COBALT NEWS

October 2019

ELECTRIC CARS, RENEWABLE ENERGY AND COBALT DEMAND

LITHIUM AUSTRALIA ACHIEVES RECYCLING BREAKTHROUGH AFTER RECOVERING LITHIUM FROM SPENT BATTERIES

SUSTAINABLE BATTERY INNOVATION PILOT INTRODUCES NEXT GENERATION EV BATTERIES

THE CI IN PICTURES

Cobalt Institute

Promoting the sustainable and responsible use of cobalt in all forms

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RESPONSIBLE SOURCING AND THE ENERGY TRANSITION

Today, cobalt is considered a critical raw material by the EU and a strategic mineral by the US, largely due to its essential use in existing technology and improvement of new technologies from super-alloys and magnets to integrated circuits, actuators and re-chargeable batteries which in turn are currently essential to store renewable energy and to enable the energy transition to carbon neutral.

Cobalt's unique properties, particularly those related to providing better safety and stability in important applications, has positioned cobalt as a technology leading metal in many industry sectors, something clearly visible in the EV field where it plays a decisive role in the chemistry of batteries.

This prominent role has come with a growing interest from consumers and end-users and from regulators and policy makers about how this key resource is obtained and manufactured, which directly connects with the Cobalt Institute's mission of promoting the sustainable and responsible production and use of cobalt in all forms.

The Cobalt Institute acknowledges the need to work to achieve a sustainable energy transition and a true circular economy; for this reason, it encourages and supports initiatives and projects aimed at improving the way cobalt is produced and used. This commitment forms the basis of the Cobalt Industry Responsible Assessment Framework (CIRAF) initiative, launched by the Cobalt Institute in January 2019, which strengthens the ability of cobalt producers and buyers to assess, mitigate and report on responsible production and sourcing risks in their operations and supply chain.

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ELECTRIC CARS, RENEWABLE ENERGY AND COBALT DEMAND

by Greg Whiting, Professional Engineer, Certified Energy Manager; President Alpine Flamingo LLC (Seattle, Washington, USA)

Abstract

This paper explains why sales of vehicles that use cobalt-bearing batteries in their drivetrains (traction batteries) are poised to increase their combined share of the passenger vehicle market from 1% in 2015 to more than 60% by 2030. It discusses the favorable economics and policies driving the market towards battery-bearing vehicles, and highlights the remaining barriers to this growth. The most important barrier, the lack of an adequate supply of cobalt metal, is discussed in detail.

The market for vehicles with traction batteries is growing because total vehicle ownership costs are falling rapidly, and because there continues to be marketplace pressure from environmental policies. Technologies, policies and economics have each had a significant role in stimulating the rapidly-occurring change from vehicles that exclusively have internal combustion engines, to vehicles that also or exclusively have traction batteries. This paper discusses each of these factors. It explains why the change from combustion-only vehicles, to vehicles with traction batteries, is likely to be sustained in the long run. Vehicle economics and carbon dioxide emissions are discussed in detail; both show significant and increasing advantages for electric vehicles. The question of how electricity is generated, and its upstream effects on emissions, is considered, with due consideration of the also-ongoing rapid increase in renewable electric generation.

The paper then describes and analyzes the most significant remaining barrier to electric vehicle (EV) market domination: the cobalt (Co) supply. Although the lithium supply gets considerable publicity, several other metals, notably nickel and cobalt, are also required for the batteries used in electric and hybrid combustion/electric vehicles. The cobalt supply is more difficult to increase than the lithium and nickel supplies, because cobalt is often produced as a byproduct of other metals rather than being produced in its own right; thus, additional cobalt mining can require very high prices. Cobalt is, therefore, the metal most likely to stall EV market growth.

Movement to EVs has already affected, and will continue to significantly affect, the Co market. Current cobalt production rates are not sufficient to meet cobalt requirements for realistic electric vehicle growth projections. Investment in new Co mining activity is justified, immediately. Given the magnitude of the need for new Co, even if new mining activity is successful, and even if manufacturer efforts to reduce the cobalt content in batteries are successful, a significant increase in the cobalt price is likely.

1 The evolution of the electric vehicle market

JP Morgan's research group projects that the market share for hybrid electric/combustion (HEV), plug-in hybrid (PHEV) and battery electric (BEV) vehicles, combined, will increase to more than 60% of the global automotive market by 2030, up from about 1% in 2015 and 11% in 2020[i]. As recently as 1995, the automotive market was 100% internal combustion vehicles (ICVs). With improving economics and an increase in relevant policy-based driving forces, this transformative shift to electrified transportation is not only here, but is also likely to accelerate.

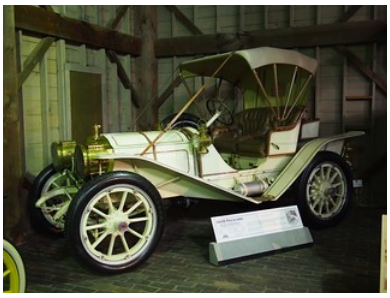
1.1 Why don't all vehicles use traction (drivetrain) batteries already?

The first mass-produced, fuel combustion vehicles *(whether gasoline, diesel or steam)* were unreliable, difficult to start and expensive, and the internal combustion vehicles were notoriously loud. Electric motors are reliable and quiet. The early auto industry made use of those attributes. In 1900, BEVs accounted for almost a third of the automotive market[ii]. HEVs were invented in 1901, but their primary advantage, better fuel economy, was not enough of an issue at that point to enable manufacturers to justify the cost and electromechanical complexity, so they were not introduced on any meaningful scale.

The only batteries produced in any large quantities during that era were based on lead/acid or nickel/iron chemistries. Both of those battery types are heavy relative to their contained energy. The batteries thus inherently limited the range of the vehicles; despite the efficiency of BEVs, much of the available energy had to be used to move the batteries, not passengers or cargo.

1905 battery electric car

1908 steam car



1908 internal combustion car

During the early days of the automotive market, combustion-based vehicles were unreliable, and all vehicles were limited in the distance they could travel by bad or unavailable roads, so the BEV's limited range between charging cycles was not a significant issue. Battery first cost was relevant, but all cars were hand-built and expensive. The additional cost of traction batteries was not significant enough for early ICVs to completely overcome BEV advantages in reliability, ease of starting and silent operation.

When mass production was introduced, though, the retail price of ICVs dropped very rapidly. No BEV *(or steam)* manufacturer successfully followed the lead of the ICV companies, notably Ford and General Motors (GM), into mass production. Without mass production, BEVs and steam vehicles became relatively unaffordable; ICVs and their low first cost became the industry standard. The technology disadvantages of ICVs were gradually overcome. Lead-acid batteries, ironically, contributed to the BEV's initial demise by powering starter motors, eliminating the need for hand-cranking and thus solving one of the ICV's biggest problems. Reliability and noise were eventually addressed by the ICV industry. Ultimately, BEVs were not able to keep up on first cost or range between refueling cycles, and their commercial production stopped in 1935.

1.2 Why did cars with traction batteries suddenly return after almost 80 years?

HEVs were reintroduced on a large scale with the launch of the Toyota Prius in Japan in 1997; plug-in hybrids soon followed. BEVs failed to make a comeback with the General Motors EV1 *(1996 – 2003)*. Then, against prevailing industry opinion, they did, starting with the Tesla Roadster in 2012.

Several major factors have enabled the recent success of EVs:

- Key technologies, the lack of which previously limited EV performance, have been developed and introduced on a large commercial scale, at affordable (and still declining) costs. The most important technologies have been low-cost computer chips, variable frequency drives, and advanced batteries.
- Range between recharging cycles, and time to recharge BEVs, have each been issues discouraging BEV use. Battery and charging technology improvements are making these issues less important.
- Legislative policies aimed at encouraging the production and sale of vehicles with high fuel mileage and low emissions have significantly contributed to HEV and BEV development.
    - There have been three waves of relevant policies. Some tailpipe emissions reduction and fuel mileage-related policies initially predated *(but have been updated, and are helpful to)* recent EV development. More recently, carbon dioxide-specific emissions reduction policies have provided a significant additional driving force just as key technologies became available.
- EVs have become competitive with ICVs on economics. Trends toward lower first costs and greater environmental regulation are likely to make EVs even more competitive economically.
    - Having now gained advantages from mass production, first costs of EVs are decreasing.
    - Maintenance costs are lower for EVs than for comparable ICVs.
    - Energy use, emissions and energy costs are lower for EVs than for comparable ICVs.

