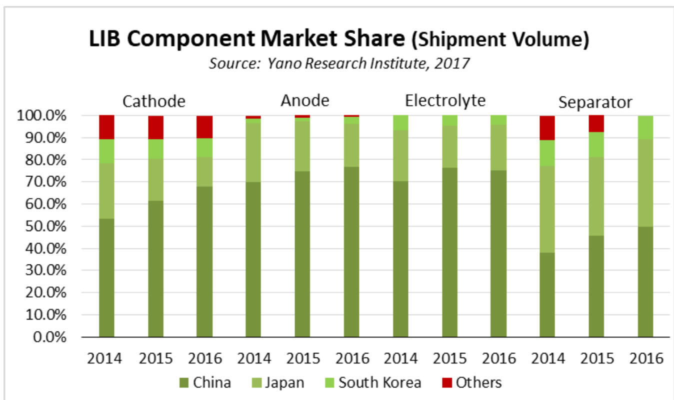
- Anode is the negative electrode containing some form of carbon, currently with graphite as the dominant material. The carbon is combined with a binder and the anode produced by coating another metal foil (copper).

- Separator is a thin semi-permeable layer generally made from plastic with a ceramic coating. The separator keeps the two electrodes from connecting and short-circuiting, while the permeability allows for the ion flow. Separators can also act as a fuse if batteries overheat, as the plastic melts, closes the pores, and shuts down the connections. The importance of this component to safety is illustrated by the Samsung Galaxy Note 7 problems in 2017 which were the result of too-thin separators that caused the batteries to fail. Although the material inputs are widely available, the high level of technical expertise required to produce separators with the necessary specifications for electric vehicle batteries has concentrated supply within the producing Japanese companies.

- Electrolyte is comprised of lithium salts in an organic solvent and other additives providing a pathway for ions to travel between the two electrodes.

Battery cells are generally produced by stacking (pouch and prismatic cells) or wrapping (cylindrical cells) layers with the separator between the two electrodes. Additional connections, terminals, vents, and safety devices are incorporated into the final case, and electrolyte is introduced before sealing. Tesla is the major electric vehicle producer using cylindrical cells (made by Panasonic), while other automakers rely on pouch or prismatic cells. Consumer products and other battery application use all three cell types, along with a fourth, nonrechargeable button/coin cell also used extensively in medical, consumer, and other one-time use or replaceable applications.

While some capacity to produce these battery cell components is located in the US and to a lesser extent in the EU, primary production for lithium-ion batteries is concentrated to a high degree in the East Asia countries of China, Japan, and South Korea. As shown in the chart below, product shipments in 2016 from East Asia were estimated at 99 – 100% for anodes, electrolyte, and separators and 90% for cathodes. These figures account for companies such as Umicore which is EU-based but which has their production facilities in South Korea.



Estimates vary but generally place cells at about 60% of the total battery cost in 2015, growing (as total costs are expected to drop) to about three-quarters of cost in 2025 and 2030. Most analyses indicate that most of the potential cost reductions required for a broader electric vehicle market lie in the non-material costs related to production efficiency and the pack process, especially as production consolidates and reaches scale economies. However, these projections of future battery price declines also rely heavily on the cell component costs, in particular if cobalt is economized in future chemistries and through fewer production quality rejects as both pack and cell production are scaled up and standardized.

Countering these cost reductions on a per kWh basis will be the continuing need to increase range and reduce recharging times. While batteries are projected to become more cost efficient on a unit kWh basis, their total share of vehicle cost will remain significant due to these two consumer factors.

Battery Types

The current range of lithium-ion battery types are generally defined by their cathode chemistry:

- Lithium Cobalt Oxide (LCO) is used extensively in consumer electronics. Earlier electric vehicle applications have included Tesla's Roadster model, Nissan Leaf, and BMW i3e.

These batteries have the high energy density required for consumer products, but the high cobalt content, lower safety, longer recharging times, and lower cycle life have limited their use more widely in vehicles.

- Lithium Iron Phosphate (LFP) has very high safety (including tolerance for misuse during operation) and long cycle life (but with higher self-discharge rates as the battery ages), high power density but lower energy density, and fewer intellectual property protections than the other technologies. These attributes made LFP the target of early subsidies in China, enabling it to gain ground quickly for buses and other HDVs. The shift in these subsidies to NMC, however, has affected the overall vehicle use for this chemistry. The various projections discussed later vary widely on the assumptions concerning this cathode type, ranging from those that see it being largely phased out by 2030 to those seeing additional applications particularly through increased applications for HDVs. Other applications promoting its use now and potentially in the future include power tools and providing a replacement to lead-acid starter batteries.

- Lithium Manganese Oxide (LMO) is a more mature technology used in early hybrids along with medical applications and power tools. These batteries have high safety and overall moderate cycle life and can be optimized for either cycle life, maximum load, or high capacity with most applications seeking a balance between the three. Current LMO products generally blend with other cathode chemistries to improve energy density and cycle life.

- Lithium Nickel Cobalt Aluminum (NCA) was one of the first successful efforts to replace cobalt with nickel, and is used in Tesla models and consumer products. Very high energy density and long cycle life but lower safety margins that are controlled through other systems in a vehicle.

- Lithium Titanate (LTO) is named from the anode chemistry which replaces graphite more generally used in lithium-ion batteries. LTO has much higher safety, faster recharging, and longer cycle life but at a higher cost and lower energy density. These attributes limit its use more to uninterruptible power supplies (UPS), solar powered lighting, and similar applications.

- Nickel Manganese Cobalt (NMC) is the primary chemistry used by other automakers, and continued development is leading to growing use for other transportation applications as well including two- and three-wheelers and low speed EVs. Increasing the nickel content improves energy density but decreases thermal stability, manganese improves stability, and reducing cobalt improves the cost. Although other chemistries are used or in development, these batteries generally are classified NMC 111, NMC 622, and NMC 811, with the number indicating the relative proportion of nickel-cobalt-manganese.

Currently, none of the predominate battery types has more than a third of the total market. The different brands of EVs differ in their battery needs, and individual automakers have designed their models around individual battery packs produced for an individual company or model. In the energy storage market, batteries have different space and weight constraints depending on where they are used.

NCA is used extensively in Japan and US, primarily due to the current roles played by Panasonic and Tesla. NMC is the primary technology elsewhere. While the less expensive LFP was previously used extensively in China, especially in commercial EVs, the 2017 change in China's subsidies to apply to NMC has resulted in a rapid shift away from LFP to NMC.[2]

Other battery chemistries remain under active development, both in the continued search to reduce cost by replacing cobalt but also to address other features of current battery technology that affect consumer acceptance of ZEVs including recharging speed, range, and safety. These potential technologies include Lithium-Sulphur, Lithium Air, High Voltage Lithium-Ion, Solid State Lithium-Ion, Sodium-Ion, and Zinc-Air. None has yet to reach the stage required for large-scale manufacturing, and most technologies still represent a trade-off rather than simultaneous attainment of the required consumer preference factors of lower battery cost (to reduce vehicle cost), shorter recharging time, and increased range (through higher energy density).

While these new technologies may offer growing contributions beginning around or after the current policy timeframe through 2030, the aggressive schedules envisioned in those policies—especially in China and in California—mean in practice the current lithium-ion chemistries will retain most if not all of the market. While product line adjustments will always be possible, investments must be made in the next few years to remain in compliance with the policy sales requirements, and these decisions for core production line capacity of necessity will be made around the current and foreseeable commercially viable technologies. Similarly, given the length of the product development cycle, core vehicle model lines to comply with national and subnational policies are undergoing design now and in the next few years. Built around specific battery types and packs, these designs as well must be guided by what appears now on the commercial horizon. While other battery chemistries are possible, the relevant policies and regulations as they are now structured in essence mandate that compliant products will rely on those summarized above.[3]

Consequently, the projections reviewed for this report of necessity—as a result of the scale and pace of the associated vehicle policies—assume that the chemistries summarized above will remain dominant in the coming 2025-30 compliance period. The projected raw materials use and potential related risks fall out from this structure as well.

Production Capacity

The concentration of lithium-ion cell production in East Asia is the result of explicit economic policies. Japan first pursued a "supply chain cluster" approach in the 1990s with government assistance in the form of R&D and low cost capital to create clusters of suppliers in close proximity to final cell production for the evolving consumer electronics market. These clusters encompassed the full range of supply from raw materials processing to the final pack stage. This strategy was then continued in South Korea through joint industry/government efforts. China—through government R&D, tax incentives, investment incentives, domestic content requirements, and export constraints—subsequently targeted lithium-ion cells both through development of domestic companies and through location of Japanese and Korean facilities in China. China has since

[2] International Energy Agency, "*Commentary: Who Wants to be in Charge?,*" News, November 21, 2017.
[3] e.g., "*Cobalt Cannot be Eradicated from Electric Car Batteries – Unicore,*" Basic Materials, February 12, 2018.

extended the cluster approach by seeking to secure priority access to battery critical raw materials as well, as discussed later in this report.

This cluster approach has several cost efficiencies. The close proximity of the entire supply chain reduces costs related to areas such as production planning, transport, inventory, and coordinated capacity expansion. Integration at the group level also provides additional supply chain advantages including product development and supply priority that are not always available to outside buyers. For example, battery manufacturers and procurement managers in the EU recently have raised concerns over the reliability of battery cell supplies, especially smaller companies who have seen cancellation or delay of orders as shipments are instead diverted to sales in China.[4] Last December, rumors began circulating—and driving up consumer product cell prices—that production problems were cropping up at Tesla's Gigafactory due to uneven energy supply (the facility is powered by wind and solar) and labor shortages. The unconfirmed reports indicated Panasonic resolved the cell shortages by redirecting production from Japan to Tesla, creating subsequent shortages and price increases for other users of cylindrical cells such as power tools, electric bikes, cordless consumer products, consumer electronic products, and power banks.[5] Other analysts were unable to confirm this situation, however.

These cluster efficiencies have enabled manufacturers in East Asia to produce cells at much lower cost, providing cost advantages both directly from cell production and from component savings for the domestic automakers using them in vehicle production. Other countries seeking to develop a competitive battery supply face the challenge of not only creating cell production capacity but as well replicating the fully supply clusters that now exist in these countries. Building a domestic battery cell capacity in any country no longer means simply constructing one facility, but replicating the entire battery value chain that now operates in East Asia. [Clean Energy Manufacturing Analysis Center, 2016]

For example, Tesla is now on track to expand greatly US cell production capacity through its Nevada Gigafactory. However, rather than create a full supply cluster on its own, Tesla tapped into an existing one through its partnership with Japan's Panasonic.

The EU has long sought, so far without success, to develop a lithium-ion battery consortium (similar to Airbus) to support its electric vehicle goals, with the most recent scaled-down proposal for the EU Battery Alliance released in February.[6] For individual companies, Daimler exited the home power storage market,[7] and turned instead to developing a network of battery pack plants for their vehicles, reaching agreement with China-based Contemporary Amperex Technology Ltd (CATL) to provide the battery cells.[8] Bosch previously had intended to develop cell capacity serving the full

[4] "*Leading Battery Manufacturers Warn of Possible Shortage,*" Electrive.com, February 9, 2018.
[5] "*Problem with Gigafactory Leads to Global Shortage of Cylindrical Batteries,"* ETNews, December 6, 2017.
[6] "*European Union Battery Alliance Lays Out Plans for Lithium Ion Battery Industry*," Manufacturing.net, February 26, 2018.
[7] "*Mercedes-Benz Exits Home Battery Market*," Green Tech Media, April 30, 2018.
[8] "*Daimler to Buy EV Battery Cells from Chinese Upstart CATL*," Automotive News Europe, May 2, 2018.

German auto industry, but withdrew earlier in 2018 after concluding it could not compete with lower cost Asian competitors.[9] Instead, BMW recently announced an agreement for $4.7 billion worth of battery cells from CATL.[10] CATL also recently announced a 14 GWh cell plant to be located in eastern Germany,[11] the first lithium-ion cell production in Europe for electric vehicles and a facility that is likely to disrupt the economics of any EU-based companies seeking to compete in this market.

Total lithium-ion cell production capacity by country is summarized in the table below, including current, under construction, and commissioned capacity as of 2017. The 2022 numbers further incorporate current announcements—including the EU Battery Alliance expectations—and consequently do not necessarily reflect capacity that will actually be built. Other estimates make adjustments for projects that are less likely to be realized. For example, Bloomberg New Energy Finance (2018) shows somewhat lower cell capacity, at 131 GWh in 2018 (commissioned, with no capacity shown as under construction) and 406 GWh in 2021 (including just over half as announced).

EV & Energy Storage Lithium-Ion Battery Cell Production Capacity (GWh)

	2010	2016	2017	2022
China	9	69	145	373
Asia-Pacific*	5	31	31	57
North America**	1	11	18	46
Europe	0	3	4	41
Other	0	0	0	79
Total	*15*	*114*	*198*	*596*

Source: IEA [2017]
*Notes: *Primarily Japan/South Korea;*
***Growth primarily from Tesla Gigafactory (35 GWh cells/50 GWh packs by 2020)*

As indicated in the table, China contained 73% of world capacity in 2017, with East Asia holding 89%. By 2022, China will still retain 63% and East Asia 72%, but at higher levels if production announced for Europe and other countries is not fully built. Capacity announced for China has a relatively higher probability of being completed, in part due to access to both national and local subsidies. For example, the Bloomberg (2018) numbers show greater concentration, with China at 73% and East Asia at 83% in 2021.

Despite $2.4 billion in grants under the federal American Recovery and Reinvestment Act to develop a US battery cell capacity, there are primarily 5 major companies producing cells in the US. A123 (owned by China's Wanxiang Group) has already announced it will cease production here by 2020. Johnson Controls, LG Chem (South Korea), and A123 have announced capacity plans for Europe and China, but not in the US, while the primary domestic capacity expansion is currently slated to come from Tesla. XALT Energy announced layoffs in 2017 after Los Angeles Metro awarded its electric bus contract to China-based BYD instead of a US-owned provider. While BYD

[9] "*Will Europe Make Its Own e-Car Battery Cells?,*" Deutsche Welle, April 10, 2018.
[10] "*BMW Agrees $4.7 Billion Contract with China's CATL for Battery Cells,*" Wall Street Reporter, August 7, 2018.
[11] "*Chinese-German Battery Cell Deal Key Step for Mobility Transition*," Clean Energy Wire, July 10, 2018.

has located a facility in California to assemble these buses,[12] XALT maintained that China's heavy subsidy levels gave them an unfair advantage in the contract bidding. [13]

Acceleration of capacity in China has been the result of these high subsidy levels for battery cell production along with other restrictions favoring domestic producers, with more than 40 domestic manufacturers in 2017. These include both start-ups and existing companies entering the industry primarily because of the high subsidy levels such as former apparel maker, Ningbo Shanshan, which has now moved into making anode materials.[14] This rapid capacity expansion in China has already produced some retrenchments elsewhere comparable to the recent solar panel experience, particularly in the lower technology components of the battery value chain. For example, Ube Industries of Japan previously produced about half of the commercial electrolyte market, but in 2016, consolidated its Chinese production with Mitsubishi Chemical in response to continuing losses.[15]

China's industry is currently going through a rapid concentration. Draft guidelines issued in 2016 announced that battery cell makers must have total capacity of at least 8 GWh in order to qualify for continued subsidies in the future. Currently, only CATL and BYD can meet this level, although other producers may be on track to reach this point and beyond as the industry consolidates. The result, however, is the shift to much larger companies who are dependent on securing sales share, both to secure their future operations and continue access to national and subnational subsidies.

Repeating the Solar Panel Experience?

While Gigafactory level additions are required to keep pace with the ambitious goals in the national and subnational policies discussed in the next section, the timing of this growth also has potential implications to both prices and the ability of current nonplayers to enter and compete in this market in the future.

These battery supply additions in large increments raise the risk of large differences between supply and demand as both the battery cell and electric vehicle industries gear up on separate schedules. Between 2011 and 2016, sales of electric vehicles fell short of expectations while investments in battery cell capacity of necessity moved forward. Global cell capacity utilization is estimated at only 22% in 2014 and around 40% in 2016, resulting in downward pressure on battery prices as producers jockeyed for sales. While declines in battery prices have also come from material cost and

12 "*Stalls, Stops and Breakdowns: Problems Plague Push for Electric Buses,*" Los Angeles Times, May 20, 2018.
13 "*More Job Cuts at Battery Maker XALT Energy in Midland, Pontiac*," Michigan Live, August 23, 2017.
14 "*China's Lithium-ion Battery Makers Devour Foreign Rivals,*" Nikkei Asian Review, September 19, 2017.
15 Ube Industries, Ltd., "*Ube Industries and Mitsubishi Chemical Announce Tie-Up for Electrolyte Business in China*," press release, October 13, 2016.

production efficiencies, at least some of the observed price trend is the result of these oversupply conditions.[16,17] Other analyses indicate many battery cell makers have been selling at or below their costs of production in recent years.[18,19]

Battery cell capacity additions have since continued to outpace electric vehicle sales. This oversupply will likely continue to depress battery prices, a factor that should improve prospects for future electric vehicle sales but one that may also lead to greater concentration and thereby reliance on East Asia for this power source.

The current situation risks becoming analogous to the recent experience with solar manufacturing. In the euphoria accompanying national and subnational policies requiring greater reliance on alternative energies, many countries—along with California as well—targeted solar panels as a strategic economic goal and a means to defray the economy-wide costs of this energy shift through new manufacturing jobs. As with battery cells, panel manufacturing capacity was promoted or begun in many areas, but was heavily subsidized in only a few, especially in China, a situation that also ended in creating a substantial global oversupply as Chinese producers pursued subsidies as much or more than profits from operations. In seeking to dominate the market, China producers were able to rapidly expand capacity, lower costs, and cause prices to drop by 70%.[20]

The resulting price competition driven more by the need to maintain or expand market share in the hopes of remaining a survivor capable of long-term profitability led to severe concentration in the market. In 2009, domestic production accounted for 42% of panel shipments in the US, but by 2013 the data was no longer reported due to the small number of producers left in the country. By 2017, imports accounted for 92% of US shipments.[21] Panel manufacturing in areas such as the EU suffered the same outcomes as well.

With the possible exception of producers such as Tesla and BYD that have vertically integrated cell production with vehicle production, the current and looming period of likely oversupply favors those with access to subsidies or deep-pocket financing capable of surviving a period of low or negative profitability. But other investments will be at risk from a repeat of the solar panel pricing cycle.[22] China producers are well placed to cope with this disruption with subsidies that promote scale to survive. US and European manufacturers may have options through up front negotiations

[16] Clean Energy Manufacturing Analysis Center, 2016.
[17] "*Lithium-ion Battery Costs: Squeezed Margins and New Business Models,*" Bloomberg New Energy Finance, July 10, 2017.
[18] US Department of Energy, Office of Strategic Programs, Cost and Price Metrics for Automotive Lithium-Ion Batteries, February 2017.
[19] Bank of America and Merrill Lynch, Global Electric Vehicle Primer: Fully Charged by 2050, October 4, 2017.
[20] *"Electric Cars: China's Battle for the Battery Market,"* Financial Times, March 5, 2017.
[21] US Energy Information Administration, Annual Solar Photovoltaic Module Shipments Report, various years.
[22] "*Hard to Invest in Batteries When Prices Keep Plummeting*," Wall Street Journal, December 4, 2017.

on tax relief and expedited permitting that allows them to get quickly into the game. But within this structure, California doesn't even get to the starting line for jobs in an industry it basically created.

China also appears to be using its industrial policies to ensure that the survivors of this cycle will largely be Chinese owned. Anticipating China as the center of the emerging electric vehicle market, South Korea's LG Chem in 2015 opened a battery cell plant in Nanjing, and Japan's Samsung did as well in Xian, declaring the company would "forge its foothold in the world's biggest new energy vehicle market." In 2016, a list of producers allowed to sell vehicle batteries within China contained neither firm nor any other foreign-owned producer. In 2017, draft guidelines stated that only producers with capacities over 8 GWh would be eligible for subsidies, a level that only China-based BYD and CATL are expected to meet.[23]

Further concentration within the current cell producing countries in East Asia also becomes more likely as they continue to secure not only the production capacity, but also a high level of control over the battery critical raw materials as well—a topic discussed further in the sections below.

As indicated above, this cycle is already being seen as established producers such as Ube Industries have already hedged their risk to reduce losses, and by established vehicle parts makers such as Bosch who have reassessed the market conditions and shelved their plans to engage.

The fuel efficiency and vehicle emission standards have long been promoted in part on their role in promoting national energy security—replacing imported oil with presumably more secure domestic electricity supplies. At a time when the nation is now far closer to its energy goals through the increase of domestic supplies across the board—oil, natural gas, and alternatives as well—the vehicle policies now carry the potential to reverse this progress altogether. With a few outliers such as Tesla's Nevada facility, the core element for the energy policies on which California has now staked its economic future appears to be heading towards a far greater reliance on imports than any energy source in the past.

Of more importance to fulfillment of the current ZEV policy goals, the current cycle is seeing creation of a battery cell capacity surplus that most analyses indicate will continue to put deflationary pressures on battery cell prices at least through the 2020-22 period. Moving into 2025, most analyses see tighter market conditions as demand comes more into balance with capacity, weaker players—particularly those without access to subsidies and the battery critical raw materials—fall by the wayside, and the battery critical raw supply constraints discussed later in this report start coming into play. The policy risk is that these conditions could arise just as consumer acceptance of ZEVs is improving, affecting in particular the more battery-intensive BEVs and potentially stalling ZEV introduction outside China at the HEV stage. This outcome is less likely to occur in China, which has taken the steps to secure capacity throughout this cycle and instituted the controls to ensure first priority for domestic consumption.

[23] "*Electric Cars: China's Battle for the Battery Market*," Financial Times, March 5, 2017.

Battery Uses: ZEVs

Beginning with their commercial introduction in 1991, lithium-ion batteries have grown in importance as a critical component of an increasing range of products in both developed and developing economies. These batteries have served to boost growing demand in the marketplace for products as diverse as cell phones, tools, and household appliances. Public policy in California, the US, and a growing number of other countries is now set to drive an accelerated spike in lithium-ion battery production along with related growth in the component supply chains.

Growing sales of electric vehicles will be a primary—but by no means sole—factor pushing demand for lithium-ion batteries over the next few decades. Current growth remains largely driven by government mandates and subsidies tailored to promote ZEV technology, however, with consumer-driven acceptance alone still not at levels required to support the vehicle sale levels envisioned in California's current policies or others'.

Regulatory Drivers

Regulatory mandates for ZEVs began in California primarily for clean air purposes, later moving into direct government intervention to subsidize and expand sales as a result of the state's climate change programs. Comparable actions by other states and nations have followed the same general policy path, but in recent years, the policy framework has begun to be augmented if not led by other factors such as economic security and industrial policy in countries such as China.

California ZEV Policies

California has had some form of ZEV mandate in place since 1990. These rules, however, since have been modified several times primarily in response to periodic findings that the technology development required to produce ZEVs at reasonable costs was not keeping pace with the original deadlines. The program has also changed focus substantially, moving from an air quality to climate change policy purpose. The key steps include the following:

- AB 234 (Leonard, 1987) created an Advisory Board on Air Quality and Fuels to develop incentives to facilitate use of alternative fuels. This program, along with related early policies to promote ZEVs and other alternative energy vehicles, was driven in large part by both state and national policies seeking greater energy independence in face of growing oil imports.

- AB 2595 (Sher, 1988) created the California Clean Air Act, giving the California Air Resources Board (CARB) the authority to adopt any "technologically feasible" standards for vehicles and fuels.

- California's first mandates for ZEVs stem from the LEV I (low emission vehicles) regulations adopted by CARB under its air quality strategies in 1990. A footnote to these rules required that each manufacturer of light-duty vehicles offer for sale—but not necessarily sell—at least 2% ZEVs from 1998 to 2000, 5% in 2001 and 2002, and 10% every year after.

