# All Charged Up!

## Exciting developments are on the horizon in battery technology

DIVERSIFIED TRUST

**By Bill Spitz, Principal**

*As a Co-Founder of Diversified Trust, Bill has been instrumental in the ongoing development of the firm's investment platform. Bill also serves on the Board of Directors of Mass Mutual Financial Group, Acadia Realty Trust, and is Trustee emeritus of Kenyon College in Ohio. He authored Get Rich Slowly: Building your Financial Future through Common Sense and is a frequent speaker at financial conferences.*

Observers of the tech scene rightly wax eloquent about the amazing progress in areas such as robotics, artificial intelligence, big data, machine learning, natural language processing, and edge computing. However, there is another corner of the tech world that may at first seem pedestrian but is actually critically important to the future of electric vehicles, energy storage, and the convenience of all electronic devices. ***Batteries*** are currently experiencing significant reductions in cost. More important, there are really exciting developments on the horizon in battery technology that will result in dramatically increased efficiency and safety. As just one potential outcome, imagine an electric vehicle that would have a range of six hundred miles and require only ten minutes to fully charge; that could be a reality as soon as 2024! Similarly, phones may soon be charged with a cable in just one minute or continuously through the air without the need for any connection to an electrical outlet. Unfortunately, as is often the case, there are complicating factors. Batteries currently rely on highly specialized materials that are sourced from a small number of countries, some of which are politically unstable and hostile. Moreover, Chinese companies control almost 45% of global battery manufacturing including one (CATL) that alone controls 30%. This concentration obviously raises political and security concerns. Finally, some battery materials are in limited supply and also highly toxic which calls for a significant improvement in the world's recycling capability. First, let's consider the good news which is that the cost of producing existing battery technology is falling rapidly.

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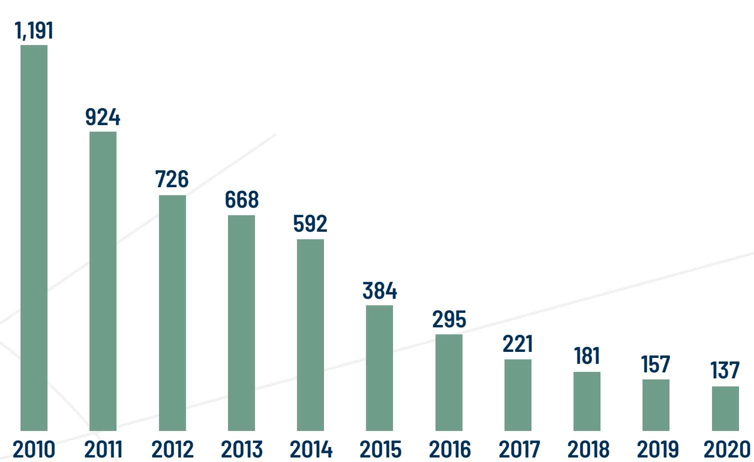
## WRIGHT'S LAW

Putting aside environmental preferences, the relative attraction of electric (EV) versus internal combustion (ICE) vehicles boils down to cost, range, and ease of recharging/refueling. First, we consider cost. The all-in cost of ownership has two components: initial purchase price and annual operating cost. The numbers vary somewhat depending upon the actual vehicles in question, location, insurance costs, the price of electricity and gasoline, miles driven, and so on. However, most studies find that EVs are 30% to 50% cheaper to operate, primarily because they have fewer moving parts resulting in lower maintenance cost. However, the initial purchase price of electric vehicles tends to be materially higher which leads to an all-in cost comparison that is a tie or only favors EVs slightly. However, this dynamic is changing quickly because of the declining cost of batteries.

The battery pack is the most expensive component of an electric vehicle representing about 30% of the sticker price. Wright's Law, also known as the learning curve effect, predicts that the cost of production will fall by a constant percentage for every doubling in the cumulative number of units produced. The constant percentage ranges from 3% to about 25% depending upon the industry and application. In the case of lithium-ion batteries, the figure has been a whopping 28%. As depicted in the following chart, the cost per kilowatt hour decreased from just under $1,200 in 2010 to $137 in 2020 with a further estimated drop to $132 in 2021.

**Lithium Battery Prices Plunge**

*Volume-weighted average of lithium-ion battery price from all sectors (in USD)*




Source: Bloomberg

The key point is that the decline in the cost of the battery pack is expected to make the initial purchase price of electric vehicles competitive with that of internal combustion vehicles by 2023. Combined with lower operating costs, a lower purchase price tilts the overall economics of ownership heavily in favor of EVs. What about range and convenience considerations?