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<tr><th colspan="3">Major enabling technologies for today's electric vehicles</th></tr>
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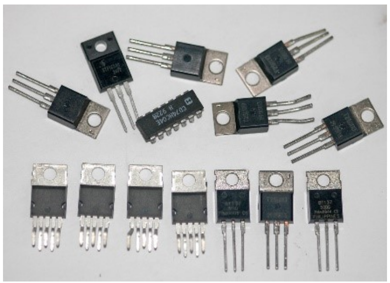
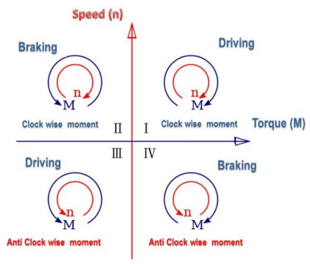
<td></td>
<td>
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<tr>
<td>Solid state electronic components</td>
<td>Computer controlled solid-state variable frequency drives</td>
<td>Advanced Ni/MH and Li-ion batteries</td>
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1.2.1 Enabling technology: Low-cost solid-state computers

Low-cost solid-state computers, based on integrated circuit chips and durable enough for automotive use, make it possible to control HEV drivetrains for optimum fuel mileage. Chips are also critical to managing the safe and automated recharging of EV batteries so as to ensure that the batteries will actually last for hundreds of cycles, rather than failing prematurely[iii], whether the computer is controlling charging from the grid or stored energy, or controlling charging via regenerative braking *(also see section 1.2.2)*.

Durable, inexpensive solid-state chips were not an option available to the initial *(1890s – 1935)* generation of EVs. However, by the time NiMH and Li-ion batteries became available, the required computer technologies were already on the market.

1.2.2 Enabling technology: Variable frequency drives

Chips enable the production of solid-state *(and thus durable enough for automotive use)* variable frequency drives (VFDs), which are also a key enabling technology for modern EVs. VFDs are used for efficient conversion back and forth between mechanical and electrical power. Although VFDs have been available for decades, modern solid-state VFDs have only been available since the 1980s.

Compact, durable, inexpensive VFDs are essential to several EV performance criteria, including cost, reliability, smooth acceleration and braking, and especially the use of regenerative braking. Via regenerative braking, energy that would otherwise be lost as heat in the brake system is instead diverted to recharging the traction battery.

- Regenerative braking enables HEV batteries to be recharged without plugging in the vehicle and is critical to the fuel mileage advantage of HEVs.
- Although PHEVs and BEVs can be plugged in, their net energy consumption is also reduced through the use of energy recovered from regenerative braking.

1.2.3 Enabling technology: Advanced batteries

Cobalt-bearing nickel/metal hydride (NiMH) and lithium-ion (Li-ion) batteries have overcome the deficiencies of lead/acid and nickel/iron as traction batteries. These new battery types contain more energy per unit weight than the older lead/acid and nickel/iron chemistries. They can be recharged for thousands of cycles and they do not require ongoing maintenance, such as water refills. Mass production of these battery types started in 1989 (NiMH) and 1991 (Li-ion).

In a HEV, the battery is a relatively small part of the overall vehicle weight, so the lightest Li-ion batteries were not necessary to launch HEVs successfully. NiMH batteries have been proven both reliable enough, and sufficiently tolerant to multiple recharging cycles, to make HEVs practical. When the Prius was designed, NiMH batteries, and their similar predecessor, nickel/cadmium (Ni/Cd) batteries, were available on a large scale. They proved to be sufficient to get the HEV market started. Today, some HEVs still use NiMH batteries, while others have converted to lighter Li-ion batteries.

BEVs require the lightest possible battery, to provide sufficient range between charging cycles for the mass market. The EV1 slightly predated large-scale availability of (relatively) lightweight Li-ion batteries. When the EV1 was being designed, the Li-ion battery was a brand new technology with safety issues. By 1996, when the EV1 was launched, the largest commercially available Li-ion battery was used in a laptop computer. The EV1 initially used heavy lead-acid batteries; because of its resulting high battery weight, it only had a range of about 50 - 90 miles before charging. Later versions of the EV1 used NiMH batteries and extended the EV1's range to 140 - 160 miles, but this change also extended the time required for a full battery charge from three, to eight, hours.[iv] Neither a 50 mile range nor an eight hour charge time are sufficient for mass market acceptance.

After the Li-ion battery was: available, proven reliable, and sufficiently mass-produced to make its cost acceptable for automotive use, the next BEV introduction attempt succeeded. Starting with the Tesla Roadster in 2012, the light weight and long cycle life of Li-ion batteries have enabled the production of BEVs with long ranges and acceptable charging times. BEV ranges between recharging cycles are now over 300 miles for several models, and are still improving.

1.2.4 Policy environment: Environmental concerns

Starting with California's first tailpipe emissions standards in 1966,[v] policies have been implemented globally to require and/or provide incentives, for increased control of tailpipe emissions, and also to require and/or provide incentives for indirect emissions reductions via fuel economy standards and fuel taxes. Early emissions standards were focused on airborne hydrocarbons, sulfur and nitrogen oxides, and carbon soot from diesel engines. Recently, a new generation of policymaking, such as Europe's Zero Emission Vehicle mandate, has focused on also reducing carbon dioxide (CO_2) emissions.

As shown in Table 1, all EV types are helpful in meeting emissions standards.

- HEVs use fuel and have tailpipe emissions, but an HEV inherently uses less fuel, and thus has fewer emissions, than a directly comparable ICV.
- Vehicles with electric motors at the wheels, including BEVs and fuel cell EVs *(FCEVs, which use hydrogen in fuel cells to produce their electricity)*, are more efficient than vehicles with combustion engines, including both ICVs and HEVs.
    - FCEVs are so much more efficient than ICVs that they would have lower CO_2 emissions than similar ICVs even if all of their hydrogen fuel was produced by removing carbon from natural gas. FCEVs can achieve zero CO_2 emissions if hydrogen is produced by electrolyzing water with renewable electricity. The only tailpipe emission of an FCEV is water. *(FCEVs will not be discussed in detail herein as they are in an earlier stage of commercial introduction [both the vehicles, and the required fueling infrastructure] than other EVs.)*
    - BEVs have no tailpipe emissions. Including the electric supply CO_2, a BEV will have lower CO_2 emissions than a comparable ICV in all cases – even in an unrealistic hypothetical case in which all electricity is generated using coal, the fuel with the highest CO_2 emissions. A BEV with a realistic generation mix, such as the US average generation mix shown in Table 1, would only have about a third the CO_2 emissions as a comparable ICV. Also, it is possible to achieve zero CO_2 emissions by charging BEVs exclusively with renewable electricity.