- Federal Clean Air Act Amendments of 1990 preserved California's authority to set its own vehicle emissions standards for clean air purposes, subject to approval of a waiver from US Environmental Protection Agency (USEPA). The other 49 states retained the option to follow either the national emissions standards adopted by USEPA or California's—in full as subsequently clarified by the courts—as approved by USEPA through their state implementation plans.

- A review of current technology by a Battery Technical Advisory Panel in 1995[24] concluded that lithium-ion or other advanced batteries necessary for consumer acceptance would not be available at cost-effective levels until sometime around 2010. Accordingly, the ZEV requirements were modified in 1996 to eliminate the interim ZEV requirements, allow credits against the 2003 standard for ZEVs sold prior to that date, and commit the seven major auto manufacturers to a voluntary National LEV (NLEV) program for early introduction of LEV vehicles nationwide. The NLEV program was voluntary—but required an enforceable agreement between the manufacturers and the other adopting states—due to Federal Clean Air Act restrictions on USEPA's ability to adopt new mobile source emission standards prior to 2004.

- CARB adopted the LEV II regulations in 1998, tightening emission standards for other vehicle classes but primarily revising the credit provisions for ZEVs to incorporate Partial ZEVs (PZEVs).

- A second expert panel technical review in 2000[25] concluded that while nickel-metal hydride (NiMH) batteries were being used successfully in some applications, lithium-ion and other advanced batteries required for increased range and lower unit costs were still several years away from mass production. Additional rule revisions were adopted in 2001 but were put aside under an injunction and subsequent settlement agreement to revise the requirements more in keeping with the then-current level of technology. The 2003 revisions under the agreement reset the requirement for large manufacturers at 11% ZEVs (measured by credits rather than vehicles) starting in 2009, increasing to 16% in 2018 along with specified options to apply credits through various PZEV levels (including hybrids to reflect technology development in the industry) to comply with these mandates.

- AB 1493 (Pavley, 2002) gave CARB the authority to adopt regulations to achieve "*maximum feasible reduction of greenhouse gases emitted by passenger vehicles and light-duty trucks and any other vehicles*

[24] Battery Technology Advisory Panel, Performance and Availability of Batteries for Electric Vehicles: A Report of the Battery Technical Advisory Panel, California Air Resources Board, 1995.
[25] Year 2000 Battery Technology Advisory Panel, Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost, and Availability, California Air Resources Board, May 2000.

determined by the state board to be vehicles whose primary use is noncommercial personal transportation in the state." The implementing regulations—which do not address the ZEV compliance dates directly—were adopted in 2004.

- A third expert panel technical review[26] concluded that NiMH batteries were likely to remain too costly but lithium-ion technology was developing rapidly. Full commercialization of BEVs was projected for 2030 and beyond, but HEVs were already at that stage and PHEVs were expected to be by 2015. Rule revisions in 2008 further changed the credits by adding various ZEV classes and modifying other credit values, but retained the target date levels.

- CARB adopted the LEV III regulations in 2012 under its Advanced Clean Cars program, addressing both priority air pollutants under the Clean Air Act and greenhouse gas emissions under AB 1493, the AB 32 (Nunez, 2006) climate change program, and the related executive orders. As stated in the 2009 CARB resolution directing staff to develop these revisions,[27] the program at this point became less directed by outside evaluations of ZEV technological feasibility. Instead, ZEV requirements shifted to what was needed to meet the climate change program targets set administratively in Executive Orders[28] and to move toward the CARB staff conclusion that to meet these administrative targets *". . . ZEVs will need to be 100 percent of new vehicle sales no later than model year 2050.*"[29]

  Following subsequent regulations on various vehicle credits and other issues in 2013 and 2014,[30] the current ZEV requirements applied to the large and intermediate volume manufacturers now require them to show ZEV credits equal to 22% of light vehicles "*produced by the manufacturer and delivered for sale in California*" by 2025 and in subsequent years. The amount of credits applied to individual models generally vary by vehicle technology and range. For large volume manufacturers, at least 16% of the credits must be from actual ZEVs, while the remainder can be provided through transitional ZEV (TZEV) credits. Due to how the ZEV credits are calculated, the actual number of vehicles required to be offered

[26] Independent Expert Panel, Status and Prospects for Zero Emissions Vehicle Technology, Report of the ARB Independent Expert Panel 2007, California Air Resources Board, April 2007.
[27] CARB, Resolution 09-66, December 9, 2009.
[28] Executive Order S-3-05 administratively set a 2050 greenhouse gas emission target at 80% below 1990 levels. This level was repeated in Executive Order B-30-15, which also set an interim target of a 40% reduction by 2030. The 2030 target was codified by SB 32 (Pavley, 2016), but not the 2050 level.
[29] CARB, Resolution 09-66, December 9, 2009. Based on modeling, the staff conclusion was later revised as requiring ZEVs to be at 100 percent of new vehicle sales between 2040 and 2050 in order to meet the 2050 climate change target (CARB, January 2017, p. ES-34).
[30] Other changes proposed in 2015 were withdrawn prior to adoption.

for sale in 2025 will be lower than 22%, and based on staff calculations in the regulatory documents, closer to 15% of vehicles offered for sale.

- With some revisions, the LEV III provisions where substantially confirmed in a Mid-Term review[31] mandated in the regulations, with the review components applicable to 2021-25 model years done jointly with the federal agencies. While these rules remain under question pending resolution of the proposed USEPA actions on California's waiver, CARB in March 2017 voted to move forward with its standards under the applicable waiver issued in 2013. USEPA's recently proposed waiver withdrawal would apply to the Advanced Clean Car program, ZEV mandate, and Greenhouse Gas standards for model years 2021 through 2025 and not the state's other waivers under the Clean Air Act.[32] The withdrawal is also within a proposed rulemaking, and still is not final as a result of the administrative process and likely litigation on this issue.

- Specific vehicle targets under the climate change policies were established administratively in Executive Orders B-16-2012 (1.5 million ZEVs "*on California roads*" by 2025) and in B-48-18 (5 million ZEVs "*on California roads*" by 2030). Subsequent tracking by the agencies has interpreted these targets to mean total sales—rather than actual vehicles still operating in California—in these periods, including both true ZEVs (BEVs and FCEVs) and PHEVs that operate on both batteries and conventional motor fuels. Subsequent ZEV Action Plans [Governor's Interagency Working Group on Zero-Emission Vehicles, 2013 and 2016] outline strategies to reach these targets through both direct and indirect (e.g., regulatory and recharging infrastructure) subsidies benefiting producers of this technology.

One key change in this policy evolution is that at least in the initial stages, both the LEV program overall and ZEV components as well were designed to be "fuel neutral," namely that they were standards-based without giving preference to any individual technology. While CARB has long anticipated that battery technology would be the dominant compliance path at least in the foreseeable timeframe, the program at various points has embraced other technologies including a focus on hydrogen and fuel cells throughout much of the LEV I and LEV II stages. The shift to accelerated sales targets along with decisions to invest public and utility ratepayer dollars in the associated recharging infrastructure has in essence resulted in a state mandate for the use of battery technologies as the current, most likely viable technology. This outcome drives many of the projections on raw materials use discussed later in this report.

<u>Other States</u>

Aside from state credit/rebate programs similar to those in California and at the federal level, a number of other states have adopted comparable regulatory policies concerning ZEVs:

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[31] CARB, California's Advanced Clean Cars Midterm Review, Summary Report for the Technical Analysis of the Light Duty Vehicle Standards, January 2017.

[32] US EPA and National Highway Traffic Safety Administration, "The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light Trucks," Notice of Proposed Rulemaking, August 2, 2018.

- Currently, 12 states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Vermont, Washington) and District of Columbia have adopted the California vehicle emission standards ("Section 177 States"). Combined with California, these states comprise about 35% of the national light duty vehicle market. Actual ZEV penetration in these states has been significantly lower than in California due primarily to the fact that through 2017, "travel" credits in the ZEV regulations were available to demonstrate compliance within these states as a result of ZEVs bought and used in California.

- In 2013, the Governors of California and seven of the Section 177 states signed an MOU stating a goal of at least 3.3 million ZEVs "*on the road in our states*" by 2025. As of 2017, California was the only state appearing to be on track to meet those commitments [Next 10, 2017].

- In June 2018, New Jersey joined with the other MOU states on a Multi-State ZEV Action Plan to reach the ZEV goal components applicable to the years 2018 – 2021.

In addition to these specific policies, regulatory credits also serve to subsidize the growth of some ZEV sales. As indicated, manufacturers producing more than their mandated level of ZEVs can sell compliance credits to other companies needing to demonstrate compliance in California and the Section 177 states. More broadly in a regulatory double-dip, ZEVs also produce credits that can be sold for purposes of compliance with the national CAFE (Corporate Average Fuel Economy) standards. For example, Tesla—one of the few companies to identify this revenue stream separately—shows $1.3 billion in total regulatory sales revenue in their 10-K filings for 2010 – 2017. As consumers continue to shift their buying preferences to light duty trucks,[33] ZEV sales will also continue to be driven in part by these regulatory subsidies paid by non-ZEV consumers through higher prices on conventional fuel vehicles.

<u>Other Countries</u>

A number of nations have announced specific ZEV targets, for instance those from the UK[34] and France[35] stating their intent to ban gasoline and diesel vehicles by 2040. However, most of these policy statements have been in the form of proposed targets, with only a relatively few such as in

[33] Most recent data from California New Car Dealers Association shows light-duty trucks were 64% of US sales (51% of California) in 2017, up from 60% US (47% California) in 2016.
[34] "*Plan to Ban UK Petrol Diesel and Hybrid Cars Watered Down to 'Mission',*" Financial Times, June 18, 2018.
[35] "*France Plans to End Sales of Gas and Diesel Cars by 2040,*" New York Times, July 16, 2017.

Ireland[36] and Taiwan[37] incorporating the necessary provisions to reach these goals or announced as part of an overall energy strategy such as Israel's[38] actions to move to increased reliance on domestically produced natural gas to fulfill 80% of its power needs. Others such as in Germany[39] and India[40,41] have acknowledged their targets will not be met or have pulled back after the initial announcements to reconsider how to move forward. More complete policy frameworks such as those in the Scandinavian countries have had a more immediate effect.

The strongest policy measures promoting this technology have come from China, most recently in its 13th Five Year Plan in 2016 (and related Strategic Energy Action Plan), which set a goal of 5 million more ZEVs in the period 2016 – 2020. Along with specific targets for related charging infrastructure in the Plan, the resulting New Energy Vehicle (NEV) regulations issued at the beginning of 2017 are intended to replace the current vehicle purchase subsidy system[42] (which is to be phased out by 2021). The regulations apply only to passenger vehicles manufactured or imported for sale within the country, and combine NEV credit targets (10% of sales in 2019 and 12% in 2020) with increasing Corporate Average Fuel Consumption (CAFC) requirements. The new rules apply to automakers with domestic sales of 30,000 vehicles or higher. Producers subject to the rule with a NEV or CAFC deficit must achieve compliance through the NEV credits, which vary by vehicle technology, range, and efficiency. Similar to California's ZEV credit system, the details of the credit interactions are expected to produce a lower share of actual vehicles, or about 4% of sales in 2020 compared to the 12% credit requirement. [International Council on Clean Transportation, 2018]

Going beyond environmental to industrial policy, the Five Year Plan also contains actions to position China as the dominant producer of ZEV vehicles and components (including batteries) as

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36 "*Ireland 2040: €22bn to Turn State into Low-carbon Economy,"* Irish Times, February 16, 2018.
37 "*Cabinet Proposes to Ban Sale of Nonelectric Vehicles,*" Taiwan Today, December 22, 2017.
38 "*Energy Minister Calls for Banning Diesel, Gas-based Cars in Israel by 2030*," Jerusalem Post, February 27, 2018.
39 "*Merkel Concedes that Germany Will Likely Miss the Government's Target of 1 Million EVs on the Road by 2020,*" Autovista Group Daily Brief, May 16, 2017.
40 "*India's Electric Vehicle Sector is Finally Sorting Out the Basics,*" Quartz India, April 17, 2018.
41 "*The Indian Government Isn't Ready to Walk the Talk on Electric Vehicles,"* Quartz, February 21, 2018.
42 Current national subsidies range from about $3,000 to $6,700 a vehicle, with local government subsidies adding another 15% to 50% to the amount. While HEVs continue to be eligible to provide credits under the NEV system, national subsidies were canceled in 2013, and the focus shifted to BEVs both for subsidies and purchase quotas in certain cities. Other non-monetary subsidies also are used. For instance, Beijing and other cities limit the number of vehicle licenses. Beijing may get 3 million applications for the 3,000 licenses available in each monthly lottery. EVs are exempt from this process and are guaranteed a license. NEVs also not subject to driving ban days.

part of the country's economic strategy. These actions have enabled China to take over a role California largely abrogated by failing to enact policy reforms necessary to match its policy goals in this area with actual manufacturing capacity and jobs beyond what is now largely centered on the Tesla Fremont plant. [California Center for Jobs & the Economy, 2018, pp. 39-42]

While addressing climate change, the NEV policies are also intended as key policy elements related to China's pressing air pollution problems and energy security goals. The Five Year Plan also contains strategies to expand domestic energy supplies to lessen its dependence on imported oil (over two-thirds of crude oil use in 2017[43]). In order to achieve all four policy purposes—climate change, air quality, industrial, and energy security—and facilitate the NEV expansion, the related Energy Plan calls for a greater shift to domestic energy supplies through additions (compared to 2015) of: 150 GW wind and solar, 60 GW conventional and pumped storage hydroelectric, 30 GW nuclear, and no more than 200 GW coal.[44] Additional actions within these documents call for major expansion of biofuels, shale gas, shale oil, coal bed methane, and other unconventional oil and gas resources along with deep seabed technology development applicable to both minerals and hydrocarbon production.

The NEV program also is not China's only vehicle strategy to address these policies. Similar to other Asian nations, China has made a major push on natural gas vehicles. As of January 2018, China had 6.08 million natural gas vehicles (about 23% of the global stock),[45] compared to 1.23 million ZEVs (39% of global stock).[46] In addition to the goal for 5 million more ZEVs in the Five Year Plan, this document also calls for another 5.3 million natural gas vehicles by 2020.

ZEV Projections

Total ZEV projections from various sources are summarized in the charts below, showing vehicle sales by: (1) PEVs vs. ICE/HEV (including all classes of HEV other than PHEVs) and (2) BEVs vs. Combustion vehicles (PHEV, HEV, and ICE). In some cases, the projections go beyond the period in the charts, generally to 2050, but results are shown only through 2025 and, where available, 2030. This is done for two reasons—first, to provide a level of consistency for comparison purposes and second, to focus on the introductory and intermediate market development period when supply chain issues are likely to come into play. The longer-term projections are less problematic in this regard, as the assumptions become more tautological. The high market shares are assumed to evolve as new batteries technologies become available at lower price points and higher ranges. The raw materials risks discussed elsewhere in this report mean the high market shares can only be achieved if this assumption proves out.

[43] US Energy Information Administration, "*China Surpassed the United States as the World's Largest Crude Oil Importer in 2017*," February 5, 2018.
[44] Meidan (2016); Yatsui (2017); Tianjie (2017).
[45] NGV Global, Current Natural Gas Vehicle Statistics, updated June 28, 2018.
[46] IEA (2018).

The key elements in each of the projections are as follows. The differences should be noted when comparing the numbers in the figures below.

- Deutsche Bank (May 2016): Because this report predates most of the other sources, these numbers have somewhat lower ZEV growth over the period shown. However, these numbers also assume much higher continued sales level for standard hybrids, reflecting much of the lagging consumer acceptance factors discussed later as well as being an available technology to help achieve fleet fuel efficiency standards. Consequently, this report still reflects to some degree the current market situation in areas other than China. All numbers include both passenger and commercial, and cover both light and heavy duty vehicles. This factor accounts for most of the higher total vehicle sales numbers shown in the charts below, but these projections contain estimates of future vehicle sales overall at a higher level that is comparable to the Bank of America numbers. These two estimates in turn are exceeded only by the IEA numbers. In addition to the categories shown, these projections also anticipate significant applications of micro hybrids (all EU ICEs and 35% of North American ICEs by 2020) and mild hybrids. These additional, smaller-size battery applications are not called out in the vehicle projections, but are included in the associated battery calculations.

- Morgan Stanley (August 2017). The projections cover only light duty vehicles. The base case numbers from this analysis are shown in the charts, although the Morgan Stanley projections also include a "bull case" of stricter regulation that drives 90% BEVs by 2045 and a "bear case" of reduced/delayed regulation under which BEVs reach a peak of only 9% and fade thereafter as consumers remain with the tried-and-known ICEs. HEVs (all levels) and PHEVs are assumed to be a prime emissions compliance strategy by automakers throughout this period, but emissions compliance is assumed to shift to BEVs earlier than in the other policy-based projections. As a result, the more costly PHEVs are assumed to be phased out quickly altogether. The BEV numbers track closely with the McKinsey aggressive case below, but the Morgan Stanley projections incorporate the second lowest estimate for total vehicle sales among the different sources. The document provides numbers only for BEVs and total light vehicles, although the PHEV/HEV components are included in the associated battery calculations.

- Bank of America/Merrill Lynch (October 2017). These projections cover all light duty vehicles. In addition, numbers are provided for MHVs, which are assumed at high levels as a primary automaker strategy to meet corporate efficiency standards, and for standard HEVs. The projections assume that MHVs in particular will be a key element used to adapt to the China NEV provisions. FCEVs are also estimated separately, but grow no larger than 127,000 vehicles worldwide by the end of the period shown. Combustion vehicles (ICE, MHV, HEV, PHEV) are estimated at 88.0% of sales in 2025, dropping quickly to 65.9% by 2030.

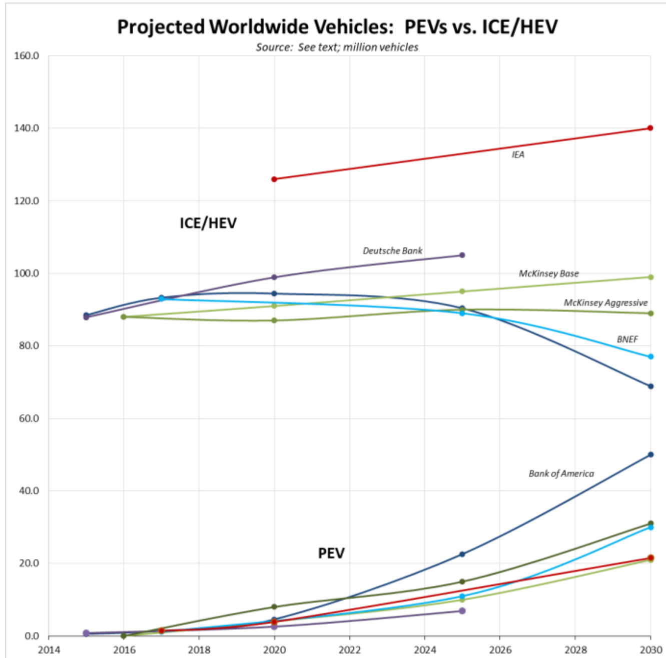
  This series is one of the more optimistic, derived from both policy estimates and a more aggressive expectation of when BEV and ICE ownership economics will meet. This assumption, however, results from a base electricity price of $0.12/kWh escalating at 2% a year, while California's current energy policies have already driven average state rates (residential) over 50% higher to $0.185 along with much higher annual growth. The projections also assume a significant shift away from car ownership to mobility services, with 49 million vehicles in car sharing and ride hailing by 2030, many of them EVs.

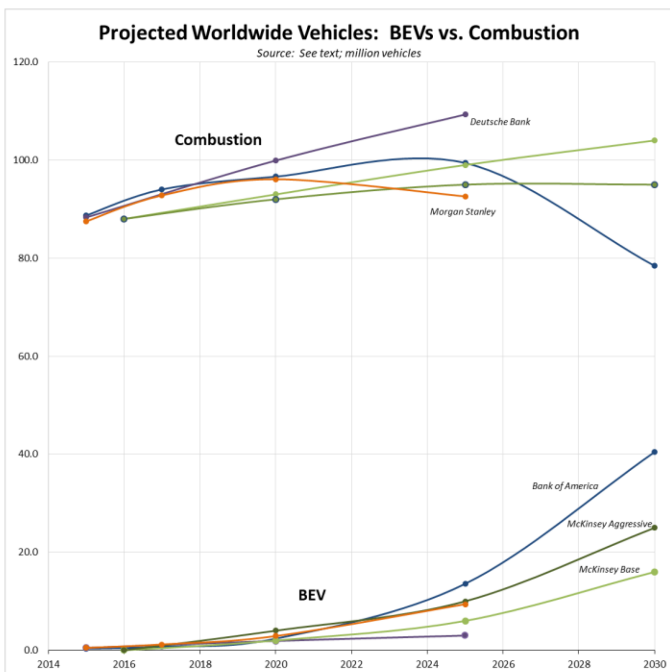
- International Energy Agency (May 2018). In contrast to the others, these projections are more strictly policy-based rather than adjusted by expectations over future battery prices and performance. The IEA numbers shown in the charts are from the "New Policies Scenario" which quantifies ZEV goals from existing country policies and implementation measures. Based on analysis in Olivetti [2017], these numbers do not appear to incorporate statements from countries such as France and UK that have announced their intent to phase out ICE vehicles, but have not yet adopted the necessary provisions to do so. IEA also developed an alternative "EV30@30" case that conceptually is consistent with California's Executive Order B-48-18, but is not shown as it is based on nonbinding goals among its participants rather than the announced national policies. The base New Policies Scenario is instead used as a benchmark that is policy based without consideration of various market factors—primarily battery cost and performance—that are factored into the other sources. The higher 30@30 scenario is included, however, below in considering the related battery and raw materials demands.

  The IEA report is focused more on stocks, and there is less information on the projected annual sales. The numbers shown cover light duty vehicles (passenger and commercial), but include only total electric vehicles (BEV and PHEV) and ICE (including HEVs) calculated from the market share numbers. As indicated, by addressing a wider range of vehicle types, IEA forecasts substantially larger vehicle numbers overall than the other sources. These total vehicle numbers are moderated within the 30@30 scenario which assumes greater policy restrictions favoring expansion of buses (largely electric) that would substitute for personal vehicle ownership. The report also addresses other battery uses, including 2- and 3-wheelers, HEVs, and HDVs. These factors are addressed in the battery projections, but not in all cases directly in the vehicle sales numbers.

- Bloomberg New Energy Finance (June 2018). The BNEF projections cover passenger light duty vehicles. Numbers are publicly available for total electric vehicles (BEV and PHEV) and ICE (including HEV) vehicles. Compared to prior year forecasts, the 2018 numbers show faster adoption rates for electric vehicles in particular due to China's recent policies, a trend, however, that the report indicates could be reversed by tight cobalt supplies. Although with lower total vehicle sales overall, the BNEF projections for PEVs converge with the McKinsey aggressive case by 2030, but with lower market share and consequently battery demand in the immediate term.

- McKinsey & Company (June 2018). Projections cover light duty vehicles, with both a "base case" derived primarily from current policies and an "aggressive case" that assumes accelerated battery technology resulting in higher consumer acceptance levels due to improvements in cost, range, and recharging factors. Both cases are included as a comparison point for some of the other sources. In particular, the base case matches closely with the IEA policy-derived estimates for PEVs, although McKinsey shows lower total vehicle sales in this period. Additional other applications including 2- and 3-wheelers, energy storage, and consumer uses are incorporated into the overall battery projections.



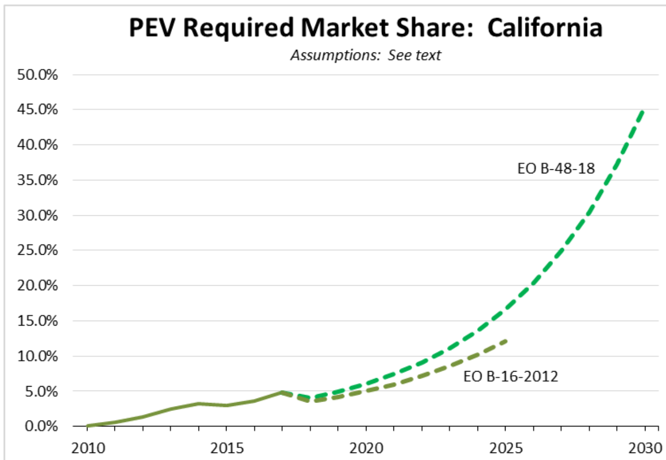


Comparing the different projections:

- PEV sales are shown at 7 million to 23 million vehicles in 2025 (6% to 20% market share), and 21 million (IEA policy estimate) to 50 million in 2030 (13% to 42% market share).