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Consumer polls indicate that the major deterrent to purchasing EVs is the perception that their range is inadequate. (Known as "Range Anxiety") Here are the numbers. The range of the average internal combustion vehicle is about 300 miles. Depending upon the model, popular EVs can travel from 100 to 300 miles with the Tesla S an outlier at approximately 400 miles. So, many current EVs are indeed at a disadvantage. However, an important mitigant is the fact that 78% of commuters drive less than 30 miles per day. Given range anxiety, the next consideration is the availability of charging stations. Since the average commuting distance is quite modest, most daily charging takes place at home so concern only arises with regard to longer distance travel. There are roughly 44,000 public charging stations in the U.S. versus 137,000 gas stations so we obviously do have a way to go. However, most of the major auto manufacturers are shifting production toward EVs which will certainly stimulate the deployment of charging stations. In fact, a number of electric utilities, vehicle manufacturers, and start-up companies are well along in developing their own charging networks and this process will be further enhanced by the recently enacted infrastructure bill that includes $5 billion designated specifically for this purpose.

In addition to the availability of charging stations, the other major factor is the time required to recharge which varies according to the individual vehicle and the power of the charging station. The average EV requires about 8 hours to progress from empty to fully charged using what is known as a Level 1 charger that requires only household current. (However, some cars require as much as twelve hours) Level 2 chargers reduce charging time by one-half to two-thirds using a 240 volt, 40 amp circuit. However, whereas a Level 1 charger is generally included with the purchase of an EV, a Level 2 charger averages about $2,000 for purchase and installation. Finally, DC Fast Chargers require 480 volts of direct current but produce 100 miles of range in only 30 minutes. Once again, they are quite expensive to purchase and install. Importantly, most EV drivers "top up" which involves plugging in at the gym, grocery, or mall in order to gain extra range with a minimum of down time and inconvenience.

So, in reality, the necessity to fully charge a vehicle in one session should be relatively infrequent for most people. All in all, range and charging time remain an issue that should diminish with new technology and increased EV infrastructure. One window into the future may be Norway where two-thirds of new cars sold are electric vehicles and another 26% hybrids.

Solar energy is a topic for another day but the ability to store energy is a critical component of "green" power systems. Solar energy is generated during the day which is a period of low energy consumption in most households and then stored until the evening hours which is the period of peak usage. The most cost effective method of storage for residential applications is once again lithium-ion batteries that are packaged in products such as the Tesla Powerwall. As was the case with electric vehicles, these systems will produce increasingly favorable economics as the cost of batteries declines.

## WHIZ, BANG TECHNOLOGY

The key to evaluating future enhancements is a basic understanding of the anatomy of a battery. A battery is a pack of one or more cells, each of which has a positive electrode (the cathode), a negative electrode (the anode), a separator, and a liquid electrolyte. Briefly, lithium ions produced in a chemical reaction attach themselves to the carbon anode during charging. During discharge, the ions travel through the electrolyte and are released through the cathode in the form of electricity. Lithium-ion represents a quantum improvement over previous technologies such as lead-acid batteries but they still suffer from a number of shortcomings including:

- Long charging cycles, particularly to reach the 100% level
- Declining efficiency with the number of charging and discharging cycles. Ultimately, limited battery life
- Liquid electrolytes that are flammable occasionally producing fires and explosions
- Cathodes that are typically manufactured using cobalt and other rare minerals
- Sensitivity to both high and low temperature environments
- The necessity for a small computer to manage the battery pack as well as a cooling mechanism

In every corner of the globe, corporate and university researchers are working on the next generation of batteries. Not surprisingly, technical improvements are beyond the comprehension of most of us (including me), but they take the form of new materials for the electrodes as well as more stable electrolytes. For example, graphite anodes may be replaced by readily available alternatives such as silicon or carbon, and cathodes will likely be made from carbon, glass or other materials rather than cobalt and rare earths. Similarly, potentially volatile liquid electrolytes will be replaced by solid state substances such as polymers and inorganic compounds.

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The real question is: what will all of this mean for the performance of the devices in my life? Much of this technology is still in the laboratory stage, but dramatic improvements are likely in the next two to four years. Here are some of the claims that have been made by research teams:

- Future batteries are likely to be 100% recyclable and non-flammable
- A South Korean team claims its technology can achieve a 90% charge in six minutes
- An Israeli firm states that its battery will be 100% charged in 10 minutes
- A Chinese team has developed a battery that it expects will last for sixteen years and /or one million miles in an EV
- An Australian researcher's battery appears to hold three times the energy of current lithium-ion batteries of the same size

Some of these claims have been substantiated by independent testing laboratories. The most obvious and significant beneficiary of this new technology will be Electric Vehicles that will become mainstream given increased range and short charging time. One caveat is that rapid charging will require widespread installation of high voltage chargers.