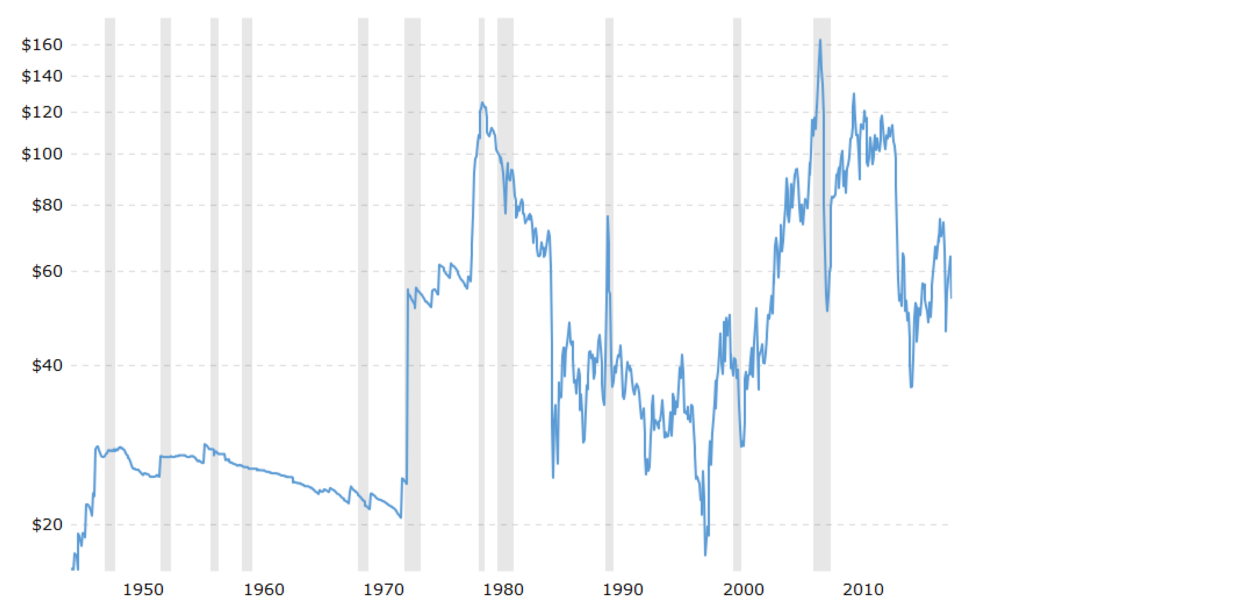
Table 1 Comparison of energy use and CO_2 emissions by vehicle type

	ICV	HEV	FCEV [vi, vii]	BEV
Fuel economy *(gasoline, hydrogen or electric)*	26 miles/US gallon gasoline	44 miles/US gallon gasoline	49 miles/kg hydrogen	26 kWh/100 mi
Annual energy use @ 12,000 miles/year	462 US gallons gasoline	273 US gallons gasoline	245 kg hydrogen	3,120 kWh
Annual energy use at point of use, equivalent BTU *	52,714,200	31,149,300	27,783,000	10,645,440
CO_2 emissions – best case *(100% renewable electric)* **			0 kg/yr	0 kg/yr
CO_2 emissions – average US fuel/electric sources***	4,107 kg/yr	2,427 kg/yr	2,424 kg/yr	1,431 kg/yr
CO_2 emissions *(hypothetical 100% coal electric)* ****			Not applicable	3,201 kg/yr
CO_2 emissions *(100% natural gas-derived hydrogen)*	Not applicable	Not applicable	3,432 kg/yr	Not applicable

* 114,100 BTU/gallon of gasoline; 113,400 BTU/kg hydrogen; 3412 BTU per kWh
** 8.89 kg CO_2 per US gallon of gasoline[viii]
*** Average 2017 US electric generation 1,849,749,927,000 kg CO_2 and 4,034,268,431,000 kWh.[ix]
FCEV estimate based on California requirement for 33% renewable hydrogen *(California is the only US state with significant hydrogen fueling infrastructure)*.
**** Coal power plants *(conservative)*: 10,500 BTU/kWh[x] and 97.7 kg CO_2/1,000,000 BTU[xi]

1.2.5 Policy environment: Oil prices and fuel mileage

The price of a barrel of crude oil increased from US $20/barrel in 1973, to US $124/barrel in 1980 *(both numbers inflation-adjusted to 2019 dollars)*.[xii] Additional short-term oil price spikes occurred in 1990 and 2008. Unstable and increasing oil prices attracted political attention; voters were upset that their personal budgets had been significantly disrupted by abrupt and substantial changes in fuel prices.



Oil prices in constant 2019 US dollars. Gray areas show US recessions.

The economy does not react instantaneously to oil price increases, but it does react; oil-related expenses affect every industry. High oil prices make goods, the delivery of goods, and transportation services more expensive in real-dollar terms. Each of the post-1970 recessions were shortly preceded by a significant oil price increase. The rapid change in the oil price was almost certainly either the major cause of each recession, or a significant contributing factor.

The political reaction in auto-producing nations to these sudden oil price increases has included legislation that encourages production and sale of vehicles with better fuel mileage. Several such policies have had the desired effect, and have significantly stimulated both the HEV and BEV markets. *(Compliance with these regulations, of course, also helps to achieve emissions goals and emissions concerns have also been relevant to the passage of these policies.)* For instance:

- Fuel economy mandates, such as the US Corporate Average Fuel Economy (CAFE) standards, have been implemented. Such standards require manufacturers to increase the average energy efficiency of the vehicles they sell. These policies encourage all EV types.
- Fuel taxes have been increased, notably in Europe, where fuel taxes alone can be as high as the retail fuel price in the US.[xiii] High refined fuel prices increase demand for energy-efficient vehicles.

1.3 Other vehicle types

Vehicles other than passenger cars and light trucks are beyond the scope of this paper. However, it should be noted that EV technologies *(hybrid, battery and fuel cell)* are being used in a variety of additional vehicle types, including but not limited to motorcycles, buses, forklifts and airport ground support equipment. Cumulative demand for batteries for these vehicle types is also growing quickly.

		
Electric motorcycle	**Electric bus**	**Airport ground support equipment**

2 Long-term sustainability of traction battery vehicle market share growth

JP Morgan projects that, by 2030, HEVs will capture 39% of the global automobile market share, PHEVs 2%, and BEVs 18%. These are dramatic increases from 1% for HEVs and nearly zero for PHEVs and BEVs, respectively, in 2015.[xiv] Nevertheless, this projected shift in the vehicle market from ICVs to EVs is expected to be sustainable, for a variety of cost, performance and policy reasons. These reasons will be discussed in detail in this section.

Vehicle manufacturers are planning for this market transition. Nearly all manufacturers have announced, or have already introduced, both HEVs and BEVs. A limited number of FCEVs are available.

- Toyota announced, in June 2019, that all of its models would have HEV or BEV versions by 2025.[xv]
- GM, initially perceived as reluctant to get into the BEV business following the failure of the EV1, is participating, with the Chevrolet Volt and Bolt, respectively, representing HEVs and BEVs in their current product line, and plans afoot to add a BEV to the Cadillac line.[xvi]
- Even Ferrari, previously publicly opposed to EVs, is now planning a BEV.[xvii]

2.1 EV cost and performance trends

Due to the first cost of batteries, HEVs and BEVs are more expensive than otherwise-identical ICVs. However, first costs are down substantially and are still falling fast. Some HEV models, with only slightly different features, are priced nearly identically to ICV variations of the same vehicle. BEV first costs are higher, but are falling and are becoming competitive.

In addition to first costs and financing costs, total costs of vehicle ownership include energy and maintenance. Electric costs are low relative to the cost of liquid fuels with equivalent energy content. EV maintenance requirements are also lower than they are for ICVs. Therefore, total lifetime costs are starting to favor HEVs, PHEVs and BEVs, relative to ICVs.

EVs have been accepted on most performance dimensions, no matter how performance is defined *(e.g., fit and finish; reliability; ease of use; acceleration…)*. BEVs still have a few specific performance issues as regards range and recharging time, which are being addressed in several ways as described further in section 2.1.2.3. It is reasonable to believe that these few remaining issues will ultimately be resolved, and that, in the meantime, they will not impair BEV market growth, because available BEVs are already good enough for enough consumers that their use will continue to grow while the technology improves.

2.1.1 HEVs vs. ICVs: Economic and performance details

HEVs are similar to, and are operated identically to, ICVs. HEVs have an internal combustion engine, but the engine does not run all the time. Instead, an HEV uses electric energy from its traction battery when it is idling or moving at low speed.