- BEV sales alone—a key element of the battery and battery raw material estimates—range from 2 million to 4 million in 2025 (3% to 12% market share), and 16 million to 41 million in 2030 (13% to 34% market share).

- For comparison, attainment of the California's Executive Order B-16-2012 goal would require PEVs to be at a 12% market share in 2025, while fulfilling Executive Order B-48-18 means a PEV market share of 17% in 2025 and 46% in 2030. Consequently, California's current policies are more in line with the higher estimates for battery raw materials contained within the studies reviewed above. The risks and impacts associated with raw material use necessary to attain the executive order goals are therefore towards the upper ends of the discussion in the subsequent sections.

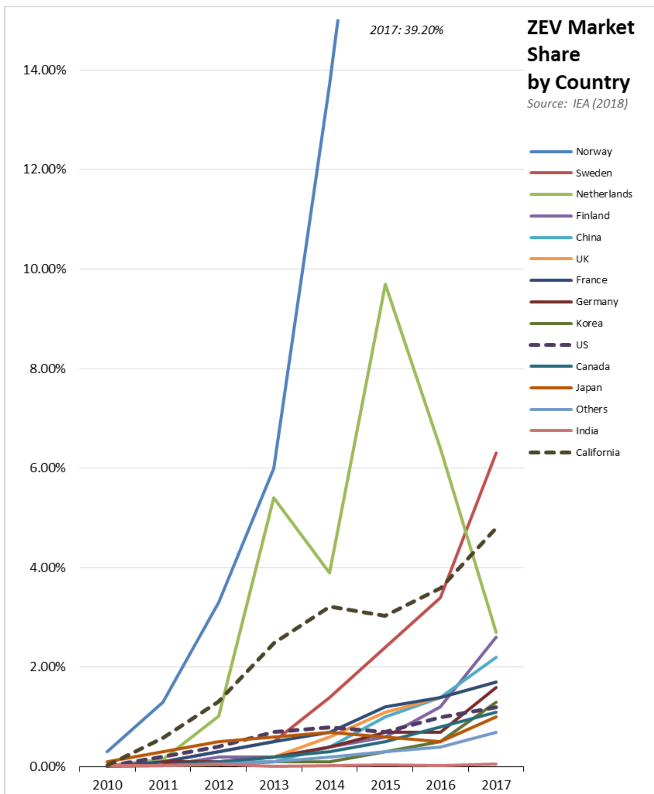


These California market share numbers assume: (1) the executive order goals continue to be measured by sales rather than actual stock on California's roads (which would factor in shifts in the fleet from accidents, trade-ins, out of state moves, and other events affecting the number of PEVs on California's roads); (2) sales grow at a constant rate; and (3) total vehicle sales continue to average about 2 million annually as a result of cyclical factors and application of state and local policies discouraging personal vehicle ownership.

While the charts and the projections behind them lump all vehicles within a class together, comparison of these numbers should be done from a recognition that there are PEVs, and then there are PEVs. Models currently offered and under development are being designed with domestic buyers in mind, with many models in the most aggressive market—China—oriented more towards urban mobility rather than the larger vehicle sizes targeting the North American and some EU markets. As an illustration from one of the reports, current battery capacities for LDVs range between 20 kWh in China to 60 kWh in the United States, with higher end models such as those from Tesla at larger sizes ranging up to 100 and 125 kWh. Vehicles in 2030 are expected to be more in the 70 – 80 kWh range for BEVs, around 15 kWh for PHEVs, and variable for HEVs depending on assumptions concerning fuel efficiency standards and overall market share for PEVs. [IEA, 2018]

ZEV Projections Compared to Current Sales

As indicated in the chart below, ZEV market share (expressed by PEV sales as a percentage of total light-duty vehicle sales) has gone beyond 2% to date only in those countries with significantly higher subsidy levels, led by Norway (39.2% in 2017) which provides some of the highest buyer assistance in the form of credits, tax relief, free use of bus lanes and toll roads (combined with increasing tolls for other drivers), and other benefits. In 2017, monetary subsidies (national, state, and local) averaged less than 1% of ZEV price in Italy, 10% in Japan, 12% in Sweden, 13% in Germany, 15% in UK, 18% in the US, 30% in South Korea, to highs of 45% in Norway and 49% in Denmark.[47] Combining both national and local government sources, monetary subsidies in China ranged up to 40% in 2016.[48]



This current reliance on subsidies for consumer acceptance and market expansion is well illustrated by trends in the Netherlands. As a result of hefty tax and other incentives, ZEV market penetration reached a high of 9.7% in 2015, but following elimination of a tax advantage for PHEVs, plunged to 2.7% in 2017 when PHEV sales collapsed.[49] A similar trend reversal was seen in Denmark following changes to the vehicle registration tax preferences for BEVs in 2016. Danish ZEV sales plummeted

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[47] McKinsey & Company, Dynamics in the Global Electric-Vehicle Market, July 2017.
[48] Deutsche Bank, 2016.
[49] IEA (2018), pp. 21-22.

from 4,762 in 2015 to only 913 in 2017.[50] ZEV sales in the US similarly took a dip when Georgia's $5,000 tax credit ended in 2015.

Within the US, subsidies are also on track to become lower. Tesla has reached and GM is nearing the 200,000 cap on plug-in sales eligible for the federal tax credit of up to $7,500 a vehicle, after which the credits are reduced progressively in a two-quarter phase-out period. Estimates for July 2018 place Tesla cumulative eligible sales at 221,158 and GM at 186,685, with Nissan at 60% and Ford at 55% of the cap.[51] In addition, California—the most aggressive state in promoting ZEV sales through various subsidies—has already pulled back by placing income restrictions on rebate eligibility beginning March 29, 2016. In general, the new income limits are $500,000 joint filers/$250,000 single in 2016 and $300,000 joint/$150,000 single in 2017. California also is currently in the process of rescinding single-occupant ZEV access to carpool lanes.

The other primary source of subsidies—the sale and use of regulatory credits by ZEV automakers for industry compliance with both California's vehicle emission standards and federal vehicle emission standards—now also is under question as a result of proposed changes from the federal agencies and California's litigation response. While shifting the cost of subsidies from government budgets to ICE vehicle buyers, these regulatory credits had the potential to become a far more significant subsidy source in the future as the two underlying regulations became more restrictive, but their availability is now subject to what likely will become a years-long period of uncertainty as litigation moves through the courts, with some effect on ZEV sales more likely beginning to occur after 2020.

While consumer acceptance has been improving, it is not yet anywhere near the level required to pull sales to the projected policy-driven levels discussed in the prior section. Sales penetration levels continue to be heavily dependent on a pull from the public subsidies. As illustrated by the experience of the Netherlands, Norway, and Denmark, electric vehicles—with the possible exception of the high performance, higher end offerings from manufacturers such as Tesla—largely remain products that governments must pay consumers to buy. Broader consumer acceptance necessary to reach these levels—with the possible exception of economies applying a higher degree of command-and-control regulations over both production and consumer options such as in China—has not yet developed.

- Consumers are showing interest in ZEVs, but few are actually buying. A 2016 survey [McKinsey & Company, January 2017] found that between 30% (US) to 45% (Germany) of vehicle buyers considered buying an electric vehicle. However, only 3% (US) and 4% (Germany) ultimately chose to do so. The purchasing level was higher in Norway (22%) due to the high level of government subsidies.

- In California, one of the most developed markets, consumer interest is not growing. An analysis of a series of consumer surveys beginning in June 2014 [Kurani, January 2018] concluded that the share of car-owning households considering a PEV as their next vehicle purchase was no higher in 2017 than it was in 2014. The share of Californians able to name

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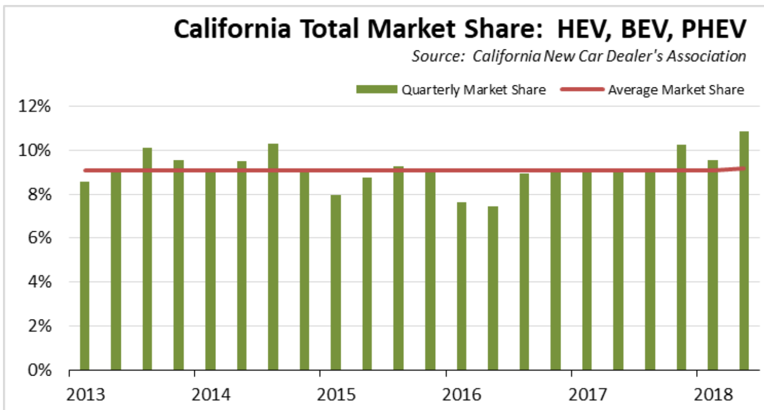
50 "*Denmark Rethinks EV Incentives After Market Collapses,*" Clean Technica, May 1, 2018.
51 "July Update – 5 *Automakers Closest To Losing The Federal Tax Credit,*" InsideEVs, August 6, 2018.

a PEV model for sale was lower in 2017 than in 2014, despite a doubling of the available offerings in this time period. This analysis also concluded that many current PEV sales are to households who are repeat buyers, rather than a market broadening to a greater share of households in the state making the actual transition. In a separate recent survey by CarMax [2017], one-third of the owners were repeat buyers.

- This static market is also reflected in actual California sales. While most analyses of ZEV sales look only at BEVs and PHEVs to project an exponentially growing sales share, another way to look at the market is those consumers showing a preference for alternative fuel vehicles, in this case HEVs in addition to the other two classes. FCEVs would be another component, but have not yet reached significant sales levels that would affect the numbers shown below.



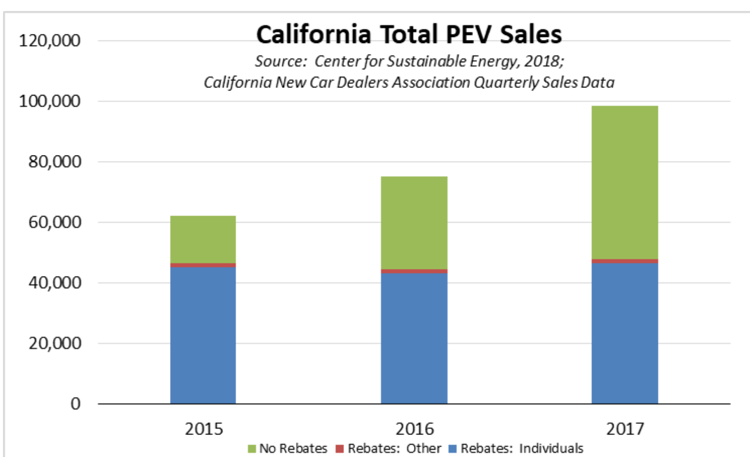
For California, the chart above shows that from this metric, the total market share has not deviated substantially over the past 5 years from the long term quarterly average of 9.1%. Shifts have occurred as buyers looking for something other than a traditional ICE vehicle have moved from HEVs to PHEVs and BEVs, but the total share of this group has not changed substantially.

The market share did go up somewhat in the 4th Quarter in 2017, but this result was more associated with shifting sales as consumers (and dealers in their advertising) anticipated the end of federal tax credits during most of this period. The credits were restored to the federal tax reform bill only at the last minute towards the end of the quarter, by which time most of the quarter's sales had taken place. The drop-off in the following quarter reflects this shift in sales timing.

The 2nd Quarter 2018 similarly shows an uptick in market share, but sales in this period were heavily affected by Tesla beginning significant shipments of its long-promised Model 3. Tesla's California shipments were up 9,815 from 2nd Quarter 2017, of which 8,951 were Model 3 shipments for orders posted in the prior year. Consequently, while this shipments show up in the 2018:Q2 results, they really reflect sales decisions made over the course of the prior year. The fact that Tesla is finally shipping Model 3 may indicate that a break from the 9.1% long term market share may finally be taking place, but more than one quarter of data and sales generated by current rather than prior-year consumer decisions will be needed to show a change in this trend. Moreover, counter to previous expectations that Model 3 would finally represent a break-through in BEV prices that would open up electric vehicles to a wider market, current deliveries are at a price point that keeps this model in the premium and near luxury categories, limiting its future ability to appeal to a wider segment of the market.

- Consumer preferences vary widely by gender. An analysis of available survey and other data [Kurani, March 2018] concluded that both males and females express about the same level of interest in considering a PEV for their next household vehicle. However, actual buying behavior during the early year sales and leases of these vehicles showed males making good on this decision at ratios of 4:1 to 6:1 over females. In the general vehicle buying market, the ratio of male to female buyers is about 1:1, with any deviations generally showing more female than male buyers. In the CarMax survey of ZEV owners [2017], 93% of the (self-selected) respondents were male.

- In California, the cost of these vehicles, although declining, results in consumer acceptance developing more readily at higher income levels. Prior to 2015, available survey data provided more demographic information to identify a typical buyer profile. Currently, information on state rebates can be used to provide more general conclusions due to the fact that income limits were imposed beginning 2016. The income limits in general are $150,000 gross annual income for single filers and $300,000 for joint filers. Comparing the number of rebates issued in 2017 from Clean Vehicle Rebate Project data[52] to the number of vehicles sold from the California New Car Dealers Association quarterly reports results in the chart shown below. As indicated, primary growth of PEV sales has come from persons with incomes above these limits or otherwise not applying for the California rebates. In 2017, the number of vehicles sold without rebates comprised 52% of all PEV sales. By comparison, the share in 2015—a year with no income limits—was 25%. Note that while 2016 is included in the chart, data for that year should be considered as incomplete. State rebates were suspended for a portion of that year, but then resumed with the first phase of the current income limits.



52 Center for Sustainable Energy, California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. Data last updated June 5, 2018.

- While many companies have announced investments in PEV models, many have not reached the point of believing that the future lies solely with BEVs. In the latest KPMG [2018] survey, 54% of auto executives world-wide (vehicle manufacturers, suppliers, dealers, and financial services) agreed with the statement "*pure battery electric vehicles (BEV) will fail due to the challenges related to setting up the required infrastructure*," compared to 30% who disagreed. The numbers were only slightly better than the 59% - 20% split in 2016. Respondents in North America were somewhat more pessimistic (67% - 17% in 2017, up from 63% - 19% in 2016).

- Moreover, 75% of the same group in the KPMG survey absolutely or partially agreed with the statement "*fuel cell electric vehicles (FCEV) will be the real break-through for electric mobility*," compared to 77% in 2016. The industry respondents instead appear to still see near term consumer preferences more attuned to ICEs and hybrids (both standard and plug-in), with much of the current public investments in recharging infrastructure rendered less useful as only an interim solution until markets shift to fuel cells as a more permanent replacement power train. For example, as with the Asian countries in general, automakers are not concentrating solely on electric vehicles. Volkswagen anticipates that even with increased electric vehicle sales, natural gas vehicles could make up to 10% of total LDV sales in Germany where electric vehicles will fall short on range or take too long to recharge.[53]

- A number of vehicle manufacturers, especially in Europe, have announced their intent to move to an all-electric line-up or to offer an electric version within their existing lines (in each case, a mix of hybrids and all electric). A number of analyses have pointed to these decisions as evidence of evolving market acceptance for these technologies. However, at this stage, it is difficult to separate these announcements from an equally pressing customer relations need to counter fall-out out from the recent "diesel-gate" revelations of improper emissions reporting,[54] along with the need to develop models to replace the role diesels previously played in industry compliance with national and EU climate change and fuel efficiency policies. For example, Chinese-owned Volvo Cars which has made one of the most sweeping change announcements concerning ZEVs is also the company most in need of new models, as it was also the most heavily reliant on diesel, comprising 78% of its European sales in 2017.[55] As with any factor affecting the assumptions behind the ZEV projections, it remains early in the technology curve to make any definitive conclusions either way.

Consumer acceptance also faces barriers that are unique to different countries. India is often named along with China as a market with tremendous growth potential for ZEVs, but electricity was accessible to less than 80% of the country in 2014 and reliability in many areas is still uncertain. Rather than recharging stations, current policies instead are promoting networks of stations where batteries can be swapped out. As economies develop, many face a shift in consumer preferences

[53] "*Natural Gas Could Power Up to 10 Percent of All Cars—Volkswagen,*" Clean Energy Wire, July 3, 2018.
[54] See for example, "*Volkswagen Races to Put 'Dieselgate' in the Rear View*," Fortune, July 23, 2018.
[55] "*Risk of Diesel Bans Force Automakers to Ditch or Defend CO2-crucial Powertrain,*" Automotive News Europe, April 4, 2018.

similar to the US towards larger vehicles capable of fulfilling a wider range of household trip purposes. For the 12 months ending May 2017, SUV sales in China grew 17% to 3.78 million vehicles, while NEVs grew 8% to only 0.14 million. [IEA, 2018] ZEV sales in China, instead, are heavily concentrated in only 6 cities, where local policies heavily promote ZEVs while penalizing ICEs, including tight restrictions on the number of vehicle licenses issued each year applied to ICEs but not to ZEVs. Elsewhere including California, ZEV sales will of necessity will be responding more to the carrots from subsidies, rather than the sticks that are being employed to ensure success of China's NEV numbers.

Policy-Based Projections as the Base for Analysis

Consideration of ZEV market shares to date provides additional insight into the current barriers to attaining the stated policy goals—including many factors that must be addressed through battery technology as explored below—but the policy goals themselves define the base numbers from which to consider the potential raw materials risks and impacts. The policies lay out investment targets producers and their suppliers must achieve in order to remain in compliance. The policies also define the planning parameters that are guiding related infrastructure such as recharging, recycling, generation, transmission, and emergency response capacity.

Attainment of the goals remains uncertain, but electric vehicle development has progressed to the point where models with competitive ranges and better recharging times are now in the market. They are still at price points that in the absence of continued, heavy government subsidies—both direct and indirect through regulation—keep them in the higher end of the market, but continued advances in battery technology hold out the potential to bring costs and recharging convenience to levels competitive with ICE vehicles.

The focus in the projections on declining battery costs, however, in some instances shortchanges expectations for technology development in other areas. At least in the earlier phases, the implicit expectations behind California's vehicle regulations were that they would result in accelerated market shares for alternative fuel vehicles, in particular electric. The fuel-neutral nature of the rules at these stages instead also promoted additional technology change for ICE models—both in the fuels and the vehicles—that kept combustion technologies compliant throughout this period. At least as measured by patents, R&D for ICE vehicles continues to outpace electrics and hybrids.[56]

In recognition of these trends, even the most optimistic of the projections still envision a significant continuing role for combustion vehicles, ranging from 97% to 88% in 2025, and 87% to 66% in 2030. While pursuing battery drives, China and other Asian nations are hedging through equal policy weight to natural gas vehicles, and the discussion in the previous section suggests that many in the auto industry remain uncertain over whether batteries are only a transitional technology to fuel cells or whether they are capable of becoming the dominant consumer choice. But the shift in regulation policy especially in places such as China and California from standards-based to technology choice means that at least over the foreseeable period, these policy goals are set and will be used to guide expenditures of private investments along with taxpayer and ratepayer funds.

[56] "*Old-Style Combustion Engines Get More Patents than Electrics*," Bloomberg, July 31, 2018.

The electric vehicle policy goals are certain to be met in countries such as China which retain significant authority over the course of their economies, and which are crafting their policies more through a command and control approach that affects directly both production and consumer choices. China is also pursuing these policies as much or more from both an energy security and industrial strategy perspective, and is actively pursuing the development of production and supply line capacity to ensure they can be met. As discussed in subsequent sections, however, the way in which China has pursued these goals may limit the ability of other areas to attain theirs as well, both in the 2025 – 2030 time frame and positioning for the longer term.

Battery Uses: Other

Growth in other sectors beyond PEVs will contribute to—and under some of the scenario projections compete for—lithium-ion battery demand. While some of these components are addressed in the battery numbers from the projections cited in the previous section, the analyses are not consistent in their treatment or assumptions about the potential growth.

Other Transportation

Light duty PEVs are only one form of electric vehicles currently in use, and in some instances in much wider use.

- Hybrids. These vehicles include: (1) standard hybrids such as Toyota Prius, (2) mild hybrids using battery systems for start-stop capacity and acceleration assistance, and (3) micro hybrids—currently used extensively in the EU—with start-stop that turns off the regular motor during idling. All three classes are generally incorporated into the projections to some degree, except the Bank of America analysis that assumes all hybrids are phased out quickly due to accelerated battery development that shifts the market quickly to BEVs. The different studies, however, vary in their assumptions of future market share, with several of the more recent reports assuming rapid expansion of mild and micro hybrids in order to meet fuel efficiency standards.

  Nickel metal hydride batteries are currently the dominant technology for standard hybrids, while lead-acid is associated with the other two categories. The different projections assume a greater shift to lithium-ion due to its superior energy density, weight, and recharge capacity.

- Two- and Three-Wheelers. While increasingly seen in North America and the EU, electric two-wheelers are found predominantly in China as a result of regulatory exemptions that do not require operator or vehicle licenses and that allow these vehicles to use bike lanes in crowded urban areas. In 2017, China had an estimated stock of 250 million vehicles and annual sales of about 30 million. Indicating the expansion potential, the total number of two-wheelers (both electric and ICE) in just China, India, and Southeast Asia is estimated at about 900 million. [IEA, 2017, 2018] Older electric models relied on lead-acid batteries, but the projections incorporating this travel mode assume a rapid shift to lithium-ion as a result of safety, environmental, weight, cost, and—for areas outside China with generally longer commutes—range considerations. For example, the Deutsche Bank projections assume e-bikes will go from 22% lithium-ion batteries in 2015 to 100% by 2020.

  Three-wheelers are more generally used for commercial purposes, and outside China remain largely ICE vehicles. Increasing government attention is being paid to electrification of these vehicles, particularly in Asia. China is estimated to have about 30 million electric three-wheelers. [IEA, 2018] The projections incorporating this mode assume increasing use of lithium-ion batteries.

- Low Speed Electric Vehicles. These vehicles generally have a top speed below 25 mph (70 kph/100 kph with unauthorized modifications in China) and gross vehicle weight below 3,000 pounds. Outside China, they are generally found as golf cart-type vehicles; but beginning in 2011, the Chinese version (built on 1930s-level auto technology) has become very popular due to the low cost and unregulated status, especially for lower income households. At a total China stock of about 4 million and annual sales of around 1 million, they are viewed as a very low cost competition both to PEVs and electric two-wheelers especially in suburban areas, with the potential to slow consumer uptake of PEVs. Concerns over safety, environmental, product quality, and the competition factors led to proposed regulations in 2017 which have since restructured the product offerings in this market segment.[57] Most models in China run on lead-acid batteries, but regulations are generally assumed to force them to shift more to lithium-ion.

- Heavy Duty Vehicles. The Deutsche Bank projections are the only ones to break out electric HDVs specifically in the vehicle projections, with 0.3 million fully electric vehicles by 2020 and 0.4 million by 2025. Most include this use within the associated battery numbers, in particular growing uses for buses. Combining both HDVs and smaller medium duty vehicles, IEA [2019] estimates China had 370,000 PEV buses in service in 2017, with another 2,100 in Europe, Japan, and the US plus another 250 FCEV vehicles. The high numbers in China are the result of substantial purchase subsidies begun in 2009, which were reduced in 2017 and revised to shift to operating subsidies in part to combat fraud.

  This portion of the battery market was previously dominated by LFP batteries—relatively lower cost but also lower power technology with fewer intellectual property barriers that can be better used in HDVs capable of handling the additional weight—but primarily as a result of the China market. The Chinese subsidies previously were available only for LFP vehicles, a policy that strongly favored local manufacturer BYD at the expense of foreign manufacturers with a presence in the country. The 2017 rule revisions made NMC eligible for subsidies, a move consistent with the current Five Year Plan provisions promoting rapid capacity expansion for this technology by Chinese-owned companies.[58] Most projections assume a consequent shift to NMC along with a growing share of PEV buses overall, in addition to wider use of MHEV technology that is well suited to the frequent stop-and-start operation of these vehicles.