Many of the improvements in technology will also transfer to smaller batteries used in a wide array of products. For example:

- Small devices may be recharged wirelessly using Wi-Fi or sound waves
- Smartphones will be recharged in one minute or less using a power cord
- New technology will allow everyday items to convert movement into power. For example, clothing, sidewalks, and car tires could all generate electricity
- Foldable and flexible batteries will enable many new applications
- Phones will eventually have a transparent solar screen that allows them to charge in sunlight
- And while unlikely to be available for some years, researchers are testing a technology that would magnetize roadbeds allowing for continuous charging of electric vehicles, particularly long haul trucks

***While not typically in the headlines, this is pretty heady and exciting stuff!***

## POLITICS, NATIONAL SECURITY, AND THE ENVIRONMENT

Unfortunately, the shift to EVs and other lithium-ion battery applications is not without important issues and risks. The first involves the source of the critical materials used in their construction. Two-thirds of the global supply of cobalt is mined in the Congo which has a reputation for labor abuses and bribery. In fact, cobalt has been labeled the "Blood Diamond of Batteries." While a number of large mining companies in the Congo operate responsibly, there is also an "artisanal" sector in which individuals including children scavenge on land owned by industrial mines in conditions that are unregulated and quite dangerous. Similarly, one quarter of the world's nickel reserves are found in New Caledonia with most of the remainder sourced from the Philippines, Indonesia, and Madagascar. Finally, 58% of the world's lithium is found in Chile, Argentina, and Bolivia. In addition to questionable labor practices in some instances, extracting all of these minerals requires a great deal of energy and results in large volumes of hazardous emissions and by-products.

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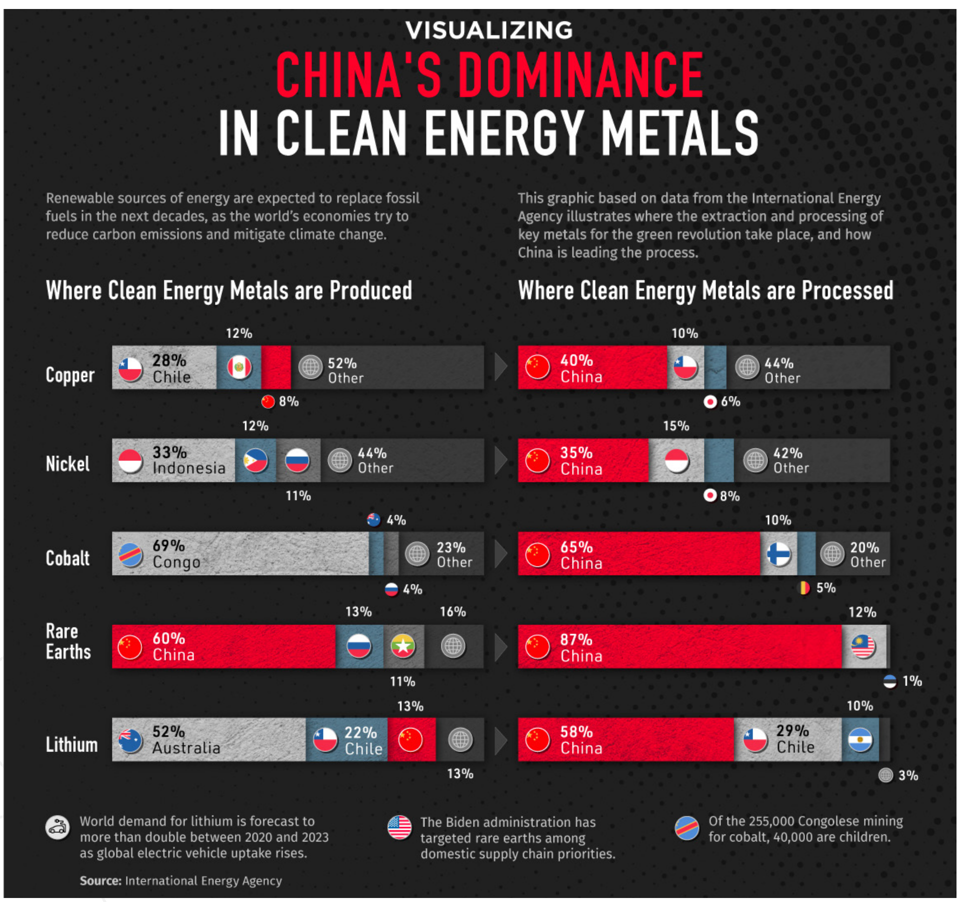
A second critical issue is the reliability and security of the supply of battery components and batteries themselves, and the focus of this concern is the dominance of China. In 2011, China designated batteries a strategic industry. Today, 15 of 19 cobalt mines in the Congo are either owned or financed by Chinese companies. Similarly, China owns or controls roughly 70% of the global lithium supply. Next, roughly 80% of the chemical refining capacity that converts lithium, cobalt, and other materials into battery ingredients is under Chinese control. China then dominates the manufacture of critical battery components such as electrodes, electrolyte solutions, and separators with more than one-half of global capacity. Finally, as previously mentioned, China manufactures about 45% of the finished product. In fact, China has roughly fourteen times the battery manufacturing capacity of the U.S. While the U.S. has a stated objective of ramping up its capacity, it obviously has a long way to go leaving us highly vulnerable to shortages and price shocks in the interim.