Honda Insight – one of the first recent hybrids

Since the combustion engine is frequently not running in an HEV while it would instead be using fuel in an ICV, HEVs offer up to twice the fuel economy of similar ICVs. The initial price of the HEV and ICV versions is similar, which enables the HEV version's total lifetime cost to be lower:

- For example, the ICV version of the 2019 Lincoln MKZ, a 4-door sedan, has a fuel mileage rating of 24 miles/US gallon (mpg). Its comparable HEV version is rated at 41 mpg.
- Over a ten-year life at 12,000 miles/year, the HEV MKZ would save its owner 207 US gallons of gas a year for a total of 2070 gallons; at US $3.50/gallon, the value of the gas saved would be US $7245 *(net present value $4973 at 7.5%)*.[xviii]

In a self-contained HEV *(one without the ability to recharge the battery from the grid)*, all recharging is based on regenerative braking. PHEVs are HEVs with an extended electric-drive capability. In addition to recharging the battery through regenerative braking, PHEVs also have a larger battery, and the ability to charge the battery from the grid. This increases all-electric drive time and improves net efficiency. Although there was some initial concern about hybrid battery life, batteries have improved significantly since the first hybrids were introduced. After years of experience, mid-life failures have been sufficiently rare that hybrid batteries are even starting to be regarded by car manufacturers as a lifetime component.[xix]

Car buyers are not concerned about the distance they can travel in HEVs, nor about refueling times. HEVs use conventional fuels *(gasoline and diesel)*. These fuels are widely available. Tank refilling times are consistent with consumer expectations developed through years of filling fuel tanks of ICVs.

There are a few purpose-built HEVs, like the Toyota Prius and Chevrolet Volt, but most HEVs are adapted from, and nearly identical to, the same models of conventional ICVs. Hybrids are thus very similar to ICVs as regards maintenance and repair.

- Maintenance on non-drivetrain parts *(body, interior, etc.)* is identical to ICV maintenance.
- A hybrid's combustion engine is nearly identical to the engine in a similar ICV, with the major exception of the systems associated with the traction battery. Drivetrain maintenance items *(e.g., spark plugs, oil changes, and starting-lighting-ignition lead/acid batteries)* are all still required.
- The traction battery and its subsystems can require maintenance and repair, but they are very reliable. These HEV systems are now widely understood by auto shops and emergency first responders; consumer concerns about them are no longer a significant obstacle to mass-market HEV adoption.

2.1.2 BEVs vs. ICVs: Economic and performance details

Modern BEVs, while slower to reach the market than HEVs, are now approaching critical landmarks that support projections for exponential demand growth. Key landmarks include competitive lifetime costs, and competitive performance even when considering range and charging constraints.

2.1.2.1 BEV economics

Large-scale battery and BEV production have dramatically reduced the first cost of a BEV. The only BEV available in 2008, the Tesla Roadster, had a list price of $112,000. Today, several BEVs, including models from several traditional auto companies, have list prices below US$40,000.[xx]

Tesla Roadster

BEVs have lower energy costs than ICVs, and require less maintenance.

- The motors at a BEV's wheels rotate; there is no need for the complex and heavy parts required to convert the up and down motion of ICV pistons into wheel rotation. BEVs are thus much more efficient than ICVs. The cost of energy for a BEV is usually much lower than for a comparable ICV, with a few very unusual exceptions, e.g., oil-producing countries which significantly subsidize petroleum fuels.
- Maintenance costs for BEVs are lower than for ICVs. There is no need to change oil, or for replacement of parts *(coils, spark plugs, mufflers, etc.)* used to create, and deal with the byproducts of, combustion.

BEVs are, therefore, becoming cost-competitive with ICVs when lifecycle costs, rather than first costs, are considered. Table 2 illustrates BEV economics via a hypothetical case with realistic cost and energy use assumptions. Each vehicle is driven 12,000 miles (19,000 km) per year. The net present value of the lifetime cost of ownership of the BEV is only about US $5,000 more than the cost of the ICV, despite a US $22,000 first-cost disadvantage. As BEV prices continue to fall, this gap will continue to close.

Table 2 Comparison of lifecycle costs of ICV vs. BEV (all currency numbers in US$)

Assumptions	**ICV**	**BEV**
Initial base price of vehicle	$25,000	$40,000
Price after 8.25% sales tax/VAT	$27,063	$43,300
Down payment @ 20%	$5,413	$8,660
Amount financed @ 7.5% for 6 years	$21,650	$34,640
Total interest	$5,302	$8,483
Install home EV charger	$0	$3,000
Energy economy *(ICV: gasoline; BEV: electricity)*	26 miles/US gallon	26 kWh/100 miles
Annual energy use	462 gallons	3120 kWh
Annual energy, gas @ $3.50/gal, electric @ $0.12/kWh	$1,617	$374.40
Cost comparison results		
Total cost of vehicle including financing & EV charger	$32,365	$54,783
10-year total energy cost	$16,170	$3,744
10-year total maintenance *(ICV $1,000/yr, BEV $500/yr)*	$10,000	$5,000
Assumption: Sell after 10 years @ 20% of base price	($5,000)	($8,000)
Sum: Total cost of ownership, simple	**$53,535**	**$55,527**
Total cost, net present value (NPV) @ 7.5%	**$41,535**	**$46,506**

In some markets, the calculations for Table 2 show that low electric prices, high gasoline prices, and *(in the near term)* tax credits and subsidies ***already*** favor BEVs on a lifetime cost basis. For instance:

- British Columbia has gasoline prices of C$ 1.58/L *(about US $4.50/US gallon)* and electric prices of C$ 0.125/kWh *(US $0.0938/kWh)*. In BC, the NPV of the BEV in Table 2, over ten years, is only $1,239 more than the ICV…before considering Canadian federal and BC provincial EV incentives, which can be up to C$ 10,000 *(US $7,500)* and thus tip the scale in favor of the BEV, in this case.

2.1.2.2 BEV performance advantages

BEVs have additional performance advantages over ICVs:

- Lower costs of maintenance also mean that consumers are not as often inconvenienced by the need to have their car out of service for routine maintenance *(e.g., BEVs do not need oil changes)*.
- At low speeds, BEVs are nearly silent. The European Union is now requiring them to add artificial noise, at 56 decibels (dB), to protect pedestrians. For comparison, average ICVs at 30 km/h average about 66 dB. *(At high speeds, noise differences are not significant.)*[xxi]
- The lack of mechanical inertia in the drivetrain, and the ability of electric motors to deliver full torque instantly, gives BEVs better acceleration than similar ICVs. For example, a 2019 Tesla Model S-LR, a sedan with a nominal price of US$84,200 and a range of 355 miles between recharging cycles, claims an acceleration time *(0 - 60 mph)* of 3.0 seconds.[xxii] A 2019 Porsche Panamera 4, a similar car with a nominal price of US $90,900 and a range of 520 miles, claims a 0 - 60 time of 5.2 seconds.[xxiii]

2.1.2.3 BEV performance concerns

Some performance concerns have slowed adoption of BEVs: long-term battery life; range between recharging cycles; the time it takes to recharge; and whether recharging infrastructure is available. However, all of these concerns are being addressed. Battery reliability and lifecycle have been proven satisfactory by the current inventory of EVs. The other three concerns are still relevant, but further improvements are expected.

It is realistic to believe that all four concerns have been resolved for many consumers, but that many of the potential buyers at the current state of the technology are still unaware of the current state of the technology. If consumer education about BEV technology is improved, these issues – other than, possibly, a need for more rapid enough installation of fast charging infrastructure – should not impede expansion of BEVs to an 18% share of the total passenger car market by 2030.

2.1.2.3.1 Battery reliability

When modern EVs were introduced, there were questions about whether the batteries would be durable enough for service in automobiles. Consumers want to be sure that auto batteries are reliable and that they will not have to replace the battery, which is the most expensive part of an EV, prematurely.

NiMH and Li-ion batteries are capable of being recharged for hundreds of cycles if managed carefully. EV chargers are programmed to maximize battery life. Charging is controlled by an on-board computer that accounts for battery management practices such as not fully discharging *(or, indeed, fully charging)* the battery, not charging too fast and not charging too slowly. Performance does vary; consumer usage practices will affect battery life no matter what the manufacturer programs into the charging computer.

EV batteries no longer appear to be a significant consumer concern; they have proven to be both durable and reliable. In 2015, a study of 35,000 Nissan Leafs in Europe showed only 0.01% had experienced battery failures bad enough to disable the vehicle. The comparable statistic for ICV engine failures over the same time period was 0.26%.[xxiv] Manufacturers know that EVs will not sell to people who are very concerned about battery life, so they offer substantial warranties.[xxv] In a Volvo survey,[xxvi] batteries were not specifically listed in the top seven concerns of potential buyers. Cost of service and repair was a top seven concern, but EV drivers were less concerned about it than average drivers.