Energy Storage

At the same time various public policies are promoting an exponential increase in battery demand from ZEVs, a comparable focus has been placed on turning to renewable energies for electricity through policy tools such as renewable energy portfolios. While the two policy drives may produce a degree of competition for the same battery cell supply, total projected battery needs for energy storage are relatively small compared to potential PEV demand and are likely to present potential conflicts, if any, during relatively defined investment and installation periods. Moreover, not all countries with a policy emphasis on energy storage have followed California's lead in staking their

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[57] "*New Rules Set to Govern Low-Speed Electric Vehicles and Tackle Questions of Safety*," China Daily, February 27, 2017.
[58] "*Electric Cars: China's Battle for the Battery Market*," Financial Times, March 5, 2017.

supply on batteries, and instead have crafted their actions on a more diversified portfolio of technologies in particular in the largest energy storage market, China.

Current and future demands for energy storage come from two primary sources:

- Behind-the-Meter Storage. As exemplified by Tesla's Powerwall and similar products, these systems extend the usefulness of distributed wind and solar sources by storing energy produced during peak periods and making it available when actually needed by residences and businesses. Not all the projections incorporate significant demand for this purpose as use remains relatively low, and assume distributed energy producers instead will continue to rely more on net metering agreements.

  The expansion potential also remains somewhat uncertain due to the potential for residences to use their PEV batteries for this purpose, through use of vehicle-to-home and, for those seeking to arbitrage time of day electricity rates, vehicle-to-grid modules such as Nissan's xStorage Home unit.

  Additional uncertainty comes from the likelihood that this form of storage also may be provided by old PEV batteries rather than creating additional demand for new ones, especially in developing economies where cost considerations will outweigh efficiency. As detailed in the Recycling section later in this report, PEV batteries still retain 70% to 80% of their recharge capacity after being replaced. In many countries, repurposing them for storage rather than recycling for materials makes greater economic sense now and likely will do so for some time into the future.

- Utility-scale Storage. As California, other states, and other countries pushed forward with their renewable portfolio strategies, it quickly became obvious that wind and solar plants do not always generate electricity when it is most needed. As a result, renewable generation at times has been curtailed or sold into interconnected states at a loss.[59] In response, energy regulators have turned to energy storage as an essential tool for system balance—storing renewable energy when it is generated in excess and releasing it when needed during peak usage hours—but for other system purposes as well including supply capacity, voltage support, frequency regulation, black start capacity (to deal with blackouts or brownouts), and others.

  The US Department of Energy, Global Energy Storage Database shows that as of July 2018,[60] total world energy storage capacity (verified and unverified; projects that are contracted, offline/under repair, operational, and under construction) was 180.3 GW. Of this amount, 2.8 GW is some form of lithium-ion battery, compared to 171.8 GW pumped

[59] "*California Invested Heavily in Solar Power. Now There's So Much that Other States are Sometimes Paid to Take It*," Los Angeles Times, June 22, 2017; "*In Central Europe, Germany's Renewable Revolution Causes Friction*," Wall Street Journal, February 16, 2017.

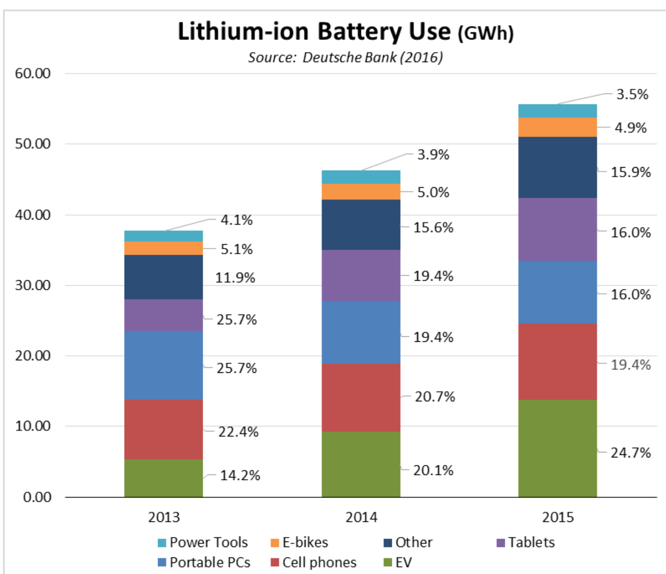
[60] Site accessed August 4, 2018.

storage hydroelectric. Announced projects (verified and unverified) totaled 14.1 GW, of which 0.6 GW are lithium-ion battery and 12.3 GW pumped storage hydro.

Growth of battery storage, however, remains uneven and heavily dependent on policy drivers, with global installations of energy storage up only 4.6% in 2017 following a 61% spurt in 2016.[61] Through decision D-13-10-040, California Public Utilities Commission chose to implement California's utility-level storage requirements under AB 2514 (Skinner, 2014) with additional technology requirements that in essence will require 1.325 GW of battery storage by 2020 (some of which is included in the Department of Energy figures above). Other policy actors have not followed this path. For example, China—with the most ambitious storage targets—instead calls in their Five Year Plans for an additional 17 GW of pumped storage hydroelectric capacity in addition to other storage technologies in this period. Oregon, Massachusetts, and New York have adopted storage targets similar to California's, but without the technology constraints or, in the case of New York, with the details yet to be developed. Battery and other storage projects are proceeding in other states and countries, but based primarily on project economics rather than technology mandates.

Battery projections for this purpose, consequently, vary widely. Recent projections by Bloomberg New Energy Finance[62] see battery storage growing to more than 125 GW (300 GWh) by 2030, of which 70% would be in only 8 countries—US, China, Japan, India, Germany, U.K., Australia, and South Korea. The IEA analysis [2018] contains a lower amount of 21 GW by 2025.

Total Battery Use



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61 "*Global Storage Growth of 4.6% in 2017 Reflects Patchy State of Sector, Finds BNEF,*" PV Magazine, February 15, 2018.
62 "*Global Energy Storage to Double 6 Times by 2030, Matching Solar's Spectacular Rise,*" Green Tech Media, November 21, 2017.

Rechargeable batteries in general and lithium-ion in particular have become an essential component of a growing range of other products as well, including forklifts and other heavy equipment, power tools, household appliances, consumer electronics, and other consumer products. Total world distribution by use through 2015 is shown in the chart above. The "Other" category includes camcorders, digital cameras, video games, MP3, toys, marine use, telecommunication systems, and miscellaneous other. Other estimates are generally consistent with the Deutsche Bank numbers shown, although some such as Avicenne Energy [2017] show a slightly higher overall total for 2015. Other lithium-ion demand at much lower levels than shown above further comes from single use and replacement applications using button/coin cells in medical, consumer, and other products.

In an instance of projections looking the most prescient in the year they are produced, earlier studies expected that rechargeable lithium-ion battery demand growth would be driven heavily by camcorders, cameras, and MP3s. Within the three years shown, these products instead dropped from 4.5% of battery use to 2.0% as they were largely superseded by smart phones.

Future Battery Demand

Future demand for lithium-ion batteries will not just be the result of the current ZEV policies. While ZEVs constitute the most substantial increment, this increased demand will come on top of other growing applications—including those arising from growing preferences for portable consumer products and lower-tech mobility alternatives, along with those driven more by other national and subnational policies such as for energy storage. Combined, these uses will draw on the same raw materials supplies, with each supply base having a different level of risk of evolving into a potential barrier to the state's goals and a potential source of rising consumer costs.

Projected Lithium-Ion Battery Demand

Several of the studies discussed in the ZEVs section above provide details on the related battery and raw materials demand. This information varies widely, however, according to which demand components are addressed—whether they are limited to vehicles or incorporate other demand sources, along with the level of detail provided on resulting raw materials use.

- Deutsche Bank (May 2016): The battery projections incorporate lithium-ion demand from all sources. While HEVs have previously relied more on nickel metal hydride batteries, this and other projections assume a shift to lithium-ion in this period. This report also assumes elevated use of micro HEVs and mild HEVs to achieve fuel efficiency standards. Energy storage is estimated at 50 GWh in 2025, of which lithium-ion would provide 48 GWh. The raw materials numbers are those related to the battery projections.

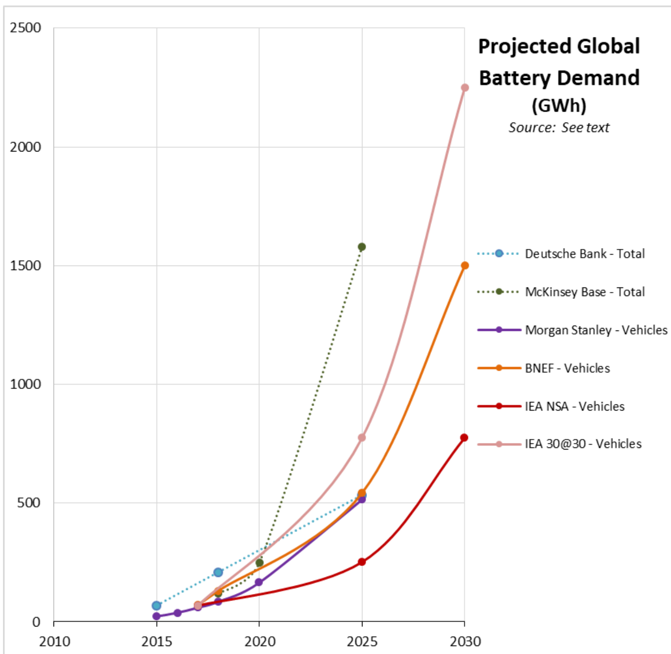
- Morgan Stanley (August 2017). The projections cover demand only related to HEVs, PHEVs, BEVs, and buses. The underlying vehicle projections are not available as this document focuses primarily on BEV penetration. By cathode material weight, the projections assume a shift from 13% NCA, 51% NMC, and 36% LFP/LMO/other in 2017 to 22% - 58% - 19% in 2025.

- Glencore (2017). As part of their 2017 annual report, Glencore contracted with CRU to analyze expected raw materials demand associated with the electric vehicle policies, using the IEA 30@30 scenario as the projection base. The numbers cover vehicles in the IEA assumptions along with required infrastructure for generation and grids, charging infrastructure, and grid storage. The underlying battery numbers and assumptions are not provided in the publicly available documents, but resulting estimates for cobalt and nickel use are shown in the following section on raw materials.

- International Energy Agency (May 2018). The battery projections cover vehicles for both the New Policies (NPS) and 30@30 scenarios, and include a much broader range of vehicle types than some of the other studies including LDVs, HDVs, HEVS, two- and three-wheelers, and low speed electric vehicles. The central estimate battery chemistry mix is assumed to move to 50% NMC 811, 40% NMC 622, and 10% NCA by 2030, with alternative low cobalt (90% NMC 811) and high cobalt (90% NMC 622) scenarios included. Numbers in the chart below are for the central estimate.

- McKinsey & Company (November 2017, June 2018). Battery numbers related to the electric vehicle numbers are not broken out separately, but total battery demand from all uses are provided, including all LDVs and HDVs, two- and three-wheelers, machinery, energy storage, and consumer electronics. Raw materials use covers both battery and non-battery use. Along with the Deutsch Bank estimates, these are the most comprehensive projections for overall material use.

- Bloomberg New Energy Finance (June 2018). Battery projections are for vehicles. The numbers assume faster adoption of e-buses compared to the other estimates, along with an accelerated switch to NMC 811.



The different battery projections are summarized in the chart above, with interim points interpolated from the average annual growth rates to produce exponential curves. While the Morgan Stanley and BNEF projections show some consistency for vehicles alone, the differences with the others reflects several points:

- The battery projections are changing over time, with more recent ones anticipating more rapid introduction of both PEVs and battery technologies into other transport modes, including lower power vehicles and greater use of micro and mild HEVs to achieve fuel efficiency standards. For instance, the IEA numbers while covering a larger number of battery vehicle types incorporate more of the smaller size battery applications, resulting in lower overall GWh demand.

- The battery projections also are sensitive to assumptions about both the types of vehicles and the speed at which they enter the global fleet. The slightly older Deutsche Bank numbers project total lithium-ion battery use at comparable levels to vehicle use alone in estimates that are only one or two years older. The estimates differ in their assumptions about how quickly consumers will accept BEVs rather than various HEVs. The estimates also depend heavily on the assumed geographic distribution, with North American vehicles being introduced at larger battery sizes compared to the more recently accelerated NEV goals in China. Some recent projections consequently show larger electric vehicle numbers overall, but with relatively lower battery sizes compared to earlier projections anticipating greater shares in North America and Europe.

Compared to IEA's identified battery production capacity of 596 GWh by 2022, these projections indicate demand will likely be tight leading into the 2025 goals. This level of capacity is sufficient to accommodate projected use under the earlier Deutsche Bank and the current IEA New Policies Scenario, but all other projections show the capacity nearly required for vehicles alone with little left over for energy storage, consumer products, and the other growing demands. Any accelerated demand, as reflected in the higher vehicle levels seen in the EIA 30@30 scenario and McKinsey total battery demand numbers, would significantly exceed this supply. Other sources assuming that fewer of the announced facilities will actually be built, however, would indicate much tighter supplies as the 2025 goal deadlines are neared. Additional investments are possible within this period, but only if there is sufficient access to the battery critical materials, as discussed in the subsequent sections.

With either result, though, current battery cell investments mean market conditions will remain tight, and overall battery capacity still remains a potential limiting factor in the ability to attain individual national or subnational policies. The nations that have been the most aggressive in pursuing this capacity are likely to be the most successful in attaining their goals at the lowest cost to domestic consumers and employers. In any case, additional capacity will be needed beyond what is already announced to ensure further progress in the various battery-related policies regardless of which projection turns out to be close.

Battery Raw Materials

Estimated Unit Raw Material Use by Battery Type (kg)

	Cobalt	Nickel	Manganese	Lithium
BEV - 80 kWh				
NCA	10.4	53.6	0.0	8.0
NMC 111	32.0	32.0	29.6	12.0
NMC 622	15.2	48.8	16.0	10.4
NMC 811	7.2	60.0	7.2	8.8
LFP	0.0	0.0	0.0	8.0
PHEV - 15 kWh				
NCA	2.0	10.1	0.0	1.5
NMC 111	6.0	6.0	5.6	2.3
NMC 622	2.9	9.2	3.0	2.0
NMC 811	1.4	11.3	1.4	1.7
LFP	0.0	0.0	0.0	1.5

Source: Derived from BatPaC results cited in IEA (2018)

The amount of raw materials required to fill expected battery demand will vary both by the size and type of batteries used in future vehicles. Currently, BEV batteries average about 60 kWh in the US and 20 kWh in China,[63] and most projections expect the overall average to grow to 70-80 kWh in the 2025-2030 time period, with larger batteries required to handle typical driving ranges in areas such as North America and the Middle East. PHEVs are generally expected to top at around 15 kWh, with some of the projections assuming these vehicles will be phased out during this period and others anticipating that HEVs will remain a key offering as consumer acceptance of BEVs continues to lag.

An illustration of the importance of battery size and type is given in the table above, derived from kg/kWh factors reported in IEA (2018). Cobalt can vary by more than a factor of 4 depending on the distribution of the dominant NCA/NMC chemistries eventually used, while nickel will differ only by a factor a 2. Lithium is not as variable, while manganese—which has far fewer supply risks than the others—will be less of a factor regardless.

Battery size is also a consideration in the supply risks each region will face in pursuing its vehicle policies. At present, the typical BEV sold in California requires three times as much battery-critical materials as one sold in China. While this differential may balance to some degree as longer range vehicles are produced for both markets, a significant portion in China and some other Asian nations will continue to be served by smaller urban vehicles and lower range vehicles such as two- and three-wheelers and low-speed electric vehicles. All other things being equal, providing the same number of vehicles in the US compared to other countries will require substantially higher relative raw materials use and consequently higher supply risks.

Total Raw Materials Use

The battery projections above result in substantial new demands on at least four battery-critical materials. Cobalt—as the raw material having the highest potential to become a limiting factor on the national and subnational policies—is discussed in more detail in the following sections. The other materials—where more options are available to anticipate or resolve future shortages—are summarized below.

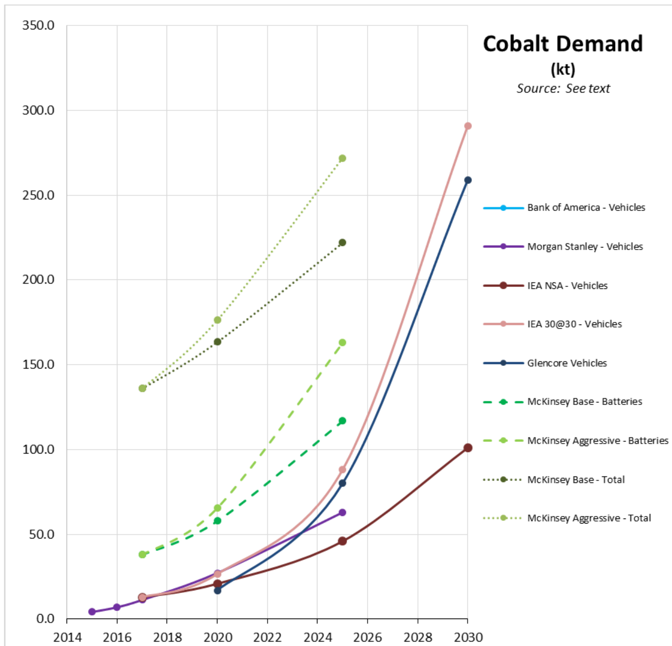
Cobalt

A number of the reports reviewed above translate their projections into the total amount of battery critical materials that will be required to fulfill vehicle sales goals under the national and subnational policies. As discussed previously, these numbers are highly dependent on assumptions concerning vehicle mix, battery types, geographic distribution of sales, and demands from non-vehicle sources, but they provide a range of anticipated raw materials demand related to these goals.

Cobalt continues to be the battery critical material most likely to be in short supply, if not a full out constraint on fulfilling the policy goals. To put the projected demand numbers in the chart below in perspective, the preliminary USGS estimate of global cobalt mine production in 2017 was 110,000 mt. This amount was not even sufficient to meet the full demand in that year, estimated in the McKinsey study at 136,000 mt, which had to be met through recycling of metallurgical applications and drawdown in stocks.

[63] IEA, 2018.

The battery projections indicate that demand will only continue growing past this level. By 2020, projected use just for vehicles averages about 24,000 mt or about a fifth of 2017 production, growing to about 70,000 mt by 2025 or about 60%. This demand will come on top of other cobalt applications including consumer product batteries, with McKinsey estimating total cobalt use in 2020 at about 150% of current production levels, and ranging from 200% to 250% by 2025. By 2030—even assuming rapid application of low cobalt chemistries such as NMC 811—vehicle use alone would require 90% to 260% of the 2017 production output.



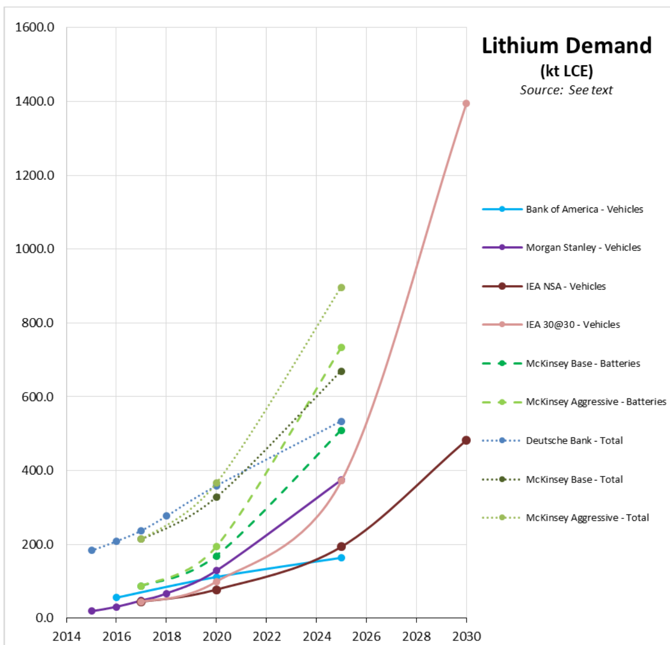
Lithium

Lithium, a metal that has received greater attention in the past, faces a similar rapid rise in use. Competing applications, however, are more limited, and future expected use is dominated more by batteries in general and vehicles specifically. In 2017, preliminary USGS production levels were approximately 228,000 mt (LCE), or roughly equivalent to total global demand as estimated by McKinsey and Deutsche Bank.

In the various projections, lithium demand in 2020 becomes only somewhat elevated above current production, but by 2025 soars to between 2.4 to 4 times this amount. By 2030, the projections are more divergent, but estimate that lithium use for vehicles alone would require 2 to 6 times the current production levels.

Current lithium production is heavily concentrated in South America, but world reserves (370 years of current production) and resources (1,230 years) are more than sufficient to meet anticipated demand. Consequently, among the battery-critical raw materials, lithium is the one most amenable to production increases. Hard rock (spodumene) production expansion primarily involves opening new mines and associated ore processing, most of which is currently located in China but with some additions now being place adjacent to new mines as in Australia. Brine production, with likely future operations in more environmentally sensitive desert areas, entails a longer time frame due to the use of solar ponds to concentrate the brines over an extended period of time, but current plans include major expansions within South America.

Most analyses show ample production currently coming on line somewhere in the 2020 – 2022 timeframe—both for metal production and converter capacity—to meet the 2025 sales projections, but shorter term shortages may arise in the period before that. Recycling will not be a supply option for lithium, both due to the general factors discussed in the next section for cobalt and due to the fact that lithium is either not recovered in current recycling or recovered with impurities that makes it not usable for batteries.[64]



The primary challenges for this metal stem from two other factors. First, current production investment has been stimulated by the current run-up in price. More recent analyses including the February 2018 report from Morgan Stanley warned of a looming 45% drop in price by 2021 as a result of overproduction, while a contrarian report from Citibank at that time concluded that this price shift had already been incorporated into most pending project finances.[65] The relatively larger incremental additions from the typical scale of these projects, however, can contribute to price volatility affecting production economics for this raw material as well as plans for the additional production that would be required to meet the higher 2030 projections. And as with all the material projections, even more beyond the 2030 numbers shown in the chart above would be needed if nations such as France and the UK that have announced intentions to ban ICE vehicles follow through with concrete policies and actions.

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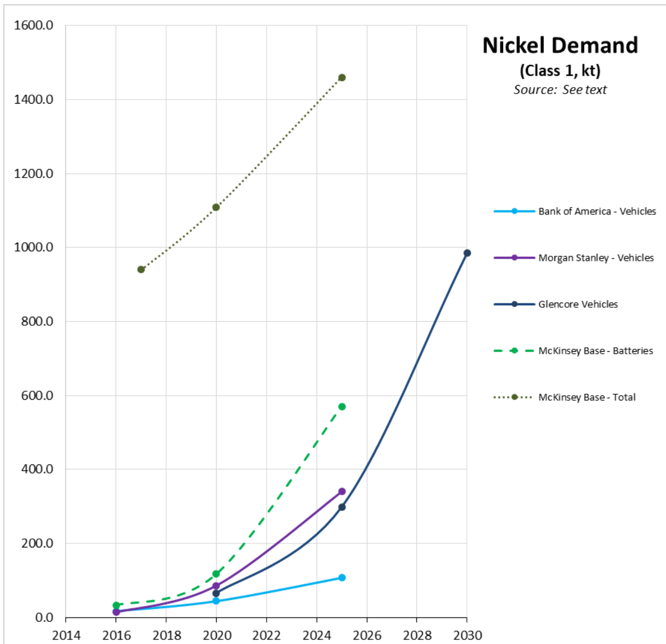
64 Olivetti, et al., 2017.