Source: https://elements.visualcapitalist.com/visualizing-chinas-dominance-in-clean-energy-metals/

## RECYCLING

Today, each EV has roughly 150 pounds of cobalt, nickel, lithium, and manganese. New technology may ultimately reduce the demand for these materials. However, until these technologies are actually commercialized, there will continue to be considerable demand for the materials currently in use. In fact, experts predict that the growing popularity of EVs will increase demand by five to ten times in the next decade. That amount would represent roughly five times current mining production. While there are significant reserves of these minerals, there is real concern that the hazardous waste and emissions generated in mining them will simply represent the substitution of one environmental problem for another. In other words, we may reduce carbon emissions into the atmosphere from internal combustion engines but increase other forms of pollution.

One of the solutions to this problem is a dramatic increase in recycling of spent batteries. Worldwide, only one-half of small device batteries are recycled with the remainder either tossed into landfills or left in unused devices. Europe and China are the leaders in recycling whereas various estimates suggest the U.S. only recycles 5% to 15% of discarded batteries. Moreover, a large portion of the spent batteries actually collected in the U.S. is shipped to China for recycling. In contrast, Europe currently recycles more than one-half of discarded electronic products.

Over the next twenty years, the number of batteries available for recycling is expected to increase four-fold as the first generation of EVs reaches the end of their useful lives and electronic devices continue to proliferate. More than a dozen companies are ramping up recycling capacity in the U.S. Interestingly, several have been funded by fossil fuel suppliers. However, two major problems remain. First, there is no uniform or consistent process to ensure that spent batteries find their way from the product user to a battery recycling facility. Many are tossed into the garbage or into aluminum can recycling bins creating real problems for traditional recyclers who are unable to process them. Second, while the actual recycling process is relatively safe, there were 245 fires at 64 waste recycling collection centers between 2013 and 2020.

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So, no one wants these collection facilities in their backyard which again raises the question of how batteries actually reach recyclers. One controversial answer might be increased regulation that would include both safety standards and even mandated recycling. At the moment, there are no Federal regulations and only two states mandate recycling although more than one half of the states have laws encouraging it. Of course, in our polarized political system, it would be very difficult to enact comprehensive regulation although both ends of the political spectrum recognize the critical importance of batteries to our economic future.

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## DO YOU WANT THE GOOD NEWS OR THE BAD NEWS FIRST?

This is the classic good news, bad news story. On the one hand, there are truly amazing developments in technology generally and batteries in particular that will change all of our lives. The bad news is that the U.S. is way behind the curve in battery technology. With China controlling the sources of raw material and dominating the manufacturing process, we are very much exposed. While China's economic growth has slowed somewhat, it is still developing a large consumer class that will demand electronic devices potentially limiting our supply. Similarly, we are exposed to potential price shocks. China currently manufactures about 45% of the world's electric vehicles which raises the specter of the decline or disappearance of the U.S. auto industry should it not be able to catch up. Finally, battery technology is obviously important to our military which results in risk to our national security. The recently enacted infrastructure bill does provide some funds in support of EVs but becoming competitive may well require a national industrial policy that entails massive public / private cooperation.

**ATLANTA**
877.955.8266

**CHARLESTON**
866.619.1003

**GREENSBORO**
855.821.4999

**MEMPHIS**
800.264.7498

**NASHVILLE**
877.386.7332