2.1.2.3.2 Range between recharging cycles

Range between recharging cycles, for the original Nissan Leaf *(the first relatively low-cost current-generation BEV, introduced in 2010)*, was only about 60 miles. This has improved very substantially; the current Leaf has a 150 mile range with an optional 40 kWh battery. Although there are a few models that still have low ranges, presumably to minimize first-cost pricing, most of the BEVs now available in the US have a range of more than 200 miles, with the highest 370.[xxvii] For comparison, ICV ranges, depending on mileage and fuel tank size, routinely exceed 400 miles.

The perception of low range *(aka "range anxiety")* has persisted even as ranges have improved; 58% of consumers in the above-referenced Volvo survey reported that the possibility of running out of power was a barrier to BEV purchase. In the US, which is noted for having more long-distance trips than most countries, 93% of daily total driving distances are under 100 miles, even including rural drivers who have longer-than-average trips. The average daily driving distance for urban-based cars is 36.5 miles, and the average for rural-based cars is 48.6 miles.[xxviii] Therefore, an EV with a range above 150 miles is practical for most users at most times, even if they want to retain a safety margin for unexpected trips, as long as reliable daily recharging *(e.g., at home)* is an option. The Volvo survey reported that 51% of vehicle charging is done at home; charging at home at the end of each driving-cycle day is an option for many.

Elimination, or even reduction, of range anxiety will significantly improve BEV sales. Experience in markets in which range is not an issue already shows this:

- In Honolulu, Hawaii and Juneau, Alaska, distances are inherently limited. Honolulu is on a small island; the longest round-trip drive theoretically possible is about 74 miles and most drivers average less than 40 miles a day. Juneau is physically separated from roads outside its immediate area by open water and a glacier; its maximum single-round-trip distance is even shorter.
- BEV range anxiety is thus less likely in Honolulu and Juneau – and, as would be expected, EVs sell better in those markets. In 2018, BEVs had a 2.2% market share in Honolulu and 3.5% in Juneau, compared to a US national average of 0.9%.[xxix]

The ability to take one-off long-distance trips will still be relevant to many drivers. This can be addressed through charging infrastructure expansion and fast charging. Both are getting significant attention. Another alternative that does not require any technology or infrastructure improvements would simply be a marketing technique…offer BEV owners a loan or rental HEV/ICV.

2.1.2.3.3 Time required to recharge

As a matter of daily routine for a vehicle that will be traveling cumulative distances well under a BEV's total range, BEV charging is faster than ICV fueling. Recharging, unlike refueling, can take place while the consumer is away from the vehicle, in a parking spot that would normally be used anyway, without a special stop at a refueling station. Top-up recharging is automated by the computers in the cars and/or the recharging stations; all the consumer needs to do is plug the car in to charge it, and unplug it before leaving the parking space.

Charging this way effectively only takes a few seconds for the user. If a particular BEV is used for daily commuting, errands and other short trips and has enough range to return to a predictable location with charging infrastructure at which it will be parked for a long time *(e.g., home or work)*, BEV charging is faster and more convenient than ICV fueling.

Some potential buyers are, nevertheless, concerned that BEV recharging takes too much time. Since routine recharging is trivial, the degree to which recharging time is related to either consumer education, or to the question of whether BEVs have sufficient range to support unexpected side trips and long trips.

If a BEV user is caught in a situation in which fast charging is desired *(e.g., the vehicle does not have enough range to get home, or the user wants to take a long trip that will require en-route* *recharging)*, recharging speed is relevant. The benchmark for full charging is that ICV fueling takes about 10 minutes. Ideally, full recharging of a BEV during a long road trip would take a similar amount of time. Charging time is limited by the battery and its programming, and by the power that can be delivered by the charger.

As regards the chargers themselves, there are currently three types, in order of slow to fast charging times: Level 1, Level 2 and Level 3.

Level 1 chargers are designed for common 120 volt, alternating current (VAC) outlets. No special installation is required. No equipment other than a Level 1 cable *(supplied with all EVs)* is required. Level 1 chargers are slow; they deliver energy to the battery at a rate of about 1 kilowatt-hour per hour (kWh/h).[xxx] *(For reference, the new 150 mile Leaf has a 40 kWh battery and the Tesla S Long Range has a 100 kWh battery)*. Level 1 chargers are thus best suited for use at parking spaces at which the vehicle will be parked for a long time *(e.g., home or work)* to keep the car topped up. An EV that uses 26 kWh/100 miles, with a 25 mile commute, can be fully recharged with a Level 1 charger during 6.5 hours of an 8 hour workday and then again overnight, always leaving a distance reserve for unexpected or side trips *(assuming full recharging will then take place at some point)*.

Level 1 chargers can be used at most conventional electric outlets *(whether 120 or 240 VAC, depending on the country)*. This helps alleviate the worst range anxiety; such outlets are installed in virtually every permanent structure in most countries. Therefore, top-up charging is possible at virtually any location with electric service, if permission can be obtained from the owner of the outlet. In an emergency, short-term access to outlets not typically used for charging can often be negotiated. It is not necessary to fully charge a BEV to drive it any more than it is necessary to completely fill an ICV's fuel tank; emergency Level 1 charging will often enable drivers to extend BEV ranges long enough to reach a Level 2 or 3 charger. Availability of small amounts of fuel for an ICV with an empty tank can easily be a more significant problem.

Level 2 chargers are attached to their own local infrastructure, e.g. a wall, or a bollard specifically designed for the chargers. Cables are attached to the charger itself and do not travel with the car. Level 2 chargers are designed for 240 VAC electric service and deliver energy much faster than Level 1 chargers. Level 2 charge rates vary between 3 - 20 kWh/h, *(the average is 6 kWh/h)*, but some vehicles may have built-in limits. Use of Level 2 chargers at home, at work and at public parking spots can increase net range between prolonged fueling cycles, reducing concerns about the amount of time a full charge takes.

Level 3 chargers and Tesla Superchargers, both of which are also permanently installed, are just starting to be deployed. They operate at charging rates from 20 - 50 kWh/h. Not all BEVs can use them, but BEVs designed for long-range trips usually can. At 50 kWh/h, a full charge for a vehicle with a long range 100 kWh battery would take two hours. Although still not ideal, this is practical for most users, and charging rates are still improving. In April 2019, independent testing showed that a Tesla Model S long range can be driven from San Francisco to Los Angeles (365 miles) without recharging.[xxxi] Few trips are longer than that during one day; top-up charging during driver rest and meal stops can further extend a one day range. Then, overnight charging can enable full-range driving on the next day.

		
Level 1 charging cable	**Level 2 public charging station**	**Tesla supercharger**

2.1.2.3.4 Refueling/recharging infrastructure and recharging infrastructure availability
In the Volvo survey, 49% of potential BEV buyers expressed concern that charging stations are not widely available. Even if the trend towards faster charging technology eliminates charge rate as a significant issue, large-scale BEV deployment requires easy availability of at least Level 2, and ideally Level 3 or better, chargers in a broad range of publicly-accessible parking spaces. Large-scale availability of Level 2 and 3 chargers is currently a barrier to large-scale BEV use.

Further expansion of both Level 2 and Level 3 charger availability is essential to enable BEVs to reach their projected 18%-by-2030 market share. If fast charging stations can be made widely available at typical destinations *(e.g., work, shopping areas)* and locations where drivers stop on a transient basis *(e.g., turnpike restaurants, hotels, filling stations)*, concerns about both range and charging time would be significantly reduced.

Installation of fast chargers at publicly accessible parking spaces requires satisfactory economics and, in some cases, legislation. For instance, charging systems are not particularly difficult to install but do require that the parking places have power.

It will take time for parking space owners *(private or public)* to make the business case for, finance, and install, bigger electric service equipment and the chargers. Charging can be a profit center, or it can be subsidized or offered free *(e.g., to attract BEV owners to businesses that offer free charging)*. Installing chargers at public parking spaces may require local policy changes, which are inherently slow even when desirable, and may also require changes to utility infrastructure.[xxxii] All of these issues can be addressed – but addressing them will take time, business cases, and, in some cases, minor legislation. Further details are beyond the scope of this paper.