65 "*Lithium Suppliers Tumble on Oversupply Concerns*," Wall Street Journal, February 26, 2018.

Nickel

Nickel has received more recent attention as the current pressure for low-cobalt chemistries has raised concerns over the availability of battery grade supplies. Preliminary USGS production estimates for 2017 are at 2,100,000 mt, of which about half was Class 1 nickel. As shown in the chart below, production at this level likely remains sufficient through 2025, but becomes more problematic by 2030.



Nickel supplies show a broader geographic distribution than cobalt. Current mine production is dominated by a half-dozen countries, but not to the same degree as with the other battery-critical raw materials. Reserves are substantial (35 years) compared to current and projected demand, and total world resources are estimated by USGS as at least 130 mmt (62 years), with much larger but unknown resources in deep-sea manganese crusts and nodules and with current exploration efforts targeting new locations such as east-central Africa and the subarctic. The diversity of supply, however, is a likely reason why at least to date, there have been fewer efforts by China and other ZEV producers to dominate the supply chain as is the case with the other battery-critical minerals.[66]

The nickel market, however, is composed of two grades. Class 1 nickel is generally required for rechargeable batteries, while Class 2 (primarily ferronickel and nickel pig iron) is used along with Class 1 for the production of stainless steel—currently, 70-80% of nickel use is for this industry. The shift over the past decade to greater Class 2 production, particularly from Indonesia and the Philippines, was driven heavily by Chinese stainless steel producers seeking to reduce costs by greater use of the Class 2 materials especially nickel pig iron. Combining this factor with the general

[66] "*What if China Corners the Cobalt Market?*," The Economist, March 29, 2018.

drop in commodity prices following from weakened Chinese demand, nickel prices went from a high of about $22,000/mt average in 2010 to $9,600 average in 2016 and just over $10,000 in 2017.[67]

As the price and demand dropped, a number of Class 1 mines closed or delayed new investments for expansion. While the reserves are generally available, the required investments in new mine production are likely to require resumed growth in prices. Prices rebounded in the first half of 2018 as inventories were drawn down, but many analysts expect that sustained prices well above the current level of around $13,000 will be needed to see more investment in Class 1 mine expansion. In the immediate term, mine economics are more likely to still be driven more by the nickel pig iron component of the market.[68]

Currently, Class 1 comprises about half of the 2.1 mmt global production, but only an estimated 35,000 mt is easily processed into powder and briquettes for nickel sulphate—the form used for battery cell production. Other grades can be used to produce nickel sulphate but at higher cost. [McKinsey, November 2017] Many analyses assume that these costs still will not be barrier, and that battery cell chemistries will continue to move to higher nickel content due to the much higher costs and supply risks associated with cobalt.

The drive to nickel, however, faces competing price factors required to bring total battery costs down to consumer acceptable levels. Nickel is being favored as a cost reduction strategy, yet higher nickel prices and therefore relatively higher battery cell prices will be needed to generate additional Class 1 supply if this approach is widely adopted. Many analysts see this risk as leading to a fracturing of the market based on the suitability of grades and their associated processing costs for battery grade product, with China already launching this process by modifying its tariffs to favor imports of nickel sulphate over other forms and grades.[69] Others anticipate that nickel intermediates may provide a solution, but with yet higher processing costs to battery grades. Intermediates, however, may become essential to supply the projected 2030 demand.[70]

Graphite

Natural graphite is currently used to produce lithium-ion anodes. USGS shows China currently producing 65% of global mine production, most of which comes from small scale mines. Reserves are high (225 years), with the largest amounts in Turkey (75 years), Brazil (60 years), and China (45 years). Global resource estimates are very high (670 years), but minimal within the US. Flake graphite—the form preferred for batteries—comprises about 40% of current production, most of which currently comes from Chinese mines. Flake graphite is subsequently milled down to spherical graphite, the form used in batteries after coating.

Graphite is more widely available than the other battery-critical materials. Use of synthetic graphite is also possible, but at a higher anode cost. Fulfilling the national and subnational goals, however,

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67 USGS, Mineral Commodity Summaries (MCS), Nickel, various years.
68 "*Why Electric Vehicles Could Fracture the Nickel Market: Home*," Reuters, March 8, 2018.
69 "*Why Electric Vehicles Could Fracture the Nickel Market: Home*," Reuters, March 8, 2018.
70 "*Nickel Intermediates Can Fill Class One Supply Gap – Vale*," MetalBulletin, April 26, 2018.

will require development of new supplies and likely diversification away from the current reliance on China.

The analyses in general do not incorporate specific forecasts for graphite, assuming instead that sufficient supply will become available from the high reserve and resource amounts as battery demand produces the price signals needed to bring new mines on line. Others assume that any potential shortfalls will instead be handled through the higher-cost synthetics market.

Cobalt Production

Current Production

As defined by USGS, the different measures that can be used to assess the total mineral endowment in an area includes the following:

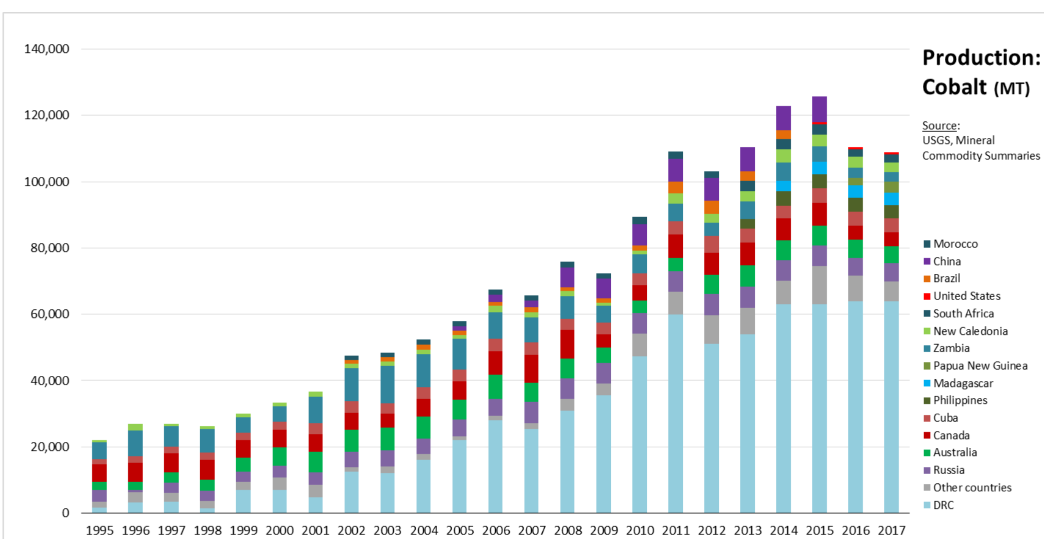
- Resource: *A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is regarded as feasible, either currently or at some future time.*

- Identified Resource: *A resource whose location, grade, quality, and quantity are known or can be estimated from specific geologic evidence. Identified resources include economic, marginally economic, and subeconomic resources.*

- Reserves: *That portion of an identified resource from which a usable mineral or energy commodity can be economically and legally extracted at the time of determination.*

In each case, these are not static numbers, but will change over time as mining and processing technology, production costs such as energy and labor, and mineral prices change and as additional exploration and testing provides new details on the likely scale and location of deposits.

In the case of cobalt, these metrics are more heavily influenced by the same factors in the far larger markets for copper and nickel. With only very few exceptions, cobalt is produced as a byproduct in mining operations for these other two metals. As of 2011, 60% of cobalt was a byproduct of copper mining, 38% from nickel mining, and although the share may grow slightly in future years, all other mine types contributed only 2%. [USGS, Chapter F, 2017]



Regardless of the measure, however, world cobalt supplies both currently and in the time frame encompassed by the current ZEV projections are dominated by a single source, the Democratic Republic of the Congo (DRC).

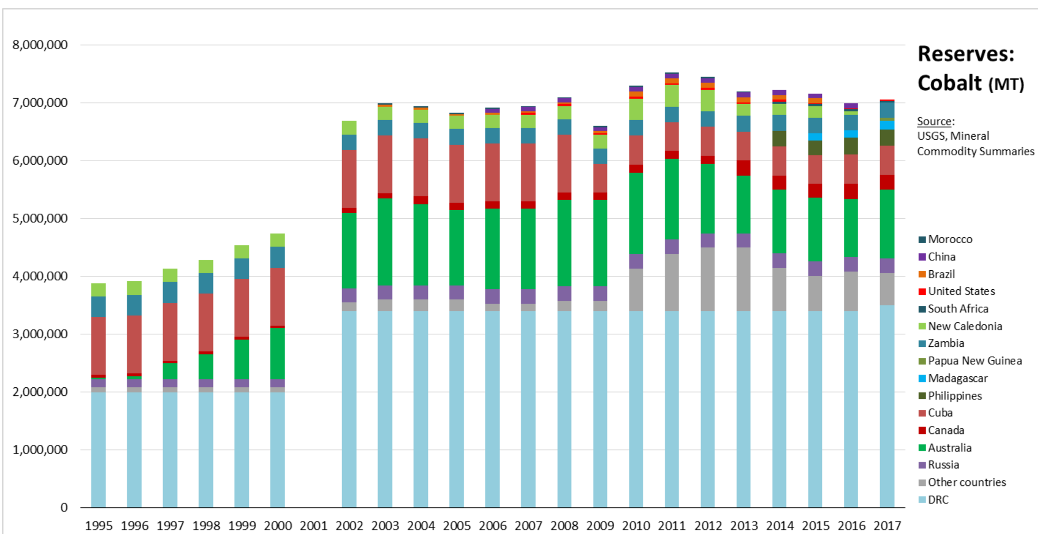
Total primary cobalt production by country is shown in the chart above. Mining production peaked at 126,000 mt in 2015 just prior to the fall in copper prices following from weakening Chinese demand. Production output since declined to 110,000 mt in 2017 (preliminary estimate) as the associated nickel and copper mining continued dropping from 2015 levels.

Following the crash of its production during the 1990s, DRC steadily regained its position as the dominant source, going from a low of 6% in 1998 at the beginning of the Second Congo War and growing to 58% in the last two years. In the last 3 years, DRC alone exceeded total world production in each of the years 1995 – 2005. Over the last decade, DRC production more than doubled, growing by 106% while production in all other countries combined was up only 14%.

US production is far more limited. The US accounted for only 0.6% of total world production in the last 3 years. Current domestic supplies come mainly from the Eagle nickel-copper mine in Michigan, which ships a cobalt-bearing nickel concentrate beginning only in 2014. Minor amounts come as a byproduct from the Stillwater platinum-groups-metal mine in Montana.

Other production in the US comes instead from secondary sources producing cobalt from scrap materials: super-alloy scrap, cemented carbide scrap, and spent catalysts. In 2017, total secondary output was about 2,200 mt, or 19% of total US cobalt consumption (for all uses).[71]

Reserves



Total world estimated reserves are shown in the chart above by country. As indicated, reserves peaked at 7.5 mmt in 2011-12, and more recently have declined somewhat to 7.1 mmt in the latest

[71] USGS, Cobalt, Mineral Commodity Summaries, 2018.

preliminary estimate for 2017.[72] DRC has accounted for about half of total reserves, ranging from a low of 43% in 2000, a high of 52% in 2009, and at the current level of 49% (3.5 mmt in 2017) in the past two years.

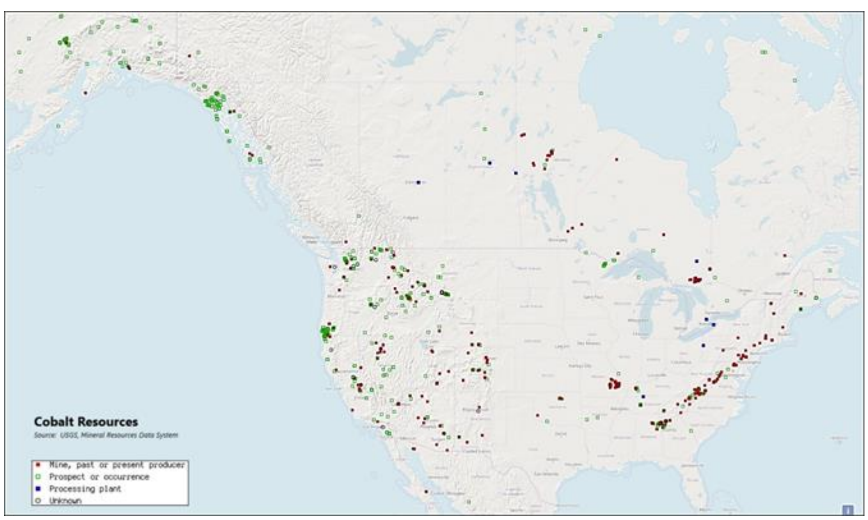
US reserves are much lower, accounting for no more than 0.5% of the world total since estimates were large enough to include in the USGS reports in 2007, and at only 0.3% (23,000 mt) in 2017.

For the purposes of the policy-based ZEV projections, the reserve numbers are the more important metric. New sources of cobalt have not been in heavy demand for some considerable time, and as a result, far less effort has been put into new prospecting and discoveries until just recently as prices have soared in response to new demands for batteries. Additional resource discoveries are possible, but will continue to be more associated as they are now with copper and nickel prospects or potentially through development of new mining technologies—especially deep seabed mining—as is now being promoted by China, Japan, and other nations.

For the period covered by the ZEV build-out projections—especially given the extreme amount of time required to discover, delineate, and permit new mining capacity as well as resolve the inevitable years-long litigation—the most likely sources for new additions are shown by the reserve numbers. In practice, these numbers mean DRC will continue as the dominant but still likely unreliable supply source for most of ZEV battery needs, with some additional supply—in order of declining reserve potential—from countries such as Australia, Cuba, the Philippines, Zambia, Russia, and Canada.

Resources: Terrestrial Estimates

In considering potential battery supplies in the period beyond the ZEV projections, the total worldwide terrestrial resource estimate has been stable at 25 mmt through the most current preliminary estimates for 2017,[73] up from the prior estimates of 15 mmt through 2012.



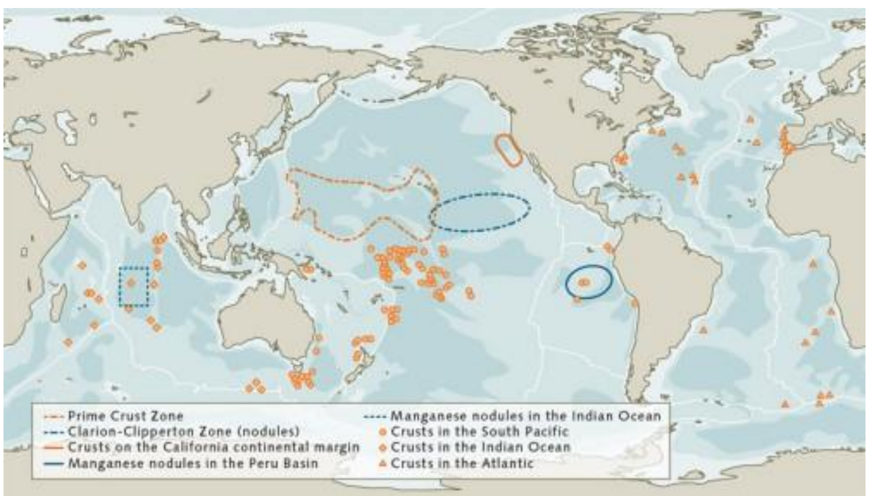
[72] Estimates for 2001 are not available due to lack of data for DRC operations.
[73] USGS, Cobalt, Mineral Commodity Summaries, 2018.

Most of these resources are associated with copper deposits in DRC and Zambia; nickel deposits in Australia, nearby island countries, and Cuba; and nickel-copper deposits in Australia, Canada, Russia, and the US.

The general distribution of resources within the US is shown in the map above. US resources are estimated by USGS at 1.0 mmt, with most in Minnesota but with other deposits of varying grades in Alaska, California, Idaho, Michigan, Montana, Oregon, and Pennsylvania. Any future production from these locations would have cobalt as a byproduct of other metal production—primarily nickel for the California resources—except for some deposits in Idaho and Missouri where cobalt is the metal with the largest potential economic output. Other than the projects discussed below, the long lead time required to bring new mine production on-line in the US in general and California specifically, however, likely means that the US resources are unlikely to play much of a role in assisting with attainment of the ZEV policy sales goals.

Resources: Offshore Estimates

Although previously set at much higher levels, the current USGS estimate of offshore cobalt resources is nearly five times larger than total terrestrial levels, at more than 120 mmt in the Pacific, Indian, and Atlantic Oceans. Cobalt has been identified in significant amounts in cobalt-rich manganese crusts, manganese nodules, and some polymetallic sulfide deposits.



Source: World Ocean Review 3, Cobalt Crusts, 2014.

Shortly following the proclamation of its Exclusive Economic Zone (EEZ) in 1983, the US formed two task forces to consider potential offshore mineral lease sales. The Gorda Ridge Task Force was formed between Department of the Interior, California, and Oregon. Interior formed a separate group with Hawaii. After an extensive research program directed primarily by the Gorda Ridge group, both efforts concluded with a symposium [McMurray, 1990] rather than proceeding directly to the lease sale stage. In both areas, the decision was based on insufficient economic return—primarily due to low levels of precious metals required to boost project economics at the time—and technology constraints. The task force work, however, identified significant polymetallic sulfide deposits about 150 miles offshore California and Oregon, along with extensive cobalt-rich manganese crust deposits in the EEZ off Hawaii and US territories and possessions in the Pacific.

Active offshore minerals exploration has since shifted to other countries, primarily through exploration leases under the International Seabed Authority (ISA). The ISA is the designated organization for the 1982 Convention on the Law of the Sea (UNCLOS) and 1994 Agreement on Implementation of Part XI of the Convention dealing with deep seabed resources lying outside national jurisdictions. The US has not ratified either document, but since action by President Reagan in 1983, has acknowledged UNCLOS as reflecting customary international law.

ISA Contractors, 2018

	Polymetallic Nodules	Polymetallic Sulfides	Cobalt-Rich Ferromanganese
Belgium	1		
Brazil			1
China	2		1
Cook Islands	1	1	
France	1	1	
Germany	1	1	
India	1	1	
Japan	1		1
Kiribati	1		
Nauru	1		
Poland		1	
Russia	1	1	1
Russia, 5 other states	1		
Singapore	1		
South Korea	1	1	1
Tonga	1		
UK	2		

Source: ISA, Deep Seabed Minerals Contractors

As shown in the table above by sponsoring state, ISA has issued several 15-year contracts (plus extensions) to companies for exploration of deep seabed mineral resources. The polymetallic nodule contracts are for the Clarion-Clipperton Fracture Zone in the Eastern Pacific Ocean and for the Central Indian Ocean Basin. Polymetallic sulfide contracts cover South West Indian Ridge, Central Indian Ridge, and the cobalt-bearing Mid-Atlantic Ridge. The cobalt-rich crust contracts are in the Western Pacific Ocean.

In addition to these activities in international waters, a number of primarily Pacific governments have launched similar efforts within their EEZs. Most of these consist of direct exploration activities or issuance of leases for exploration. Efforts that are further along include:

- Recently, Japanese researchers [Takaya, 2018] announced the discovery of deposits containing 16 million tons of rare-earth oxides near Minamitorishima Island in Japan's EEZ. Required for production of EV components along with other electronics and alternative energy systems, the deposits if they prove to be commercial would counter China's current near-monopoly on these elements by adding the equivalent of 780 years' worth of yttrium supply, 620 years of europium, 420 years of terbium, and 730 years of dysprosium. Companies involved in the effort anticipate spending the next 5 years to prepare a development plan and assess economic extraction rates.

- US-based Ocean Minerals LLC entered into an agreement with Cook Islands in October 2017 for exclusive rights to apply for exploration licenses to cover 23,000 sq km containing polymetallic nodules. The company has until April 2019 to submit the applications. Preliminary assessments indicate a potential of up to 18,000 mt a year cobalt over a 30-year project life.[74]

Commercial use of marine mineral deposits still has many barriers to cross, including further development of the mining technology required for economic extraction beyond the level previously represented by the *Glomar Explorer*, along with measures to address the associated environmental concerns. The challenge is made all the more difficult by the fact that other than the strategic mineral components such as cobalt and rare earths, many of the associated metals remain in plentiful supplies in the less costly terrestrial deposits. This factor led the earlier US Task Force proposals to conclude without further action in the absence of finding higher grades of more valuable metals, which at that time was driven primarily by the grade values for precious metals.

Growing economic pressures are now instead driven by the current ZEV and related policies, shifting the focus more to strategic minerals, in particular cobalt, rare earth elements, and others which appear to be at high grade levels in a number of marine deposits both within national EEZs and in international waters. With prices likely to remain high although variable as a result of expected shortages and continued supply uncertainty from DRC over the next several years, these components are likely to help boost exploration interest if not development economics as well. More importantly, however, countries such as China, Japan, and South Korea have already targeted these resources as a critical element of their economic security and are now seeking ways to expand access to secure supplies through active exploration and research to develop the required mining and processing technology. These pressures will become all the much higher as current supplies are more concentrated through Chinese sources. Economic extraction may remain uncertain, but this option is now being investigated by other nations as part of their overall ZEV strategies.

Production Expansion: Mining

Cobalt is predominantly produced as a companion mineral in copper and nickel mines. Consequently, current and near term production is more directly related to demand and prices for these two metals rather than cobalt itself. Current cobalt demand is not sufficient to support cobalt mining on its own in the large majority of known deposits—estimates vary but only about 5-10% of total production now is from operations where cobalt is the most valuable product being mined. Currently, cobalt comes about 55% from copper and 35% nickel, expected to grow to 75% copper and 20% nickel by 2025. Mining where cobalt is the primary metal produced and therefore more responsive to cobalt price signals is far more limited, occurring primarily in Morocco, but with plans proposed since 2013 in Cameroon, DRC, US, and Zambia.

Because of this situation, even large increases in cobalt prices will bring little change in the amount produced by mines. This point is illustrated in the production chart above. In spite of growing demand for EV batteries in the last few years that generated large run-ups in cobalt's price, production actually declined. Rather than prices, cobalt production was more heavily affected by

[74] Ocean Minerals LLC, Significant Cobalt Resource from Seafloor Nodules, Corporate Presentation, May 1, 2018.

slowing of copper and nickel demand in China. Similarly, tripling in cobalt's price had little effect on reserve estimates as well. For any other metal, a price spike of this scale would have had a profound effect on estimates of ore that could be economically recovered. Instead because cobalt reserves are defined by copper and nickel, there was virtually no movement in the cobalt numbers.

Recent estimates [McKinsey & Company, 2018] have identified announced mine expansions of 110,000 to 120,000 mt by 2025. Most of these are within the DRC, expecting to bring its share of global supply to 75%. No major capacity expansions are anticipated outside Africa, although some are in early stages of planning and may become viable at some future point.

While these expected additions if moved to production would roughly double global supply and bring it near at least McKinsey's base case projection for total demand, about one third of the announced projects are given a lower likelihood of proving out.

More critically, the economics of DRC production—both existing and expansions—are currently unsettled as a result of recent changes in DRC mining law. First announced in 2017 and final regulations completed in June, the new law substantially increases royalties and taxes, raises the DRC government's free share of mining projects from 5% to 10%, and cuts in half the term for previously 10-year stability clauses that limited changes to mining contracts. Miners are now subject to a 50% tax on "super profits" if commodity prices rise by more than 25% above what was estimated in resource feasibility studies, while the base cobalt royalty rose from 2% to up to 10%.

The effects on the operations of current major cobalt players such as Glencore, which supplies about a quarter of the cobalt market, still remain to be seen. While producers attempted to negotiate more favorable terms, none of their issues were addressed in the final regulations. Industry concerns are now that major producers may delay shipments and stockpile ore while pressing to cover these issues in new contracts, adding even more price pressure on the current market.[75] This is more pressing in Glencore's case, which is already under pressure from a recent royalty settlement[76] and subsequent DOJ investigation over this and other agreements.[77]

These changes seem to have had less an impact to ongoing efforts by Chinese investors to control a greater share of the cobalt resources. Even as the regulations were being made final, China-based Citic Metal Co. closed on a 20% stake in Canada's Ivanhoe Mines Ltd., which is now developing Africa's largest copper discovery in the DRC.[78]

Within the US, the principal mining projects currently under development are the still-in-permitting NorthMet project in Minnesota (estimated to produce 5,400 mt of cobalt over 20 years) and Canada-based eCobalt's project in Idaho (projected to produce 1,100 mt annually). Scheduled to begin operating in 2021, the eCobalt project will be one of the few mines with cobalt as the primary

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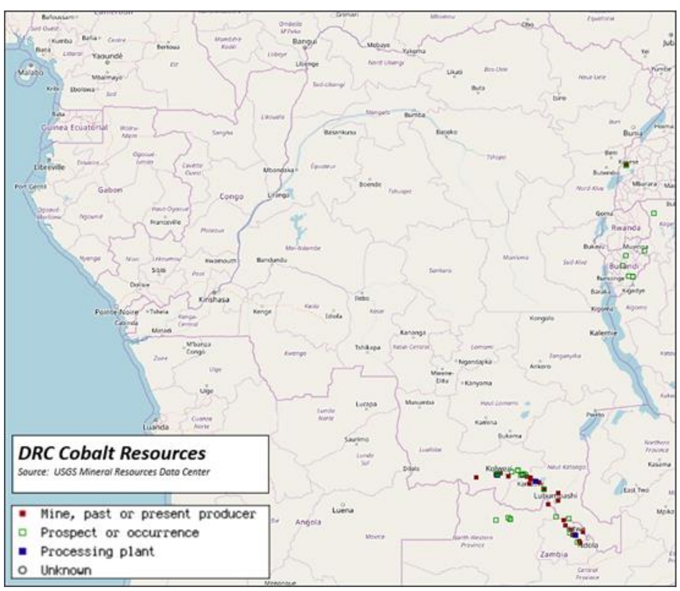
75 "*Inside China's Move to Monopolise Cobalt*," Mining Technology, June 4, 2018.
76 "*Glencore Settles with Gertler Over Congo Royalities*," Reuters, June 14, 2018.
77 "*Glencore Plunges After DoJ Subpoena Seeking Foreign Corrupt Practices Act Docs,*" The Street, July 3, 2018.
78 "Congo's Miners Face Harsh New Reality as Mining Law Finalized," Bloomberg, June 13, 2018.

metal produced, and will include processing facilities for direct production of battery-grade materials. NorthMet is owned by Toronto-based PolyMet Mining.

Production Expansion: Artisanal Mining

Artisanal mining is small scale mining often done by individuals or large numbers of individuals working separately or together in areas without commercial-scale mines or on tailings piles generated from these large mines. Often, unorganized communities spring up around these operations, ranging from transitory to longer-lasting depending on the amount of recoverable ores in the area and world mineral prices.

Artisanal mining has been hailed from some quarters as the leading way to ensure local populations can benefit directly from their country's mineral resources, which in many areas would otherwise be developed through non-domestic companies and in far too many instances siphoned off through local- and national-level corruption.[79] Within the DRC, artisanal mining became a means of economic survival for many after the main state-owned mining company, Gécamines, failed in the 1990s, and was further encouraged by the government during the Second Congo War to keep up the nation's minerals production after conflict and civil unrest halted industrial-scale mining in the eastern provinces. In their 2015 Annual Report, the DRC Chamber of Mines estimates the country may have up to two million artisanal workers, which based on average household size, means up to 15% of the population may depend on this income source. As other jobs including agriculture have been devastated by ongoing strife and conflict, artisanal mining remains the only income option for many in a nation where two-thirds of the population remains in extreme poverty (less than $1.50 a day).[80]



[79] "*Artisanal Mining is One of the Few Ways Africans Directly Benefit from Natural Resources,*" Quartz Africa, July 27, 2018.
[80] Bill & Melinda Gates Foundation, 2018 Goalkeepers Data Report.

Much of this mining activity previously was related to gold and gems especially in the eastern provinces, but following the strong rise in prices, has increasingly been associated with cobalt in the south. Artisanal miners sell their ore to local co-operatives who often set prices without consideration for market conditions, and who in turn then sell the ore to local traders who then sell to international traders or operating mines, from where it is generally shipped to China for processing along with ore from other sources.

In the early 2000s, DRC attempted to regulate these activities, but this effort failed after insufficient areas were reserved for artisanal mining and as these miners were instead displaced by mining contracts issued to Western and Chinese firms. Artisanal mining continues at a high scale—generally estimated as involving 100,000 – 200,000 miners—in the copper belt of southern DRC largely within the area of the former Katanga Province, mainly occurring within unauthorized areas or trespassing on areas reserved for the region's commercial mining operations. This lack of authorized options has put artisanal miners at increased risk to corruption from officials along with exposure to abuse and violence from state, rebel, and criminal forces.

Following the release of reports from Amnesty International [2016, 2017] and others, artisanal mining in DRC has also become associated with child labor, slave labor, and worker and human rights abuses. Key findings from the Amnesty reports include the following:

- *UNICEF estimated in 2014 that approximately 40,000 boys and girls work in all the mines across southern DRC, many of them involved in cobalt mining.*

- *The children interviewed . . . said that they worked for up to 12 hours a day in the mines, carrying heavy loads, to earn between one and two dollars a day. Even those children who went to school worked 10 – 12 hours during the weekend and school holidays, and in the time before and after school. The children who were not attending school worked in the mines all year round.*

- *Other children said that they worked in the open, in high temperatures, or in the rain. As with adult miners, they were exposed to high levels of cobalt on a consistent basis, but did not even have gloves or face masks to wear.*

- *Children who collected, sorted, washed, crushed and transported minerals were paid per sack of minerals by the traders. The children had no way of independently verifying the weight of the sacks or the grade of the ore, and so had to accept what the traders paid them, making them susceptible to exploitation.*

- *Researchers found children as young as seven who scavenged for rocks containing cobalt.*

- *Chronic exposure to dust containing cobalt can result in a potentially fatal lung disease, called "hard metal lung disease." Inhalation of cobalt particles can also cause "respiratory sensitization, asthma, shortness of breath, and decreased pulmonary function", and sustained skin contact with cobalt can lead to dermatitis. Yet researchers found that the vast majority of miners, who spend long hours every day working with cobalt, do not have the most basic of protective equipment, such as gloves, work clothes or facemasks.*

- *Researchers also spoke to women who complained of respiratory problems and pain as a result of carrying heavy loads and the physically demanding nature of the work. For example, one woman described having to* *carry 50 kg sacks of cobalt ore and told researchers: "We all have problems with our lungs, and pain all over our bodies."*

- *Artisanal miners work in mines which they dig themselves. Hand-dug mines can extend for tens of metres underground, often without any support to hold them up, and are poorly ventilated. There is no official data available on the number of fatalities that occur, but miners said accidents are common, as unsupported tunnels collapse frequently.*

- *Not only are state officials aware of the mining activities taking place in unauthorized locations, but they also financially benefit from them. Officials from a range of different government and security agencies control access to unauthorized mining sites and demand illegal payments from artisanal miners.*

As a result of these and subsequent investigations,[81] many end-user companies such as Apple and Tesla have attempted to identify the source of cobalt in their batteries and obtain assurances it is from "ethical" and child labor-free sources. A "Better Cobalt" effort is currently pilot testing an electronic-tagging system to determine whether this approach can be used to trace the source of cobalt along the global supply chain.[82]

Artisanal mining, however, provides a significant share of cobalt supply. Estimates generally put its contribution at 20% of DRC total production, or overall 10% of the world's supply and growing as DRC moves to providing three-quarters of global production.

And while individual companies are seeking to implement procedures to enable "ethical" and child labor-free sourcing of this metal, the current circumstances suggest that at best any such system would have only partial or sporadic success. As discussed later, the scale and pace of the national and subnational policies are pushing the cobalt market to likely shortages sometime within the 2022 – 2025 timeframe. Suddenly removing 10% of potential production or making it more difficult to access will only accelerate a supply crisis, leading in turn to higher prices that would incentivize even more artisanal mining and/or increase the potential payoff from subverting an "ethical" and child labor-free tracking system.

The cobalt supply chain is also substantially opaque. Cobalt is thinly traded with only an annual average of about 350 contracts since 2016, compared to copper with average of just over 330,000. The market continues to slim as more suppliers and end users lock up increasing shares of future supplies in face of the looming, policy-driven shortages. The accelerated vehicle introduction envisioned under some of these policies such as those in China and California are intensifying the competition to secure the available supply in this manner.

Furthermore, current restrictions of this kind applied to the DRC have a less than stellar record. Inserted as a provision into the Dodd-Frank Act, federal law requires US companies to verify that any gold, tantalum, tin, and tungsten they use does not come from militia-controlled sources in the

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[81] e.g., "*The Cobalt Pipeline*," Washington Post September 30, 2016; "*The Toll of the Cobalt Mining Industry on Health and the Environment*," CBS News, March 6, 2018.

[82] "*Pilot Scheme Seeks to Produce First 'Ethical Cobalt" from Congo*," Financial Times, March 25, 2018.

DRC. The DRC government first reacted to these requirements by shutting down the affected portions of the mining industry for months, and development of the required certification system was severely slowed as the result of "*a lack of political will, corruption and bureaucratic and logistical delays*." Even with a certification process in place, few of the required audits have been completed due to the size of the mining regions and the fact that government workers are at risk if they attempt to enter these uncontrolled areas. Rather than risk buying sanctioned materials, Western companies instead stopped buying from any DRC source and sought supplies from other countries. As a result, mining workers lost income as their jobs shut down. For many, the only other available means of economic survival was to join the very militias this law was intended to combat.[83]

Production Expansion: Recycling

While some cobalt recycling already takes place primarily for metallurgic applications, this option is unlikely to provide any significant supply from recycled batteries until well towards 2030. Less than 5% of lithium-ion batteries are currently recycled, and most of these are from the much smaller packs associated with electronics, tools, and other consumer products. Vehicle and energy storage batteries will be far less available precisely because they have been selected based on long product lives in order to improve consumer acceptance.

With exceptions such as Hyundai's lifetime warranty on PHEV batteries, PEV battery warranties generally cover 8 years and 100,000 miles. Companies differ, however, on whether warranties cover only battery failure or reduced capacity. Companies such as BMW, Chevrolet, Nissan, and Volkswagen include coverage against reduced capacity below 70% within the warranty period (Volt at 60%), while others such as Tesla have no such provision as vehicles with longer range are less likely to experience deep recharging that would lead to accelerated capacity loss.[84] In general, most analyses assume that batteries will have a useful life of 100 – 150,000 miles, but still have around 70% charge capacity at the end of this period.

This remaining capacity means that rather than recycled, vehicle batteries are far more likely to be repurposed to energy storage, particularly in rural areas and developing economies where cost is much more a consideration and space less so. Batteries from earlier models are already being used for back-up storage for home solar systems, street lighting, wireless transmission towers, and utility-scale storage. In Japan, retired Prius batteries are being installed outside 7-Eleven stores for solar panel storage. Current policies promoting energy storage along with distributed energy itself will only accelerate this trend.

Even in places such as California that are likely to impose recycling requirements at some point, siting of a processing facility within the state is unlikely. California-based Retriev Technologies currently operates a facility capable of recycling vehicle batteries in Trail, British Columbia. The company is also using a $9.5 million American Recovery and Reinvestment Act grant to build the first US lithium-ion battery recycling facility, but is doing so in Lancaster, OH. Batteries instead are more likely to be shipped overseas, as is much of the state's current recycled waste stream for reprocessing or disposal in China and various developing economies. This process, however, would

[83] "*How a Well-intentioned US Law Left Congolese Miners Jobless,*" Washington Post, November 30, 2014.
[84] "*What You Need to Know About Electric Car Battery Warranties*," PluginCars, April 22, 2018.

simply move batteries at the end of their vehicle life to where they are the most valuable for repurposing rather than recycling.

Recognizing this likely outcome, many car companies are in process of working with various user groups in developing ways to do this safely, spurred in part by Chinese and EU regulations requiring them to be responsible for proper disposal following electric vehicle use. Tesla instead is currently focused on recycling.[85] Through guidelines published in February 2018, China now makes NEV manufacturers responsible for building a recycling network for used batteries, and specifically calls for creating an after-market network for reuse.[86] As a result, China Tower Corp. currently plans to replace the lead-acid batteries on its 2 million telecommunications towers with repurposed lithium-ion, while Chinese refurbishers have paid nearly three times as much for batteries that can be reused compared to those that get recycled.[87]

One consequence of this situation is that through much of the coming policy timeframe, the cobalt required for vehicles and large-scale storage batteries will have to come from virgin ore. In the absence of major battery chemistry or other vehicle advances or opening of new sources such as seabed ores, dependence on DRC will grow, and predicted shortages discussed below during the mid-point of this period become more likely.

The other effect is that China is already moving to secure the refurbished and through it ultimately the recycled market. Drawing on its recent experience as the end point for much of California's and the US recycling policies, China is now moving to expand potential future supplies from this source even as it has sought control over much of the current ore supply, processing, and production capacity.

Increasing Control of Production: China

Most analyses consider current cobalt expansion plans as sufficient to provide adequate supplies up to the 2022-25 period, but with a tightening market after that if not outright shortages:

- McKinsey [2018] sees sufficient production in their base case through 2025, with shifts in battery chemistry essential after that to continue meeting vehicle projections through 2030. The aggressive case projections move this point up three years. This outcome, however, depends on completion of all the identified mining projects, and assumes a quarter of the new supply will come from expanded recycling and a large increase in artisanal mining. As discussed previously, these last two sources are subject to some degree of uncertainty.

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[85] "*Where 3 Million Electric Vehicle Batteries Will Go When They Retire*," Bloomberg Businessweek, June 27, 2018.
[86] "*China Unveils Policy for NEV Battery Recycling,*" Xinhuanet, November 27, 2018.
[87] "*China's Giving Batteries a Second Life,*" Bloomberg, March 11, 2018.

- Morgan Stanley expects only occasional imbalances through 2022, but shortfalls beginning in 2023. This analysis also assumes a high level of supply from recycling in this period. Adjusting to bring this factor in line with other analyses results in a 15% shortfall by 2025. [88]

- The BNEF numbers anticipate cobalt shortages by the early 2020s. This analysis anticipates that this situation will in part be handled by move towards lower cobalt chemistries, but most likely not at a rate sufficient to keep pace with current policy goals. Projected cobalt shortages by 2020 will instead have to be resolved through new production or development of more advanced chemistry than what appears to be commercially possible now.

- In a separate analysis focused on materials use, Olivetti [2017] analyzed both a "low" growth scenario generally in line with the McKinsey aggressive scenario, and a "high" growth case based on the BNEF vehicle projections. This analysis indicates the first scenario can reach 2025 without supply shortages, while the higher growth would encounter shortages of up to 40%, reduced to 12% if accelerated cobalt production becomes possible. This paper also indicates that the BNEF projections still fall below a case where all currently announced automaker production goals are met—such as Volvo's "all electric" pledge by 2019—along with realization of proposals that have not yet been fleshed out with concrete action steps such as the elimination of ICEs in the UK and France. Fulfillment of these grander announcements runs into a hard cobalt barrier without accelerated, major advances in battery technology.

- Earlier analyses including those by Wood Mackenzie and Transparency Market Research forecast shortages beginning or soon after 2022. Macquarie Research anticipated shortfalls beginning in 2019, growing to a 5,300 mt imbalance by 2020.[89]

The academic and policy studies conclude from this looming imbalance that producers will move more quickly to lower cobalt battery chemistries in order to keep pace towards projected 2030 sales. While R&D efforts continue towards this goal, producers within the market more immediately are instead moving to secure priority access to both current and future supplies under the likely expectation that cobalt will remain critical to batteries for some period of time.

China already has carved its place in the cobalt market. By securing supplies of this policy-essential material, China has moved to ensure its electrical vehicle goals will be met and fulfill the climate change, energy security, and economic strategy purposes behind them. And by creating local access to the only metal that now could threaten this future, the center of the electric vehicle industry has moved from California where it was fundamentally created, to the China-based clusters designed to bolster its chances to grow and succeed. While most analysts rate Japan and South Korea ahead of China in battery technology, China appears to be countering this advantage by buying up what is needed to make the batteries themselves.

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[88] "*Morgan Stanley's Cobalt Report Mirrors my Analysis of Tesla's Supply Chain Risks,*" Seeking Alpha, September 12, 2017.
[89] As cited in "*Elon Musk's Worst Nightmare: Child Labor and Cobalt Supply*," Mining.com, May 1, 2017.

China has long played a key role in the overall cobalt value chain, providing the bulk of cobalt refining capacity producing the cobalt sulphates and oxides used to make cathodes.[90] As the looming economic importance of cobalt became apparent, Chinese firms also quickly moved upstream by broadening their role and influence over the primary ore source in the DRC mines:

- China companies produce 77% of refined cobalt chemicals, up from 67% in 2012 and through planned expansions, are expected to reach 90% soon.[91] The last US refinery stopped operation in 1985.

- In 2007, China and DRC entered into a $6 billion (revised from $9 billion after IMF objections) minerals-for-infrastructure agreement, of which half was for mine development to produce an estimated 10 mmt copper and 0.6 mmt cobalt, and half for infrastructure investments. Revenues from mining were slated to repay this amount over time.

- In 2016, China Molybdenum Co Ltd (CMOC) bought a majority share of DRC's Tenke copper mine from US-based Freeport McMoRan Inc. Freeport sold its 70% share of TF Holdings Ltd, which indirectly owns an 80% interest in Tenke Fungurume Mining SA, one of the world's largest copper deposits with an estimated annual cobalt output of 16,800 tonnes. In 2017, CMOC agreed to support the acquisition of the remaining 30% of TF Holdings by Chinese private equity firm BHR.

  The Tenke production is currently processed at Freeport's cobalt refinery in Finland, the largest capacity outside China. If for some reason CMOC chose to redirect its cobalt production from Finland to China, the result would give China as much as 95% of the current cobalt chemicals market.[92]

- Other Chinese companies operating smaller mining operations within DRC include Congo Dongfang Mining, Comika Mining/Wanabao Mining, and Hunrui Cobalt.

- As a result of these acquisitions, 7 of the 10 largest cobalt producers in the DRC in 2016 were Chinese-owned, and the Chinese State Reserve Bureau stockpiles the mineral,[93] currently at about 5,000 mt.[94] USGS data shows US stockpiles in 2017 were only 302 mt.

- In 2018, China-based Citic Metal Co. agreed to buy a 20% share of Ivanhoe Mines Ltd., which owns the Kipushi zinc and Kamoa-Kakula copper projects. China's Zijin Mining Group Co. already holds about 10% of Ivanhoe.[95]

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[90] "*Inside China's Move to Monopolize Cobalt,*" Mining Technology, June 4, 2018.
[91] "*There's a Global Race to Control Batteries—and China is Winning*," Wall Street Journal, February 11, 2018.
[92] "*What if China Corners the Cobalt Market?*," The Economist, March 29, 2018.
[93] "*Hype Meets Reality as Electric Car Dreams Run Into Metal Crunch*," Bloomberg, January 11, 2018.
[94] "*There is a Global Race to Control Batteries—and China is Winning,*" Wall Street Journal, February 11, 2018.
[95] "*CITIC Metal Completes C$723 Million Investment in Ivanhoe Mines*," Mining Review Africa, July 10, 2018.

- Zhejiang Huayou Cobalt Co. is currently developing a major new copper mine near Kolwezi in southeast DRC.

- Chinese buyers are rumored to be interested in the Roan Tailings and Reclamation project in the DRC. Developed by Luxembourg-based Eurasian Resources Group with Chinese financing, this operation is projected to add about 15,000 mt of cobalt production beginning in 2018.[96]

- In 2018 at the urgings of China's embassy and DRC's mines minister, 35 companies formed the Union of Mining Companies with Chinese Capital to better coordinate the country's mining interests in the Congo.[97]

- In March 2018, China-based GEM announced it would acquire one-third of the cobalt shipped by Glencore, the world's leading cobalt ore producer, between 2018 and 2020—an amount equal to half of total world production in 2017.[98]

- Owner of the largest privately-owned stockpile of cobalt, Cobalt 27 Capital Corp., announced it was in discussions on possible tie-ups with Chinese auto and battery makers.[99]

Other producers seeking to remain viable in this emerging industry have mimicked China's moves as well, raising yet more barriers to a transparent and efficient cobalt market and increasing the overall likelihood that the predicted shortages will actually occur:

- In 2017, Glencore, CATL, and Volkswagen were reported to be in a 3-way agreement for up to 20,000 mt of cobalt products over a 4-year period.[100]

- In 2018, South Korea's LG Chem announced two joint ventures with Zhejiang Huayou Cobalt for 40,000 mt a year of precursors and cathodes in China beginning in 2020.[101]

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96 "*Inside China's Move to Monopolise Cobalt*," Mining Technology, June 4, 2018.
97 "*China Marks Cobalt, Copper Ascendancy in Congo With New Group*," Bloomberg, June 18, 2018.
98 "*What if China Corners the Cobalt Market?*," The Economist, March 29, 2018.
99 "*Cobalt Firm Says Chinese Car Companies Keen to Secure Supplies*," Bloomberg, April 15, 2018.
100 "*Exclusive: Glencore Makes Large Cobalt Deal, Securing EV Battery Supplies for VW*," Reuters, July 6, 2017.
101 "*LG Chem Lands New Cobalt Deals With Zhejiang Huayou Cobalt*," Clean Technica, April 11, 2018.

- Reports indicate BMW is in negotiations to secure a 10-year supply of cobalt and lithium.[102] BMW has entered into battery agreements with both Samsung and CATL, and intends to source raw materials itself to pass through to its battery suppliers. The CATL agreement, however, makes it responsible for sourcing materials.

- Apple has been in talks to secure long-term supplies directly from miners rather than work through its battery cell suppliers.[103]

- After earlier making commitments to develop cobalt-free batteries, Tesla's cell provider Panasonic revealed it expects to use 25,000 mt of cobalt a year in the early 2020s, up from its current use of 8,000 mt.[104]

Recognizing the potential limiting role that could be played by cobalt, China acted early to secure its supply and ensure a predominant share of this battery-critical material would be available to those producers who choose to locate their jobs in China. As China has acted on its strategy, others—often late in the game—have been doing as well, with an overall result that the limited current and likely future supplies are increasingly being locked in with long-term buyers. The opportunity for new entrants into the cell market is consequently becoming limited, with the result being to further cement cell production where it is now. While most of the projections anticipate the future is with less cobalt, current players are not acting like it is—securing the available supplies both to launch the electric vehicle industry but also to remain an industry participant over the longer run.

California has primarily paid lip service to this process, issuing policies and plans on how the electric vehicle industry it started can provide well-paying jobs in the future, but has done little to turn policies into actions.

Other Resources

In the US, the primary actions to date seeking to expand access to battery critical materials have come from the federal government.