Older multifamily complexes and public parking spaces may not have a Level 2 charger – or even an outlet suitable for Level 1 charging – at all. EV users with single-family homes typically install a Level 2 charger at their home. New condominium and apartment complexes will sometimes have one or two Level 2 chargers, but are unlikely at present to have them in a sufficient number of parking spaces to support mass adoption of EVs. Workplaces and destinations *(e.g., hotels, shopping malls)* may or may not have Level 2 chargers.

Widespread availability of Level 3 chargers, and BEV upgrades so that all new vehicles can use them, are both in process and can be expected to significantly reduce charging time anxiety. Using the Tesla S Long Range as an example, one hour of fast Level 3 charging during a meal would be enough for about 200 miles of range, which would get most long-range drivers to the next bathroom or meal stop.

2.2 Policy trend towards BEVs

Energy efficiency, the ability to charge BEVs with renewable electricity, and low emissions are interrelated. All of them encourage policies that favor BEVs. Traditional emissions – airborne hydrocarbons, sulfur and nitrogen oxides, and carbon soot – continue to be issues. However, most new environmental legislation is aimed directly at reducing CO_2 emissions. Some of the various new policies indirectly favor EVs, e.g., by discouraging ICVs, by taxing ICV fuels or by taxing or restricting carbon dioxide emissions. Other legislation explicitly favors EVs. This legislation is often very aggressive, e.g., mandating EV sales targets that would have been viewed as technologically impossible even ten years ago. Just as a few of many examples:

- In Europe, the city of Paris intends to phase out legacy vehicles by 2030,[xxxiii] and several countries are considering regulations that will ban ICVs entirely in favor of electric or hybrid vehicles.[xxxiv] The UK has a 2040 target for banning vehicles without plug-in capability, and is considering accelerating the deadline to 2035.[xxxv]
- North America is moving more slowly, but in the same direction. California initiated zero-emissions vehicle rulemaking in 1990, and, as of June 2019, requires that 22% of vehicles sold in California be zero-emissions by 2025.[xxxvi] British Columbia has mandated 10% zero-emission vehicles by 2025 and 100% by 2040.[xxxvii] Canada has also implemented a carbon tax that affects petroleum fuel prices *(details vary by province)*.[xxxviii]
- In Asia, Israel is planning to ban the import of gasoline or diesel cars starting in 2030.[xxxix] The Chinese government has not only set minimum targets for PHEV/BEV/FCEV market share, but has also provided road space quota incentives for EVs, has built charging infrastructure and has mandated charging station-enabled parking in new residential and public parking complexes.[xl]

2.2.1 Intersection of policy and technology: Renewable electric generation

The electricity supply industry is moving towards a lower-CO_2 generation mix, for reasons similar to those driving EV expansion. Energy policies provide for: direct emissions controls, economic incentives against emissions, and economic incentives that favor low-emission generation technologies. The policy reasoning favoring renewable generation is largely emission-based. Sulfur and nitrogen oxides from all fossil generating plants, and fly ash and mercury from coal plants, remain relevant. As with vehicles, carbon dioxide concerns are driving a new generation of policies.

Costs of renewable generation are declining. Again, as with EVs, mass production and technology improvements are lowering costs. As the use of renewable electricity increases and its costs decline, it is reasonable to expect still more policy and economic pressure that favors EVs.

There are four major, widespread, renewable electric generation types: hydroelectric, geothermal, wind and solar. Hydroelectric and geothermal generation are well-established technologies with low costs. Growth of hydro and geothermal power is restricted by the difficulty of finding suitable resources; the geological conditions that enable construction of these power plant types are not available everywhere.

			
Hydroelectric generation	**Geothermal generation**	**Wind generation**	**Solar generation**

Wind and solar resources are available over a wide geographic range, but have not historically been economic in most locations. That is changing. At about the same time that advanced batteries became available, aggressive policies like renewable tax credits encouraged production of wind and solar generation systems. As those initial solar and wind systems started to be installed on a large scale, the technologies were developed further. Costs declined. More legislation favoring solar and wind energy was passed. Over the last 20+ years, policies and lower costs have reinforced each other in driving large-scale development of both technologies. These developments have now driven the cost of wind and solar generation down substantially. In many markets, costs of renewable electricity per kilowatt-hour are now competitive with the costs of electricity generated with coal or gas.[xli]

Lower battery costs are not only affecting the vehicle market. They are also starting to have a favorable effect on the overall feasibility of using renewable energy on a large scale. Non-intermittent "baseload" power is needed to provide energy when renewable sources aren't available, and to stabilize the electric grid when the inherent variability of renewable sources is significant. Batteries are starting to reach a cost at which they can be used for economic electric storage,[xlii] which, in turn, is likely to increase the use of wind and solar energy by reducing grid stability issues associated with the intermittency and variability of those energy sources.

Large-scale EV production may itself soon contribute to lower renewable energy costs. Planning is underway, at electric utilities, for some degree of use of the EVs themselves to help stabilize the grid, and also for old EV batteries to be used by utility distribution systems, which would reduce energy storage costs and improve renewable source viability. The latter system would also provide additional residual value for used EVs.[xliii]

2.2.2 Renewable generation, advanced batteries and the cost of electricity for BEVs and PHEVs

Low rate periods for electric customers – specific hours of the day during which electricity is less expensive – are a well-established concept within utility rate structures. Electric systems tend to be overbuilt for most hours during a year because they have to supply electricity during the highest peak of demand for their geographic region. During other hours, capacity remains unused. Off-peak rates can be substantially lower than on-peak rates; often, without an off-peak rate, fuel will be burned but the energy will not be used because the overall system has to produce a certain amount for system stability.

In markets where very low electric rates are available, energy costs for BEV users who only charge their cars during those rate periods can further close the cost gap between BEVs and ICVs. For example, a recent Rocky Mountain Power rate schedule offered a US $0.03/kWh discount for off-peak charging.[xliv] *(Fuel prices are relatively low in some of the same markets, so the net effect will not be significant everywhere. EV economics need to be analyzed within the context of each individual market.)*

Large-scale renewable installation has the potential to provide additional opportunities for low-cost rate periods. The trend towards more renewable generation is increasing the number of hours and places in which retail rates are low during certain hours. In California, significant installation of solar power is likely to eventually drive rates down in the late afternoon, and in Texas and Washington, oversupply of wind has, in some recent years, even occasionally driven wholesale electric prices negative *(i.e., the generating utility pays customers to take electricity)* during some overnight hours.

Utilities and regulators *(e.g., public service commissions)* are giving consideration to new relevant policies, such as but not limited to: BEV charging time-of-day incentives, BEV use rates, and even incentives for consumers to make their BEVs available during certain hours to provide electric storage support to the grid. Such policies and practices may further incentivize BEV ownership.

3 Effect of electric vehicles on cobalt demand

Li-ion batteries for BEVs require many more metals than just lithium. They also use up to 15% *(by weight)* cobalt (Co) in the cathode, which is usually made from lithium (manganese, nickel, cobalt, aluminum) oxides. HEVs require up to 2% *(by weight)* cobalt for their nickel-based traction batteries.

3.1 Sustainability of use of cobalt in batteries

Despite its rapid growth over the last few years, the rechargeable battery industry is based on only a very few major chemical combinations: Alkaline *(zinc/manganese; limited rechargeability)*; lead/acid and nickel/iron *(rechargeable for multiple cycles, but very heavy per unit energy contained)*; Ni/Cd and NiMH; and Li-ion. Lithium is light and it has a high electrochemical potential; these are inherent physical characteristics and both are advantages for lithium as a battery material. The inherent physical properties of lithium cannot be duplicated or overcome by additional R&D.

Developing and testing materials for rechargeable batteries is a three to ten-year process. Established Li-ion and NiMH battery chemistries have decades of history and are generally regarded as safe for vehicle use. There would have to be a significant economic or performance driver for battery manufacturers to even go to the trouble of testing other materials. Therefore, it is very unlikely that additional battery chemistries will be developed *(during any near-term planning time frame)* to a point at which they will be widely accepted by the EV industry.

3.2 Cobalt in NiMH batteries

Li-ion batteries are now preferred in HEVs as well as BEVs, mostly for their lower weight. However, some manufacturers still use NiMH batteries in some HEV models; Toyota, for instance, uses NiMH batteries in its all-wheel drive hybrids.[xlv] Cobalt is used in the NiMH batteries that are still used in HEVs. Although the amount of cobalt in the battery and the total weight of the battery *(due to the battery's relatively small capacity)* are both less than in BEV Li-ion batteries, this vehicle type requires a significant amount of Co. As a fraction of the total battery, the amount of Co used in a nickel-based battery is estimated to be from about 0.8 to 2.0%.

HEV batteries are relatively small, as they are continuously charged by braking and discharged while idling, all during a normal driving cycle. A HEV battery might store about 1200 - 1800 watt-hours (Wh) of electricity. At an energy density of 60 - 120 Wh/kg, this nominally represents a 10 - 30 kg battery, or, assuming 1% Co by weight, about 100 - 300 grams of Co per vehicle.

3.3 Cobalt in Li-ion batteries

Lithium gets most of the publicity, but cobalt is also an essential material for Li-ion batteries. The original Li-ion battery introduced in 1991 for computers and camcorders was based on pure lithium cobalt dioxide ($LiCoO_2$). The amount of cobalt in that battery, after accounting for the other battery parts *(e.g., the cathode, separator and case)* was about 30% by weight. The amount of cobalt in the battery has fallen as chemistry variations that incorporate nickel, manganese and aluminum have been developed, but there is still a significant amount of Co in Li-ion batteries – about 25% to 50% as much cobalt as there is lithium, by weight, or, about 3 - 9% of total battery weight.

Battery manufacturers have been trying to reduce the amount of Co in Li-ion batteries since they were invented, but cobalt is *(as it is in many other applications)* difficult to replace. In Li-ion batteries, cobalt makes essential contributions to cycle life and safety.[xlvi] Tesla particularly is trying to reduce EV battery cobalt content, and has had some success. Reducing the amount of cobalt in Li-ion batteries to 1 - 2% may be possible, but it is not clear that a safe zero-cobalt battery is possible – if ever, and most likely not for wide use by 2030.[xlvii] Minor alterations to existing chemistries, including a shift towards higher-nickel chemistries, are underway.

Assuming a present-day average of 6% cobalt by weight, an energy density of 200 Wh/kg, and an average 1500 Wh battery, each HEV Li-ion battery requires 450 g of cobalt. PHEV batteries are larger than HEV batteries, at about 10,000 Wh, because they are intended to power the vehicle for longer periods. Finally, BEV batteries are already larger than PHEV batteries and are expected to get larger still. The long-range Nissan Leaf, as mentioned above, has a 150 mile range on a 40 kWh battery. The Tesla S(LR) has a 370 mile range on a 100 kWh battery. The trend is clearly to longer range vehicles, to compete with ICVs.

Cobalt use estimates are summarized in Table 3, which assumes that the global vehicle market will remain relatively stable at about 90 million cars/year. Other assumptions about market size and technology improvements are stated within the table, including improvements in energy density and an assumption that research to lower cobalt use will be successful, in reducing cobalt use by more than half, to only 2% of Li-ion battery weight. *(Even 1% Co would still require significantly more Co.)*

Table 3 Cobalt demand projections assuming unrestricted supply

	HEV (NiMH)	HEV (Li-ion)	PHEV (Li-ion)	BEV (Li-ion)
2020				
2020 market %	3.5%	3.5%	1%	1%
# vehicles, 2030	3,150,000	3,150,000	900,000	900,000
Battery size, 2020	1,500 Wh	1,500 Wh	10,000 Wh	50,000 Wh
Energy density	90 Wh/kg	200 Wh/kg	200 Wh/kg	200 Wh/kg
Weight of battery	16.7 kg	7.5 kg	50 kg	250 kg
% Co by weight	1%	5%	5%	5%
Weight of Co/car	0.167 kg	0.375 kg	2.5 kg	12.5 kg
Total Co	**525,000 kg**	**1,181,250 kg**	**2,250,000 kg**	**11,250,000 kg**
Grand total Co				**15,206,250 kg**
2030				
2030 market %	19.5%	19.5%	2%	18%
# vehicles, 2030	17,550,000	17,550,000	1,800,000	16,200,000
Battery size, 2030	1,500 Wh	1,500 Wh	10,000 Wh	80,000 Wh
Energy density	120 Wh/kg	300 Wh/kg	300 Wh/kg	300 Wh/kg
Weight of battery	12.5 kg	5.0 kg	33.3 kg	266.7 kg
% Co by weight	0.8%	2%	2%	2%
Weight of Co/car	0.100 kg	0.100 kg	0.667 kg	5.33 kg
Total Co	**1,755,000 kg**	**1,755,000 kg**	**1,200,000 kg**	**86,400,000 kg**
Grand total Co				**91,110,000 kg, or 91,110 metric tonnes**

3.4 Cobalt market reaction to 2030 EV projections

For reference, total global cobalt supply, including the 15,000 metric tonnes required for EVs in 2020 per the first section of Table 3, is only about 94,000 metric tonnes/year *(prior to Glencore's recent closure announcement in Congo)*.[xlviii] Unless there is a much more significant breakthrough than expected in battery technology, to achieve the projected EV market share:

- Cobalt production will have to nearly double by 2030, and/or
- The Co price will have to increase significantly enough to drive most other users out of the market.

Given the gap between current supply and probable demand, a dramatic cobalt price increase is likely even if production increases substantially. Cobalt historically has been mined mostly as a byproduct of copper or nickel; as a corresponding increase in copper or nickel prices is not expected, future cobalt supply growth from those sources is likely to be slow. Instead, higher prices will be required to develop primary cobalt mines.

Also, Co is essential to, and also a relatively small part of the price of, chemical catalysts and a variety of metal alloys. It is hard to say how high the price could rise if these users bid against EV manufacturers for limited supplies.

3.5 EV market reaction to cobalt price

Policy pressures in favor of EVs continue to grow and consumer choices based on economics are starting to shift to EVs over ICVs. At only 2% of the weight of the battery, a $100/kg increase in the price of Co, from $26/kg to $126, kg, would only add $533 to the production cost of the BEV shown in Table 3.

Even if the retail price increase resulting from a $100/kg Co price increase *(from $26 to $126/kg)* is $2000/vehicle, that amount is approaching insignificance to the purchasing decision for a BEV. By 2030, such an increase can definitely be expected to be insignificant; other costs are expected to have declined by then *(some projections call for first cost parity with ICVs by 2024)*. Therefore, higher Co prices should not be expected to slow EV market share growth.

3.6 Other metals

Although details are beyond the scope of this paper, investment in new mining is also desirable to ensure the near-term adequacy of the supplies of several other metals, including but not limited to:

- Lithium, nickel and rare earth metals for HEV and BEV batteries, and
- Platinum and palladium for fuel cells, for both FCEVs and non-automotive uses.

4 Summary & conclusions

Electric vehicles were introduced in the early days of the auto industry, but ultimately failed because critical technologies were not available, and because ICV mass production and technology improvements ultimately made reliable ICVs available at a lower cost, with a higher range between refueling cycles. The technologies critical to successful EVs, notably advanced NiMH and Li-ion batteries and the computers to control electric drivetrains and battery recharging, are now available. HEVs were introduced in 1997 and BEVs were re-introduced in 2012.

EVs offer lower energy use, emissions and maintenance than ICVs. HEVs and PHEVs inherently get better fuel mileage than ICVs. FCEVs and BEVs have still higher energy efficiency, regardless of the nature of their energy supplies. All EV types have lower CO_2 emissions than similar ICVs, even in unrealistic worst-case scenarios *(i.e., if all hydrogen for FCEVs was produced from natural gas, or if all electricity for BEVs was produced at coal power plants)*. Under realistic conditions, net FCEV and BEV CO_2 emissions, in the average US market, are about a third of similar ICV emissions. BEV and FCEV emissions can theoretically drop to zero if renewable electricity is used for their fuel.