In December 2017, the White House issued an executive order directing federal agencies to develop a coordinated "Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals." The Secretary of the Interior working with Secretary of Defense and other department heads was tasked with identifying policy to identify new sources of critical materials, increase activity at all levels of the supply chains, and streamline leasing and permitting to expedite exploration, production, and recycling. Critical materials are defined as "*a non-fuel mineral or mineral material that is essential to the economic and national security of the United States, that has a supply chain vulnerable to disruption, and that serves*

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102 "*BMW: Close To 10-Year Lithium + Cobalt Supply Deal — Is This Just A Response To News That Tesla Is Locking In Supply Deals?*," Clean Technica, February 12, 2018.
103 "*Apple in Talks to Buy Cobalt Directly From Miners*," Bloomberg, February 20, 2018.
104 "*After Cobalt-free Pledge, Panasonic to Triple Consumption for Auto Batteries: Sources,*" Technology News, June 14, 2018.

an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security." [White House, December 2017]

Interior published a Final List of Critical Minerals in the Federal Register in May, containing 35 critical minerals and mineral groups. The list includes battery critical materials along with other materials essential to the development of a domestic ZEV capacity, including: aluminum, antimony, chromium, cobalt, graphite, lithium, magnesium, manganese, niobium, rare earth elements, strontium, and tantalum.[105]

These minerals and groups are now being considered in a report being prepared by the Commerce Department. The report will cover recommendations for the following actions:

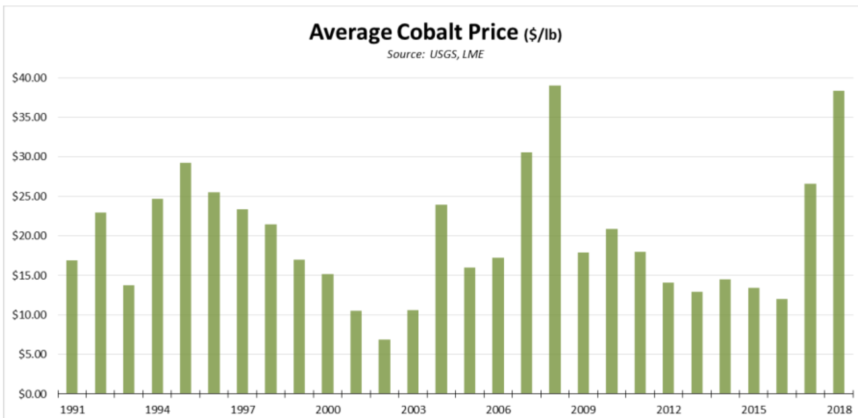
- a strategy to reduce the nation's reliance on critical minerals;
- the status of recycling technologies;
- alternatives to critical minerals;
- options for accessing critical minerals through trade with allies and partners;
- a plan for improvements to mapping the United States and its mineral resources;
- recommendations to streamline lease permitting and review processes; and
- ways to increase discovery, production, and domestic refining of critical minerals.

This report was due to the President by August 16, 2018, but no subsequent actions have yet been issued.

[105] Final List of Critical Minerals 2018, Federal Register, FR Doc. 2018–10667, May 17, 2018.

Cobalt Production Risks

The recent run up in cobalt prices brought the electric vehicle policies to many investors' attention, but also began to bring a focus to potential supply risks associated with these policies. This price behavior, however, was not new. Most of the recent reporting has focused on price spikes in the last two years. The same degree of extreme price instability can be seen in a longer period trend line, but as the result not of government regulations promoting electric vehicles but of sustained government instability in the DRC.



Note: 2018 is first half average

With little effective control by the central government over large swathes of the nation, DRC (formerly known as Zaire) has seen an unending period of civil war, civil unrest, and foreign incursions since and even before the resignation of former President Mobutu in the early 1990s. This situation has frequently led to disruption of mining operations and supplies. The nation's mineral riches have also been used by the different parties to these conflicts to support their operations, including the many militia groups and national armies operating on DRC soil throughout this period, and have fed rampant corruption that has flourished in these unsettled conditions.

As summarized by federal sources, political and economic conditions within the DRC remain highly unstable, with both civil unrest and military conflict especially in the eastern regions that have continued largely unabated throughout the periods listed below:

> *In 2009, following a resurgence of conflict in the eastern DRC, the government signed a peace agreement with the National Congress for the Defense of the People (CNDP), a primarily Tutsi rebel group. An attempt to integrate CNDP members into the Congolese military failed, prompting their defection in 2012 and the formation of the M23 armed group - named after the 23 March 2009 peace agreements. Renewed conflict led to large population displacements and significant human rights abuses before the M23 was pushed out of DRC to Uganda and Rwanda in late 2013 by a joint DRC and UN offensive. In addition, the DRC continues to experience violence committed by other armed groups including the Democratic Forces for the Liberation of Rwanda, the Allied Democratic Forces, and assorted Mai Mai militias.*
>
> *CIA (2018), DRC Background*

The lack of effective government control has also led to widespread human rights abuses in much of the country:

The Democratic Republic of the Congo is a source, destination, and possibly a transit country for men, women, and children subjected to forced labor and sex trafficking; the majority of this trafficking is internal, and much of it is perpetrated by armed groups and rogue government forces outside official control in the country's unstable eastern provinces; Congolese adults are subjected to forced labor, including debt bondage, in unlicensed mines, and women may be forced into prostitution; Congolese women and girls are subjected to forced marriages where they are vulnerable to domestic servitude or sex trafficking, while children are forced to work in agriculture, mining, mineral smuggling, vending, portering, and begging; Congolese women and children migrate to countries in Africa, the Middle East, and Europe where some are subjected to forced prostitution, domestic servitude, and forced labor in agriculture and diamond mining; indigenous and foreign armed groups, including the Lord's Resistance Army, abduct and forcibly recruit Congolese adults and children to serve as laborers, porters, domestics, combatants, and sex slaves; some elements of the Congolese national army (FARDC) also forced adults to carry supplies, equipment, and looted goods . . .
CIA (2018), DRC Trafficking in Persons

The most significant human rights issues included: unlawful killings; disappearances and abductions; torture and other cruel, inhuman, and degrading treatment and punishment, including sexual and gender-based violence (SGBV) and rape; life-threatening conditions in prisons and detention facilities; arbitrary arrests and prolonged detention; denial of fair public trial; arbitrary interference with privacy, family, and home; restrictions on freedoms of speech and the press, assembly, and association; abuse of internally displaced persons (IDPs); inability of citizens to change their government through democratic means; harassment of civil society, opposition, and religious leaders; corruption and a lack of transparency at all levels of government; violence and stigmatization against women, children, persons with disabilities, ethnic minorities, indigenous persons, lesbian, gay, bisexual, transgender, and intersex (LGBTI) persons, and persons with albinism, with little government action to investigate, prosecute, or hold perpetrators accountable; trafficking in persons, including forced labor, including by children; and violations of worker rights.

Authorities often took no steps to investigate, prosecute, or punish officials who committed abuses, whether in the security forces or elsewhere in the government, and impunity for human rights abuses was a problem.
Government security forces, as well as rebel and militia groups (RMGs) continued to commit abuses, primarily in the east and the central Kasai region. These abuses included unlawful killings, disappearances, torture, destruction of government and private property, and SGBV. RMGs also recruited, abducted, and retained child soldiers and compelled forced labor. The government took military action against some RMGs but had limited ability to investigate abuses and bring the accused to trial.
US Department of State (2017), Country Reports on Human Rights Practices for 2017

The country's political and security situation also contributes to an uncertain investment climate, raising questions about its reliability as a long-term contributor to sustainable higher cobalt supplies. The informal sector—including artisanal mining—continues to be a large part of the overall economy. The sheer size and economic importance of this sector combined with the inability of the DRC government to provide effective institutional structures calls into question any attempts to institute regulatory assurances over "ethical" and child labor-free sourcing of future cobalt supplies:

The economy of the Democratic Republic of the Congo - a nation endowed with vast natural resource wealth - continues to perform poorly. Systemic corruption since independence in 1960, combined with countrywide instability and intermittent conflict that began in the early-90s, has reduced national output and government revenue, and increased external debt. With the installation of a transitional government in 2003 after peace accords, economic conditions slowly began to improve as the government reopened relations with international financial institutions and international donors, and President KABILA began implementing reforms. Progress on implementing substantive economic reforms remains slow because of political instability, bureaucratic inefficiency, corruption, and patronage, which also dampen international investment prospects.

> *Renewed activity in the mining sector, the source of most export income, boosted Kinshasa's fiscal position and GDP growth until 2015, but low commodity prices have led to slower growth, volatile inflation, currency depreciation, and a growing fiscal deficit. An uncertain legal framework, corruption, and a lack of transparency in government policy are long-term problems for the large mining sector and for the economy as a whole. Much economic activity still occurs in the informal sector and is not reflected in GDP data.*
>
> *CIA (2018), DRC Economy*

Wider spread economic abuses in fact appear to be limited only by inadequate development of effective institutions within the economy:

> *. . . traffickers exploit lax shipping controls to transit pseudoephedrine through the capital; while rampant corruption and inadequate supervision leave the banking system vulnerable to money laundering, the lack of a well-developed financial system limits the country's utility as a money-laundering center*
>
> *CIA (2018), DRC Illicit Drugs*

Considering events from a chronological order helps to make some sense of the different regional, ethnic, and internal conflicts raging across this country since independence. The following lists some of the key but by no means all events contributing to the ongoing instability within the DRC:

1960 Shortly after independence, the army mutinies and loots the capital, and Katanga Province declares itself independent. Belgian troops are deployed to protect Belgian citizens and mining, along with 20,000 UN peacekeepers deployed throughout the country. Mining operations and others hire paramilitaries and foreign mercenaries to protect their interests.

1961-65 Various other attempted secessions occur in this period, including the Simba rebellion which took over the eastern half of the country.

1963 Katanga's secession ends, and its leader, Moise Tshombe, becomes Prime Minister as part of the peace agreement.

1965 In a series of events related to the broader Cold War, Joseph Mobutu (subsequently, Mobutu Sese Seko) becomes President following a coup against the USSR-backed government.

1973-74 Many foreign-owned firms are nationalized, including Gécamines which operates the copper and cobalt mines in the Katanga Province area.

1975-81 Mining output suffers under nationalization, accentuated by external shocks including a 40% drop in copper prices in 1975, the oil price shock, and closing of the Benguela Railroad connecting the Katanga mines to the Lobito port in Angola. Social unrest from the economic disruption led to new secession attempts in Katanga (then Shaba) in 1977 and 1978. Copper prices collapsed another 45% in 1981, followed by a 58% plunge in cobalt prices in 1986.

1990-5 Gécamines collapses, producing a sharp drop in global cobalt supplies. In spite of a near-monopoly over copper and cobalt mining in the Katanga area, profits since nationalization instead had been diverted to government officials, including contributing to the $8 to $10 billion reportedly amassed by President Mobutu during his years in office. The nearly two-decade lack of reinvestment led to declining production including the actual physical collapse of the Kamoto underground cobalt mine that sharply cut into the country's exports. DRC copper and cobalt production was subsequently revived through joint ventures with Western and Chinese firms, especially following issuance of a new Mining Code in 2002 that abolished the state monopoly over mining concessions and opened up the sector to foreign investment.

1991 The collapse of Gécamines—the main source of government revenues—led to a sharp rise in government printed money and a massive inflationary spiral. After a long period of not being paid as a result of the collapse, the army again loots the capital. A coalition government with opposition leaders is subsequently formed.

1992 After the central government attempts to pay back wages in newly printed denomination bills, soldiers mutiny and again loot the main cities, twice in 1992 and again at the beginning of 1993.

1993 The government splinters, with separate pro- and anti-Mobutu governments claiming control over the country.

1996-7 First Congo War breaks out after Rwanda forces attack Hutu militia camps. Hutu militia working with DRC government forces attack ethnic Tutsis in the eastern provinces. Tutsi rebels form their own militia, escalating into a rebellion that seizes control of the eastern provinces while President Mobutu is out of the country for medical treatment. Along with other rebels and support from Rwanda, they capture the capital in May, rename Zaire to DRC, and install coalition leader Laurent-Desire Kabila as President.

1998 Second Congo War breaks out. Movement for the Liberation of Congo led by Jean-Pierre Bemba and backed by Rwanda and Uganda seizes control of the eastern provinces. Zimbabwe, Namibia, and Angola send troops to back the Kabila government.

1999 Conflicts break out between rebel groups backed by Rwanda and those by Uganda.

Peace agreement among the six warring nations signed in July, followed by agreement with the two main rebel groups a month later.

2000 Another 5,500 UN peacekeeper force sent to DRC.

2001 Laurent Kabila assassinated by a bodyguard. Succeeded by his son and current President, Joseph Kabila.

Foreign troops begin pulling out under an UN-sponsored plan.

2002 UN Security Council releases <u>Plundering of DR Congo Natural Resources: Final Report of the Panel of Experts</u>. Among many other points, the report concluded: (1) conflict continues specifically to gain control over DRC mineral and tax revenues; (2) even as the official forces withdraw, these conflicts are being prolonged by criminal groups supported by the armies of DRC, Rwanda, Uganda, and Zimbabwe who have "*built up a self-financing war economy centred on mineral exploitation*;" (3) Uganda forces have provoked ethnic conflict specifically to justify keeping an armed presence in the DRC, in order to maintain their control over mining and other economic resources; (4) Rwanda has ensured its future control in areas by replacing DRC nationals in key business, utility, and government positions and inserting Rwanda soldiers into local DRC units rather than withdrawing them from the country; (5) senior officers in the Zimbabwe forces are forming shell businesses to transfer resource assets they previously used to support their activities in the DRC; and (6) the looting that previously was done by the armies themselves has now been replaced by "*organized systems of embezzlement, tax fraud, extortion, the use of stock options as kickbacks and diversion of State funds conducted by groups that closely resemble criminal organizations.*" This report further detailed the members and activities of an "elite network" of political and military elites, business persons, and select rebels and administrators who took control of the mineral and other economic resources within the areas controlled by DRC, Rwanda, and Uganda.

2003 Bemba becomes Vice President under the terms of a peace agreement with his Movement for the Liberation of the Congo, a rebel group since transformed into a political party.

2004 Sporadic fighting breaks out, including another coup attempt and battles with a pro-Rwanda rebel group in the east.

UN releases a report admitting that peacekeepers and staff sent to protect civilians in the DRC have instead been involved in sexual exploitation of women and girls that "*appears to be significant, wide-spread and ongoing*," with documented cases of pedophilia, prostitution, and rape.[106] Failure to control this abuse leads to reports 13 years later that the DRC leads by far reported cases of abuse and sexual exploitation by UN forces.[107]

UN estimates 3.9 million have died as a direct and indirect result of conflict in DRC since 1998.

2005 Lord's Resistance Army enters DRC. Uganda threatens to send its troops back in to fight these units.

2006 Population displaced as DRC and UN peacekeepers attempt to disarm militia forces in the northeast and later fighting between UN and rebel forces in North Kivu Province.

2007 Fighting between DRC troops and forces backing opposition leader Jean-Pierre Bemba.

Increase in refugees fleeing North Kivu as a result of militia actions.

2007-8 Revelations of illegal gold and arms trafficking between UN and militia forces appear: "*Accusations included the illegal buying of gold from the FDLR; the use of a UN helicopter to fly into the Virunga national park to exchange ammunition for ivory; trading UN rations for gold; the purchase of drugs from the rebels; and a general failure to support the disarmament of the group.*"[108]

2008 DRC government and rebel militias sign peace agreement to end conflict in the eastern provinces.

Renewed fighting by DRC forces against formerly allied Rwanda Hutu militias and militias backing rebel leader Laurent Nkunda. Subsequent successes by the Nkunda forces increase refugee flight, and leads to additional UN forces to support the DRC troops.

Uganda, South Sudan, and DRC attack Lord's Resistance Army bases in the north.

2009 DRC and Rwanda launch assault against the Nkunda-led Tutsi militia.

Joint DRC-UN assaults against Rwandan rebel militias. Following completion of this campaign, Hutu militia become active again and cause another flood of refugees.

[106] "*UN Says its Workers Abuse Women in Congo,*" Washington Post, November 27, 2004.
[107] "*UN Peacekeepers: Congo Leads World in Sex Abuse Allegations,*" AP, September 22, 2017.
[108] "*UN Peacekeepers 'Traded Gold and Guns with Congolese Rebels,*'" The Guardian, April 28, 2008.

UN High Commissioner for Human Rights issues reports accusing both the Nkunda militias and DRC troops of committing war crimes. DRC forces were accused of "*large-scale pillages as well as arbitrary killings and sexual violence against the very people they were supposed to be protecting*."[109]

DRC soldiers in the east mutiny after they haven't been paid.

2010 UN Envoy Margot released reports of mass rapes of women and children by Rwanda rebel militia and Mai-Mai militia in North Kivu. DRC forces were also reported to be involved in rapes, killings, and lootings in the area, while UN forces were criticized for not responding quickly enough.[110]

DRC launches attacks against Ugandan rebel militia in North Kivu.

After delays and various country objections, UN releases DRC: Mapping Human Rights Violations 1993-2003. Among other charges, the report suggests the Rwanda army may have committed genocide by killing tens of thousands of Hutu militia and refugees who fled to DRC following the earlier genocidal killings of Tutsis in Rwanda.

UN issues report of mass rape of DRC migrants being expelled from Angola. The 2002 Mining Code resulted in banning many artisanal miners from areas they previously worked in the DRC, and many were forced to emigrate to nearby countries including Angola to work in the diamond fields. Angola banned all foreigners from the diamond mines in 2003. Angola was accused of using violence and mass rapes to enforce expulsion of tens of thousands of DRC migrants.[111]

Former Vice President Bemba goes on trial before the International Criminal Court, accused of allowing his troops to rape, kill, and pillage in the Central African Republic in 2002 and 2003. He subsequently was convicted, but the verdict overturned on appeal based on the reasoning he could not be held liable for the actions of his troops.

2011 Failed coup attempt against President Kabila.

2012 UN report accuses Rwanda and Uganda of providing arms and support to rebel militia M23. M23 briefly takes Goma, the largest city in eastern DRC. DRC forces withdraw after only minimal resistance, but are accused of mass rape and looting along their retreat path.[112] Of 39 soldiers eventually put on trial, 2 are convicted.

2013 13 nations sign a pledge to end conflict in the DRC, with M23 declaring a ceasefire.

Another UN peacekeeping force of 3,000 deployed and engages militias in eastern DRC.

Ethnic-based militia conflicts in northern Katanga Province extend through 2015, with government forces targeting the Luba militia and other tribes.

M23 signs peace agreement at the end of the year.

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[109] "*UN Rights Chief Sees Possible War Crimes in the Congo,*" Reuters, September 9, 2009.
[110] "*UN has Failed Congo Mass Rape Victims, Says Investigator,*" The Guardian, September 8, 2010.
[111] "*Congolese Migrants Describe Horrific Abuse in Angola,*" BBC News, October 14, 2011.
[112] "*Congo's Army Accused of Rape and Looting as M23 Rebels Win Image War,*" The Guardian, November 26, 2012.

2014 DRC – Rwanda border clash.

2015 Constitutionally required presidential election delayed two years. Civil unrest begins breaking out.

Belgium-based IPIS releases Analysis of the Interactive Map of Artisanal Mining Areas in Eastern DR Congo, 2015 Update. After inspections of over 1,600 mining sites between 2013 and 2015, the report's conclusions included: (1) at least one armed actor (militia or state) was present at 56% of all visited sites, (2) the DRC army was found to be running mines accounting for 26% of the artisanal workforce.

Amnesty International releases "This is What We Die For", chronicling the fate of 40,000 children and others in artisanal mining for cobalt.

World Bank releases Harvard's Resources and Resourcefulness: Gender, Conflict and Artisanal Mining Communities in Eastern Democratic Republic of the Congo, taking a more detailed look at life in these communities. Conclusions include: (1) artisanal mining is one of the few economic opportunities remaining after rampant violence and disorder destroyed the traditional agricultural base; (2) mining provides income but the combination of debt bondage and misery of the hard labor is described by many as "slavery;" (3) women and other disenfranchised populations are generally relegated to marginal support roles – from running restaurants and transporting materials, to participating in transactional sex; (4) while money exists in the communities, much gets spent on substance abuse with little being sent back home to children and other family members; (5) close quarters and poor sanitation increase the risk of HIV/AIDS, physical trauma, diarrhea, tuberculosis, respiratory infections, malnutrition, and malaria; and (6) army and militia regulation of mines is not overt or physical, but enforced through links to powerful cooperatives, customary authorities, and taxation.

Dutch-based SOMO releases report Cobalt Blues, Environmental Pollution and Human Rights Violations in Katanga's Copper and Cobalt Mines. Conclusions include: (1) identification of specific water, air, and toxics pollution from mines including from operations approved by Ministry of Mines in areas which were preserved for other purposes; (2) disproportionate health impacts on towns and villages adjacent to mines, including "*people living close to DRC's mines had 43 times the level of cobalt, five times the level of lead, and four times the level of cadmium and uranium in their urine than is considered normal*;" and (3) failure of mining operators to follow DRC law and consult with impacted communities about prospective operations.

2017 Kamuuina Nsapu militia insurrection in Kasai Province (south central DRC). UN Joint Human Rights Office accuses DRC army elements of digging 42 identified and 38 likely mass graves.

Mai Mai militias form National People's Coalition for the Sovereignty of Congo in South Kiva, briefly captured several towns.

Internal Displacement Monitoring Centre issues report concluding about 1 million fled their homes in DRC in the first half of 2017, up from 922,000 for all of 2016 as a result of violence. The report also indicated a recent increase in refugees crossing into Angola, Uganda, and Zambia, increasing tensions with those countries. The upsurge in violence was blamed in part on the delay in the presidential election.

The Carter Center releases A State Affair: Privatizing Congo's Copper Sector, claiming that $750 million is missing from Gécamines' accounts.

Global Witness releases Regime Cash Machine, How the Democratic Republic of Congo's Booming Mining Exports are Failing to Benefit Its People, concluding that as little as 6% of annual mining exports reach the national budget.

2018 President Kabila announces he will not run for re-election. The main contenders are Interior Minister Emmanuel Ramazani Shadary, widely seen as a Kabila puppet and currently under a 2017 EU travel ban and asset freeze for "planning, directing or committing acts that constitute serious human rights violations," and two opposition candidates including Martin Fayulu, who is backed by Jean-Pierre Bemba, former Vice President and formerly-convicted (see above) war criminal,[113] and other opposition leaders barred from running.

2019 Release of election results delayed in early January, in a move widely seen as the government's attempt to rig the vote outcome in favor of Shadary after the Catholic Church released its own polling survey showing a "clear winner," likely Fayulu. The election has continued to be marred by a number of incidents including opposition charges that the new untested voting machines are subject to manipulation, violent crackdowns on opposition rallies, destruction of thousands of voting machines in the capital in a fire a week before the election, a shut-down of the internet and texting in the period following the election, and a recently revealed massacre of 535 by elements that appear to have included members of the army.[114] The US deployed 80 military personnel in adjacent Gabon in preparation to protect Americans and American interests during the unrest expected to break out after the results are finally announced.[115]

In a move widely perceived as a deal with the incumbent, the election commission finally announces that Felix Tshisekedi is the winner of the Presidential contest.[116]

113 "*Joseph Kabila Says He Will Not Run Again in Congo,*" The Economist, August 9, 2018.
114 *"Revealed: DRC's 'Invisible' Massacre,"* Sunday Times, February 9, 2019.
115 *"Tension Mounts as Congo's Election Commission Delays Results Announcement,"* Washington Post, January 6, 2019.
116 *"DRC Opposition Urges Civil Disobedience after Election Appeal Rejected,"* The Guardian, January 20, 2019.

Effects on the California Economy

The current policy reliance on promoting specific vehicle technology carries a range of risks to the California economy as it becomes increasingly reliant on a single energy source. These risks stem primarily from three factors: (1) growing applications for cobalt in the non-vehicle portions of the economy, (2) systemic risks associated with the dominant cobalt source, and (3) potential cost shifting embedded within California's current regulatory structure.

Impact on Other Industries: Competing Demand for Available Cobalt Supplies

Cobalt use is not limited to vehicle batteries. Traditional and emerging uses of cobalt are seen across the economy in addition to the now growing share for electric vehicle and electricity storage batteries. Chemical applications include use in animal feed additives, catalysts, paint drying agents, pigments, polyester, recording media, tires, and vitamin B12 along with rapidly expanding use of other rechargeable and non-rechargeable batteries for smartphones, tablets, laptops, tools, equipment such as forklifts, household equipment, other consumer products, and medical applications. Metallurgical applications include superalloys for aerospace parts, defense, power generation, and prosthetics; high-speed steel for cutting tools and maraging steels; carbide and diamond tools; and magnets including those used in electric vehicles, alternative energy generation, and a wide range of other product applications.

One estimate of current and projected demand for cobalt by use is summarized in the table below. While batteries (vehicles and other applications) are shown with the strongest growth, the other non-battery applications are still projected to expand by 8,000 mt (8%) in this period.