Energy efficiency and emissions concerns have long stimulated legislation that favors energy-efficient, emissions-free vehicles, and low-emissions electric generation. Recent concerns about CO_2 emissions have stimulated new rounds of legislation that favor all EVs. Similar legislation as regards electric power production is, simultaneously, stimulating significant increases in the installation of new renewable electric generation capacity. Costs of both EVs and renewable generation are declining, improving the simultaneous commercial viability of EVs and of a greater fraction of renewable electricity.

Due to the effects of policy-based market stimulation, advances in EV technology, and mass production, the first cost of HEVs *(including PHEVs)* and BEVs have declined very substantially in recent years. EV first costs are becoming competitive with ICV first costs. Given net fuel cost and maintenance cost advantages for EVs, lifetime costs of ownership of each of these EV types are at, or are rapidly approaching, parity with ICVs. EVs are already at a total-cost advantage relative to ICV vehicles in markets with high fuel prices.

Performance issues that have prevented large-scale adoption of EVs, such as concerns over range between refueling cycles and availability of recharging infrastructure, have, to a large extent, been addressed, and further improvements are expected. The performance of HEVs and BEVs, both economic and technical is now good enough, or has a clear path to be good enough, to displace ICVs on a large scale.

The trends towards lower costs for EVs, lower costs for renewable energy, and more legislation favoring both EVs and renewable electricity, are each likely to continue. As a result of all of these various factors, a significant increase in EV market share is imminently expected. Total combined market share of all EV types projected to increase from zero in 1995, to about 10% in 2020, to about 60% in 2030. The only significant remaining obstacles to this major growth appear to be large-scale installation of Level 2 and Level 3 charging stations, and raw materials availability for EV batteries.

Cobalt is required for both types of EV batteries; it contributes to increased cycle life and safety. Research, ongoing since at least 1994, to eliminate Co in Li-ion batteries has had some success, but it is very unlikely that cobalt can be completely eliminated from these batteries in the near future. Battery material development and testing occurs over long time periods; for a cobalt-free battery to be commercially available and regarded as safe for EV use by 2030, it would have to already be in testing in the lab today. It is reasonable to believe that cobalt use per battery will fall, but that it will still be used in batteries for EVs in 2030.

EV demand growth projections for 2030 are supported by policies, economics and many dimensions of EV performance. However, projected EV sales are so high that even if cobalt use per battery is reduced by more than 50%, demand for cobalt for EV batteries alone in 2030 can realistically be approximately equal to 2018's total global cobalt production for all uses. At the least, cobalt prices are likely to increase substantially. To avoid disruption not only to the auto industry, but to many other industries that also use cobalt, investment in new mining exploration and development is needed immediately.

Author Bio

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From 1989 - 1996 at Sherritt's Westaim division *(now part of Umicore)*, he was responsible for managing the development and rollout of lithium cobalt dioxide, nickel hydroxide and nickel powders for Ni/Cd, NiMH and Li-ion batteries, and for modeling cobalt and nickel prices.

Greg is the president of Alpine Flamingo LLC, a consulting firm for energy consumers, utilities and governments that want to: develop and implement strategies to achieve aggressive energy goals such as "net zero" or "100% renewable;" develop and roll out energy storage, generation, conservation and microgrid technologies; and understand metals supply issues.

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Lithium Australia achieves recycling breakthrough after recovering lithium from spent batteries

In a huge battery recycling milestone, Lithium Australia (ASX: LIT) has successfully recovered critical metals from spent lithium-ion batteries including lithium phosphate, nickel and cobalt.

In conjunction with the Australian Nuclear Science and Technology Organisation (ANSTO), Lithium Australia has used it proprietary refining technology to generate 99% pure lithium phosphate, with lithium recoveries exceeding 85%.

Meanwhile, nickel and cobalt recoveries are estimated at 90%, with internal modelling revealing a concentrate suitable as feed for conventional processing.

During the trial, Lithium Australia's partner Envirostream Australia Pty Ltd collected, shredded and separated spent batteries to create a mixed metal dust.

ANSTO then processed the dust to recover lithium phosphate, which was further refined using proprietary technology.

The refined lithium phosphate has been shipped to Lithium Australia's wholly-owned VSPC pilot plant in Brisbane where it will converted into lithium-ferro-phosphate and tested in coin cell lithium-ion batteries produced at the plant.

"Successfully recovering a precursor of such high purity for the production of new lithium-ion batteries from material otherwise destined for landfill is a huge step forward for the battery industry," Lithium Australia managing director Adrian Griffin said.

"Lithium Australia, together with its partner Envirostream Australia, is investigating the commercial potential of this breakthrough," he added.

Advancing the process

In addition to its lithium-ferro-phosphate material, Lithium Australia has undertaken commercial evaluation of generating a nickel and cobalt concentrate from spent batteries for re-

ethically sourced cobalt.
“Right now, we’re in discussion with consumers of lithium, nickel and cobalt – both within Australia and overseas – and we see huge potential for a local battery recycling industry,” Mr Griffin said.
Other advantages to Lithium Australia’s recycling technology include promoting a sustainable lithium-ion battery industry.
Instead of being consigned to landfill, critical materials are extracted from spent batteries and reused – providing an ethical, local and stable battery material supply.
Additionally, Lithium Australia’s process for converting unconventional feedstock into a battery grade lithium material eliminates the need for current costly and energy-intensive processes that are currently used to produce lithium carbonate and lithium hydroxide chemicals.

(This article was published on Smallcaps, on September 19, 2019)

Sustainable battery innovation pilot introduces next generation EV batteries

A sustainable battery innovation project established by the EU’s raw materials consortium has concluded after a successful pilot phase.

The ECO COM’BAT project, which ran between 2016 and 2018, was initiated by EIT RawMaterials, the raw materials arm of the European Institute of Innovation and Technology (EIT), with the aim of deploying sustainable battery innovation to develop the ‘next generation’ of sustainable high voltage lithium-ion electric vehicle batteries. The project, co-ordinated by the Fraunhofer Institute for Silicate Research, saw 10 organisations from the industry and research sectors work in partnership under the brief ‘to combine green and high performance materials and to upscale their production for the next generation of high-voltage lithium-ion batteries’.

Project co-ordinator Dr Andreas Bittner of the Fraunhofer Institute for Silicate Research said: “The main task of the ECO COM’BAT project was to substitute conventional, often expensive, rare or even critical materials as cobalt in the electrodes and of fluorine in the electrolyte.” The research team produced optimised materials and high voltage electrolytes with reduced cobalt and fluorine content, with structured carbon additives to shore up the energy capacity and power density of the new battery; the materials were integrated into pouch cells for greater cycle stability.

A report by the Fraunhofer Institute said: ‘To come from experimental laboratory level to producibility, usually several upscaling steps are necessary. Within the ECO COM’BAT project the partners combined innovative materials with well-known production properties in order to come up with only a few upscaling steps to a relevant pilot level of batch sizes with up to 20kg. For the optimization of the ECO COM’BAT materials and cells, a comprehensive simulation of the battery performance and aging was performed. Moreover, an efficient recycling concept was developed and tested to recover precious materials like nickel, cobalt, graphite and lithium and to achieve a high degree of sustainability. The commercial impact of the project results for a new generation of sustainable high-voltage batteries, is promising, as the different battery materials shows excellent performance and processing properties. The materials are ready for the near-to-production upscaling once enough market demand is obtained.’

(This article was published on Government Europa, on September 17, 2019)

THE CI IN PICTURES

SEPTEMBER

CI HS&E Committee and staff visited Sandvik Coromant in Gimo, Sweden

JULY

Geneva, Switzerland, UN Sub-Committee on the Transport of Dangerous Goods

THE COBALT INSTITUTE

The Cobalt Institute carries out activities from a head office in Guildford, UK, to promote the use of cobalt. It is legally incorporated as an association of a wholly non-profit making character in accordance with its memorandum and articles, which are available on request.

Membership of the CI is open to those engaged or interested in the industry, subject to and acceptance by the Board.

Cobalt News exists to disseminate promotion material on uses for, and development in, cobalt technology supported by items of interest to cobalt producers, users and all their customers.

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Cobalt Institute

Promoting the sustainable and responsible use of cobalt in all forms