Total Cobalt Demand by Use (kt)

	2017	2025
Lithium-ion batteries	38	117
Super Alloy	35	44
Hard Materials	21	14
Others	42	48
Total	136	222

Source: McKinsey (2018)

The projected demand for uses other than batteries is indicated at 106,000 mt in 2025, or roughly the same as the 110,000 mt produced from mines in 2017. While none of the projections reviewed for this report provide specific numbers for lithium-ion batteries broken out by vehicle and non-vehicle applications, a rough estimate can be made from factors provided in the Deutsche Bank study. Adjusting the Deutsche Bank factors for products with subsequently slowing growth rates, total cobalt demand from the McKinsey numbers for uses other than electric vehicles and electricity storage batteries would be roughly 115,000 – 120,000 mt, or 5% – 10% higher than total mine production in 2017. Using the battery numbers in Avicenne Energy (2018) would result in a higher estimate for the non-vehicle/non-electricity storage increment at 20% - 30%.

Consequently, for the current policies not to have negative supply and input price effects on other sectors of the economy, the additional cobalt demand being mandated through the national and subnational policies likely will have to be met in total from mining expansions. While a small portion of overall demand can be fulfilled through current recycling operations now focused primarily on metallurgical products, most of the demand increments will require new virgin ore production.

California Industry with Likely Cobalt Applications, 2017

NAICS	Industry	Establishments	Employment
Non-vehicle Manufacturing			
32513	Synthetic Dye and Pigment Manufacturing	16	287
32551	Paint and Coating Manufacturing	163	2,757
32621	Tire Manufacturing	30	385
3311	Iron and Steel Mills and Ferroalloys	96	2,888
3312	Purchased Steel Product Manufacturing	90	2,481
33151	Ferrous Metal Foundries	74	3,102
332	Fabricated Metal Product Manufacturing	6,299	129,579
3325	Hardware Manufacturing	78	1,712
3326	Spring and Wire Product Manufacturing	131	2,927
3327	Machine Shops and Threaded Products	2,647	42,735
3329	Other Fabricated Metal Product Manufacturing	624	17,872
333	Machinery Manufacturing	2,990	74,727
334111	Electronic Computer Manufacturing	192	58,657
3344	Semiconductor and Electronic Components	1,469	85,599
3346	Magnetic Media Manufacture & Reproducing	133	4,866
335210	Small Electrical Appliance Manufacturing	52	428
33591	Battery Manufacturing	61	1,911
3364	Aerospace Product & Parts Manufacturing	577	74,631
3365	Railroad Rolling Stock Manufacturing	12	1,115
3369	Other Transportation Equipment Manufacturing	169	3,286
3391	Medical Equipment and Supplies Manufacturing	1,754	51,767
33993	Doll, Toy, and Game Manufacturing	126	2,690
	Subtotal	*17,783*	*566,402*
Vehicle Manufacturing			
3361	Motor Vehicle Manufacturing	69	13,204
3362	Motor Vehicle Body and Trailer Manufacturing	178	6,628
3363	Motor Vehicle Parts Manufacturing	529	12,789
	Subtotal	*776*	*32,621*
	Total	18,559	599,023

Source: Employment Development Department, Quarterly Census of Employment & Wages

Given the close margins to projected cobalt supplies, increasing vehicle demand, especially the accelerated demand anticipated through the 2025-30 period, is therefore likely to result in periods of supply and price pressures on these other parts of the economy, even barring delays or unforeseen barriers to planned mining expansions. These effects will vary depending on each industry's reliance on cobalt as a product input, but are likely to be more significant for consumer electronics, metallurgical, and medical applications where cobalt is more of a critical element.

Potential industries and employment within California that could be affected are summarized in the table above. Note this table is not exhaustive, but includes the industries most likely to be linked to cobalt directly or indirectly in at least a portion of their processes. The table also only covers manufacturing, and not related wholesale, retail, and service establishments.

The actual extent of potential effects will also vary by the nature and length of any future cobalt shortfalls, caused either through rising demand for vehicles and electricity storage as a result of disruptions due to over reliance on the DRC for this metal. Cobalt price increases—comparable to the tripling in price seen recently as a result of vehicle demand and the price spikes seen previously as a result of shortfalls in DRC production as a result of corruption, war, and civil unrest—will generally be more absorbable. Other than batteries, most other applications rely on cobalt for a smaller portion of total input costs. Any cobalt price increases, however, will be reflected in product prices and therefore likely result in at least some level of higher costs for consumers, businesses, and public services such as transportation, facilities, and healthcare. Supply shortages—such as those reported by many businesses towards the end of 2017 as vehicle battery cell production began ramping up—would have a more profound effect, resulting in production delays of those products and applications where cobalt is a critical component. Such delays carry the potential for much higher price impacts on consumers and other end users as product shortages occur in a domino fashion, along with consumer substitution for alternatives including, from a policy significance, ICE vehicles.

Individual California companies would be affected to differing extents based on their reliance on cobalt-dependent components. For example, in 2017, Apple's 10-K shows total sales of $229 billion, of which about 62% came from iPhones and another quarter came from other battery-containing products including iPads, Macs (all models), and other products.[117] Google reported earnings of $111 billion that year, of which around 2-3% came from devices such as cell phones, Chromebooks, and Google Home speakers.[118]

While these particular products generally are not produced in California, increasing materials prices and/or consumer battery supply disruptions such as those reported at the end of 2017 would have an effect on the individual businesses, and more broadly the state's competitiveness in these industries. The accelerated demand now being pushed by the national and subnational polices also is increasing the importance of the supply role represented by artisanal mining, increasing the difficulty of—if not outright mooting—the efforts of companies to ensure their products are not reliant on child labor and militia/DRC military controlled sources.

[117] Apple, Investor Relations, Earnings Releases and 10-K Annual Reports.
[118] "Google Says Device Shipments More than Doubled in 2017, Passed $100 Million in Annual Revenue," AndroidCentral.com, February 1, 2018.

From a consumer standpoint, the most likely impact would come from consumer electronics, although other product categories as listed above could also be affected. Using total US sales data from Consumer Technology Association[119] and apportioning based on population, Californians bought about $41 billion of consumer electronics in 2017. Even a 1% shift in price—as a result of higher battery costs or reduced product availability due to limited battery supplies—would produce consumer costs of around $400 million annually. While companies would vary in the degree to which they would absorb these costs, longer term instability in cobalt supplies would likely produce a more apparent price effect.

Impact from Increased Energy Dependence: Stability of Cobalt Supplies

Both current and recently enacted rules are pushing California increasingly to dependence on electricity as its primary if not eventually sole energy source. The core element, battery cells, for these energy policies on which California has now staked its economic future appears to be heading towards a far greater reliance on imports from a concentrating battery cell industry in East Asia than from any energy source in the past. Battery cell production in turn relies on cobalt production which is centralized to an extraordinary extent. Currently, 58% of world output comes from DRC, increasing to an estimated 75% by 2025 just as electric vehicles are expected under the regulations and policies to achieve a significant share of light duty sales and as reliable operation of the state's electricity grid will be demanding a higher degree of duplicative storage infrastructure to match an intermittent generating capacity.

To put this dependence in perspective, the US reliance on OPEC oil production reached only one-third of consumption at its highest point in 1977, dropping to only 17% in the most recent data for 2017.[120]

DRC's history as a stable source of supply, however, is marred by endless rounds of internal and external conflict—as most recently evidenced by two years of rising civil unrest stemming from the extra-constitutional delay of presidential elections—that has frequently devastated both mining and other sectors of the economy. Corruption has also been at a scale that has drained state mineral revenues from even basic maintenance—leading to physical collapse of mines—and even basic security—leading to several rounds of looting in the capital and other cities as DRC troops took it upon themselves to secure payment of their wages through any other means available to them. Artisanal production throughout the mining sector remains an important supplemental source of income to the national forces where it is controlled by military units, and a financial support for conflict where it is controlled by the militias.

The ambitious schedule for ZEV sales—especially in China and California—leave little slack between expected cobalt demand and anticipated supply expansions. The projections anticipate periods of shortage after the 2025 timeframe even with accelerated introduction of lower-cobalt

[119] "US Consumer Electronics Sales Expected to Reach Record $351B in 2018 with Help from Streaming Services," MarketWatch.com, January 8, 2018.
[120] US Energy Information Administration production, import, and consumption data.

chemistry batteries, and prior to 2025 if announced mine expansions are not fully completed or if production overall is negatively affected by the recent changes to DRC mining law.

DRC output has encountered disruptions in the past, and the circumstances that led to these events have changed little in the intervening years. While some element of stability may be introduced through increasing control of the DRC mines by China-based companies, it will come in tandem with increasingly monopolistic/autarkic attributes stemming from China's national policies.

While most other states have diversified their risk through a wider range of options under their energy strategies, California more than any other polity has tied its economic future to electrification and consequently to battery technology for both transportation and other purposes. This choice has already progressed through the current climate change and air quality regulations. This path has been strengthened by SB 100 (De Leon, 2018) mandating 100% renewables electricity generation and Executive Order B-55-18 directing the state's regulations to require overall economy "carbon neutrality" by 2045. Both requirements entail greater reliance on ZEVs as currently evolving under the state regulations and increased electricity storage, which under current state restrictions also largely means more reliance on batteries and assured cobalt supplies from DRC sources.

While lower- and even zero-cobalt battery chemistries may become more available in the post-2030 period, at least for the next decade or so this policy direction has the potential to put the state's economy at risk to disruptions from a source that has yet to demonstrate a long-term stability of supply. The economic risks are similar to the job and income dislocations the nation experienced from a similar over-reliance on a primary energy source during the 1970s oil shocks. A related policy risk stems from the potential for supply disruption just as ZEVs are being produced in larger numbers. At a time when consumer acceptance of this technology remains low and uncertain, such an event could have lasting effects on the foundational policy on which the state has now staked its climate change and air quality policies. This point is discussed further below.

Impact from Regulatory Framework: Cost Shift to Consumers

The auto industry has long considered ZEV development from a dual standpoint. From the engineering side, ZEVs have opened up new creative opportunities and offered a means to diversify the industry's risks away from price variances within a primary fuel. From the marketing side, concerns have always remained that a flawed introduction of these vehicles carries the potential to poison consumer acceptance, potentially delaying the growth of a significant market for some considerable time.

As discussed previously, consumer acceptance remains low even after a quarter century of ZEV promotion and product refinement. Even in California which has had some of the most expansive subsidies in place attempting to get consumers to buy these vehicles, total market penetration for battery vehicles (broadly defined) has remained stalled at just over 9%. While some movement may be possible as lower cost models are finally introduced, consumer behavior to date has instead been for buyers to shift from HEVs to PHEVs and BEVs rather than growth of battery vehicle sales more broadly. Uncertainty over longer term shifts in consumer acceptance is also reflected in the KPMG [2018] surveys of auto executives, which show significant levels of concern that battery vehicles may still prove to be only a transitional technology on the way to FCEVs. The trends in

ICE R&D still indicate an interest in further developing existing power trains towards lower or even net zero emissions.

The California policies, however, put these concerns to one side and rely on a de facto selection of battery vehicles as the foundational technology to achieve the climate change and air quality goals. The related plans require rapid and increasing sales of electric vehicles. The state is now expending substantial sums of both taxpayer and ratepayer dollars to create recharging networks for this identified technology just as it once intended to do so for methanol and other liquid alternative fuel vehicles. Expansion of the state's emission goals such as through SB 100 and Executive Order B-55-18—adopted even before the cost effectiveness of strategies to achieve the 2020 goal are known—make the ZEV components even more critical to the state's efforts.

The policy risk is what happens if cobalt supply disruptions—either from the systemic risks in the DRC source or supply diversions as China-based companies continue to secure available supplies—occur just as consumer acceptance is finally beginning to broaden? If short and temporary, the effect is likely to be absorbable within a few quarters. If longer or more frequent, the risks related to cobalt carry the potential to create the flawed introduction that would undermine the future sales around which the state agencies have crafted their regulatory plans.

The state regulations, however, have been built with a fail-safe element:

> *The aggregate emissions cap of the Cap-and-Trade Program ensures that the 2030 target will be met–irrespective of the GHG emissions realized through prescriptive measures. If GHG reductions anticipated under prescriptive measures do not materialize, the Cap-and-Trade Program will be responsible for a larger share of emissions reductions.*
> *CARB, California's 2017 Climate Change Scoping Plan, November 2017, p. 53*

Approved by the Legislature in 2017, the Cap and Trade program is set to automatically cover emission reduction shortfalls in the other regulations and policies under the state's climate change plan. In this case, the potential shortfalls would come from the ZEV provisions if consumers decide not to buy these vehicles.

Under the current regulatory structure, costs would shift and increase the compliance burden on facilities within the state subject to cap and trade, primarily energy and manufacturing facilities. The full cost of such a shift would depend on the extent of the ZEV shortfall and the degree to which the resulting regulatory costs would cause individual businesses to relocate production outside the state. An illustration of the cost to consumers, however, can be shown through the potential effect on gasoline prices.

In general, the Legislative Analyst's Office (LAO) estimates that cap and trade adds 8 cents per gallon for every $10 in allowance costs. The most recent (August 2018) auction had a current auction settlement price of $15.05, or an additional 12 cents tacked on per gallon of gasoline. As the cap gets stricter, allowance costs will rise. In a recent analysis of potential price ceilings being considered by CARB, LAO[121] indicated that gasoline prices would rise from 65 cents at an auction price of $81 to $1.20 at a price of $150. Scaling up LAO's earlier estimates,[122] these price increases

[121] LAO, Letter to Hon. Vince Fong, March 16, 2018.
[122] LAO, Letter to Hon. Vince Fong, March 29, 2017.

would result in households paying an additional $510 to $980 annually for fuel. LAO also indicated that the 8 cent factor they use in their estimates is based on taxes far less than the 65 cent level, and that *". . . there is greater uncertainty about the degree to which this assumption holds under higher allowance price scenarios."* The costs to consumers from the state's current policies due to future disruptions in cobalt supplies, therefore, are likely to be larger and far more significant.

Impact to State & Local Budgets: Fiscal Effects

The fiscal effects from the state's growing reliance on cobalt-related energy sources are difficult to estimate with any degree of certainty, and would depend on the nature and duration of any supply issues related to this metal. Using the consumer products example from above as a base example, the general nature of these effects would include the following:

- Short term cobalt price increase as a result of tightened cobalt supplies as mining production and ore processing expansions adjust to demand. Short term increases are more likely to be absorbed into costs. For every 1% increase in costs—directly from cobalt prices or indirectly from cobalt-related component shortages—state revenues would fall by about $36 million (evaluated at corporate income tax rate; businesses taxed at pass-through rates would be higher; annual equivalent).

- Short term cobalt supply shortfalls as a result of mining expansion delays or DRC unrest. The most likely response would be a delay in any affected product shipments. Assuming a net margin of 20%, every 1% decrease in sales would reduce state income tax revenues by $7 million (evaluated at corporate income tax rate; businesses taxed at pass-through rates would be higher; annual equivalent) and state and local sales tax revenues by $35 million (average state-local sales tax rate; annual equivalent). Some of these losses may be offset as consumers and employers adjust their spending for services and other taxable goods rather than for savings. Given the short product life-cycle for consumer electronics, the probability that sales would be lost rather than shifted into the future would increase with the duration of any shortfalls.

- Longer term price increases as a result of demand exceeding current projections or further actions within DRC to retain a greater share of cobalt mining revenues within the country, either through official actions or as a result of corrupt practices. The most likely response would be an eventual price increase for the affected products, with a possible longer-term response that would accelerate lower and zero cobalt alternatives development depending on the size of the increase. Business income tax revenues likely would be unaffected, but for every 1% increase in price, consumers would pay an additional $35 million sales tax (average state-local sales tax rate; annual equivalent) in addition to the higher product prices. Some of these gains may be offset as consumers and employers reduce their spending for other taxable goods.

- Longer term supply shortfalls as a result of substantial delays in new mine expansions, sustained civil unrest or conflict within the former Katanga Province region, or inability to sustain artisanal mining production under acceptable humanitarian and worker safety conditions. The most likely response would be higher price increases as industries compete for the available supply until lower and zero cobalt alternatives become cost effective and available in sufficient quantities, along with relocation of production into manufacturing environments such as China that have ensured longer term access to the available supplies. Business income tax revenues would be affected as firms shift their purchasing and locations. Every 1% increase in price would still result in consumers paying an additional $35 million in sales tax, but the price increases would likely be more substantial.

Similar revenue effects would result as the other industries with cobalt-dependent products cope with the same market changes.

For vehicles, the primary fiscal effect would be seen in sales tax revenues. Tesla is currently the only vehicle producer selling directly to consumers, but has yet to show an annual taxable profit and instead retains substantial loss carry-forwards to cover potential tax liabilities for some time to come.

Using the Tesla Model 3 as the base example, currently shipped models are being sold for $49,000 and higher,[123] placing them in the premium/near luxury category and generating sales tax of at least $4,200 a vehicle (average state-local sales tax rate). In contrast, a Ford Explorer SUV begins at about $32,000, yielding sales tax of about $2,700. Many current ZEV customers are likely to remain within the same vehicle cost category should ZEV offerings become limited temporarily or longer due to cobalt supply concerns, minimizing potential revenue impacts on state and local governments. However, ZEV purchasers are eligible for up to $7,000 in rebates, potentially more (or in the case of Tesla, somewhat reduced after this year) should current state proposals move forward to replace a portion of the expiring federal rebates for individual producers. Consequently, while ZEVs currently show a net fiscal cost of at least $2,800, a shift of consumers to an ICE alternative would result in a net fiscal benefit from sales tax alone, and more when taking into account ongoing fuel taxes and transportation improvement fees.

[123] "Tax Credit for $35,000 Tesla Model 3 Slips Away," Wall Street Journal, October 12, 2016.

Conclusions

- The history of California's Zero Emission Vehicle (ZEV) program includes frequent revisions to the regulatory requirements in accordance with periodic state-of-the-technology reviews. These actions were done under CARB's authority to adopt "technologically feasible" regulations, with this term being interpreted to include economics as part of the feasibility determination. This approach has been replaced by a belief that the technology instead will be economically feasible by the policy deadlines, resulting in substantial state subsidies and investments—paid by ratepayers and consumers of everything but ZEVs—being made based on this conclusion. The current policy framework largely assumes that all will be resolved through scale, that as production rises, efficiencies will arise to match battery supply growth better with overall demand and the availability of the required raw materials. The policies assume the technology will be there.

- While nickel and lithium also present challenges to fulfilling the ZEV goals, cobalt is likely to be the critical material determining the success or failure of California's policies along with the other national and subnational policies promoting broad use of electric vehicles. The accelerated sales schedules embodied in these policies in practice mean that compliant models and associated battery cell capacity must be designed around the chemistries that are available now or foreseeable on the commercial horizon. Regardless of public pronouncements, battery cell and auto makers are acting in a manner that indicates cobalt will be an essential component over the coming period, with lower cobalt applications more likely to be prevalent around 2030 and more exotic battery technologies at some point after. Cobalt will also remain in demand for its other growing uses, including metallurgical applications; chemical uses; and batteries for electricity storage, cell phones, electronics, tools, medical applications, and other consumer and commercial/industrial products.

- Under the current national and subnational policies promoting ZEVs, most analyses reviewed in this report anticipate that current plans for cobalt expansion still result in shortages sometime in the 2022 – 2025 timeframe. These shortages become all the more likely as battery cell makers, auto makers, and consumer product companies rush, as they now are, to lock in future supplies. The end result is likely to further cement this evolving industry in place where it is locating now, primarily in Eastern Asia and in particular in China. These anticipated shortages are also likely to come deeper and earlier if the policies are further accelerated prior to development of the required technologies and supplies. The possibility exists for cobalt expansion beyond what is now planned, but new mining capacity is determined by global price and supply conditions for copper and nickel, not cobalt which is mined as a co-product of these other two metals. For example, even though cobalt prices tripled since 2016, production declined and reserve estimates were unchanged in 2017 due to slumping Chinese demand for copper and nickel.

- Attainment of the state's policies consequently means tacit acceptance their fulfillment will rely on sourcing cobalt from the Democratic Republic of the Congo (DRC), which provides half of the world's supply now and an expected three-quarters within a few years. Through 2025, projections indicate all or more of current mine output will be required to supply the competing, non-vehicle cobalt demands. The additional demand required to supply vehicles consequently will rely on the currently planned expansions, almost all of which are located in DRC.

- By extension, attainment of the state's policies also means accepting the current conditions under which cobalt is produced within the DRC, and risking the state's energy, economic, and environmental future to supply disruptions such as those that have emanated from the DRC on a repeated basis. Corruption has also been at a scale that has drained state mineral revenues from even basic maintenance—leading to physical collapse of mines—and even basic security—leading to several rounds of looting in the capital and other cities as DRC troops took it upon themselves to secure payment of their wages through any other means available to them.

- Cobalt production within the DRC also entails a substantial component produced from artisanal mining which is marked by child labor, unsafe working conditions, and associated communities where women and other disenfranchised populations are generally relegated to marginal support roles including transporting materials and engaging in transactional sex. While efforts are exploring ways to provide some level of assurance that future cobalt supplies will be from "ethical" and child labor-free sources, their effectiveness relies on a level of administrative reach, corruption control, and sustained stability the DRC has been unable to maintain or even reach over the past six decades. Moreover, artisanal mining accounts for 10% of global supplies now, likely growing to 15% or more through 2025. As developed countries increase cobalt demand to produce vehicles for higher income buyers and $1,000 cell phones, the incentives to retain this scale of supply will only increase, especially in a country where two-thirds of the population lives in extreme poverty (less than $1.50 a day) and where most other income options have been destroyed by three decades of unrelenting civil unrest, civil war, and external conflict.

- At present, the typical BEV sold in California requires three times as much raw battery materials as one sold in China. While this differential may balance to some degree as longer range vehicles are produced for both markets, a significant portion in China and some other Asian nations will continue to be served by smaller urban vehicles and lower power vehicles such as two- and three-wheelers and low-speed electric vehicles. All other things being equal, providing the same number of vehicles in the US compared to other countries will require higher relative raw materials use, putting relatively higher stress on global cobalt supplies that are expected to be in short supply and consequently exposing the state's policies to higher supply risks. China and the other East Asian nations are proactively hedging these risks by building materials refining and battery cell capacity and securing near-monopoly control over the battery-critical materials. California has not even gone so far as considering whether changes to its CEQA, permit, and other regulatory delays could attract these investments and jobs to the state.

- The core element, battery cells, for the energy policies on which California has now staked its economic future appears to be heading towards a far greater reliance on imports from a concentrating battery cell industry in East Asia than from any energy source in the past. The fuel efficiency and vehicle emission standards have long been promoted in part on their role in promoting national energy security—replacing imported oil with presumably more secure domestic electricity supplies. At a time when the nation is now far closer to its energy goals through the increase of domestic supplies across the board—oil, natural gas, and alternatives as well—the vehicle policies now carry the potential to reverse this progress altogether.

- There are more than ample cobalt resources that would ensure attainment of even expanded ZEV sales goals using currently available chemistries, but they are in deep seabed deposits. They are not economically recoverable now and likely will not be for at best 5-10 years if ever. Moreover, these are marine resources that if proposed for development within or near its own jurisdiction California would vehemently oppose. While California has long consumed resources and products developed under conditions it does not allow within the state, these generally have been consumption patterns that have evolved over time as part of general economic trends. The difference with marine cobalt deposits is that their exploitation is now being considered by other nations as a direct result of policies California alone set in motion.

- The national and subnational ZEV policies—especially those with accelerated sales targets such as China and California—mean that mines, refining, converting, production, and assembly capacity for battery cells and vehicles as well now need to be sited, permitted, and constructed quickly. And these must be done on expedited timelines that California will not even allow to resolve its most urgent economic problems such as housing. Rather than producing jobs within the state, an industry California created through its regulations has now shifted its center to China. Rather than reforming its development procedures to ensure attainment of its vehicle goals, California's policies now rely on others making the decisions in a way it has not allowed itself to take.

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