

Musings about Electric Vehicles (EVs)

<http://www.roperld.com/science/ElectricCarsMusings.pdf>

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When an affordable 500-miles battery is ready, say goodbye to the gasoline car.

<http://www.roperld.com/science/BEVvsICECost.htm>

Introduction

I have been interested in electric vehicles (EVs) for several years. I bought my first EV, a small pickup, the ZAP Xebra PK, in 2007. I drove it about 3000 miles and gave it away in January 2010. I describe it as a toy electric car. I learned from that experience never again to drive an electric vehicle that uses lead-acid batteries for propulsion. (Ref. 1)

Prior to that I bought a Toyota Prius in 2005 and converted it to a Hymotion plug-in in October 2008. When I leased a Nissan LEAF in 2013 I sold the plug-in Prius to my granddaughter for about half price. (Ref. 2)

In May 2012 I leased a 2012 Nissan LEAF SL (range: 73 miles) for 3 years. It was an excellent vehicle. In March 2015 I leased a 2015 Nissan LEAF SV for 2 years. It has a longer EPA range (84 miles) than the 2012 LEAF and charges about twice as fast (6.6 kW versus 3.3 kW). I leased because the technology, especially for batteries, used in electric vehicles is changing rapidly and because batteries' capacity decay with time. Later, Consumer Reports recommended leasing EVs for the same reasons, the first time they have recommended leasing a car. (Ref. 3) My oldest daughter bought the 2015 LEAF after I returned it to Nissan.

In 2017 I bought a [Chevrolet Bolt EV](#) (CBEV) Premium with Driver Confidence Package and fast-charging capability. With its EPA range of 238 miles and fast acceleration (0-30-mph in 2.9 seconds and 0-60-mph in 6.5 seconds) I am extremely pleased



Cajun Red Tintcoat

By driving these electric vehicles I learned much about battery electric vehicles (BEVs) and came to love the many excellent features of electric cars. I will never drive another ICE (Internal Combustion Engine) vehicle as my personal vehicle. When the range of BEVs surpasses the range of ICEs and fast charging stations are prevalent, I will never drive another ICE, period. Until then my secondary car will be a plug-in hybrid, preferably a biodiesel-electric plug-in hybrid. I recently owned a 2006 Toyota Highlander Hybrid (gas-electric, 26 mpg EPA rated), an excellent car. After driving it for 124,000 miles I traded it in for a 2016 Toyota RAV4 Hybrid (33 mpg EPA rated).

I am in the queue to get the [Tesla Model 3](#) (TM3) sometime after it becomes available. I will have to decide then whether to sell the CBEV or decline the TM3. The fast-growing [Tesla Supercharger network](#) provides a major motivation to get the TM3.

Some Facts about Electric Vehicles

- An electric MOTOR provides rotary motion for propulsion for a BEV. In a gasoline vehicle (ICE) a combustion ENGINE provides linear motion that is converted to rotary motion for propulsion. (A gasoline-electric hybrid vehicle [HEV] has an ENGINE and one or more MOTORS/GENERATORS. E.g., the Prius has one ENGINE and two MOTORS/GENERATORS, and the AWD Toyota Highlander Hybrid and the AWD Toyota RAV4 Hybrid has one ENGINE and three MOTORS/GENERATORS, two MOTORS/GENERATORS in the front with the ENGINE and one MOTOR/GENERATOR in the rear.) MOTORS can run backwards and be generators; e.g., when braking, which charges the battery (**regeneration**). (Regeneration occurs for MOTORS/GENERATORS in gas-electric hybrids, also.) (Some car companies use the word “recuperation” instead of “regeneration”.)
- CHARGERS are in the vehicle. CHARGING STATIONS are outside the vehicle. There are three standard types of CHARGING STATIONS: **Level-1/120-volts AC (1.15 kW)**, **Level-2/240-volts AC (3.3 kW or 6.6 kW or higher)** and **Level-3/480-volts DC (50-100 kW or higher)**. (My LEAFs had all three levels of receptacles; Level-1 and Level-2 use the same SAE-J1772 receptacle on the car. The 2012 LEAF has the 3.3-kW charger; later years have the 6.6-kW charger.) The Tesla S has faster chargers and Tesla is installing very fast charging stations ([Superchargers](#)) across the U.S. to recharge Tesla batteries; and using them was “free” of cost (i.e., included in the cost of the car) for Tesla drivers originally, but a fee was enacted in 2017. (A Tesla-S or Tesla-X can now travel from Mexico to Canada charging at Superchargers and across the United States on selected routes! For a map of the locations of Tesla superchargers see Ref. 19.) Tesla Superchargers animation: <https://youtu.be/YRd-23muVW8>. The chargers in the BEV have to match the charging station voltage and power. The charger receptacle(s) on the outside of a



BEV is/are standard for Level-1/Level-2 chargers (SAE-J1772 standard)



but two “standards” (U.S./Europe SAE Combo and Asian CHAdeMO)



exist for Level-3 receptacles. Many Level-3 charging stations currently in the U.S. use the Asian CHAdeMO standard; current stations containing both are being installed. (Note that the U.S./Europe SAE



Combo combines level-2 and level-3 in one plug.) The charging receptacles on the LEAF are , with level-3 CHAdeMO on the left and SAE-J1772 on the right. Apparently, there eventually will be adapters for BEV plugs to use both “standards”. (Ref. 19) The Tesla Model S can be charged through its supplied cable to standard 120-volts outlets and with a 240-volts standard J1772 plug. Tesla has an adapter for CHAdeMO (level-3)



quick-charging stations. (Ref. 19) Probably there will eventually be a Tesla adapter for the SAE-Combo charging stations. Also, Tesla has an [adapter for charging using NEMA 14-50 outlets](#) at campgrounds. The level-1 portable charging stations that come with non-Tesla BEVs can be [converted from 120-volts to 240-volts with pigtails for 120-volts and NEMA-14-50-volts charging](#).

- Electric motors have nearly instantaneous torque; gasoline engines have to ramp up torque due to more mechanical inertia to overcome. Torque provides acceleration. Therefore, BEVs have high acceleration compared to equivalent ICEs. And a BEV during acceleration is very quiet.
- Electric vehicles can travel very fast. The Nissan-LEAF’s maximum speed is 94 mph and the Chevrolet-Bolt-EVs is 93 mph. The Tesla S can be tuned to a maximum speed of 135 mph.
- BEV batteries work best and lose capacity the least if they are kept in a narrow temperature range. The best BEVs have thermal management systems to keep their batteries within the required temperature range. Generally liquid-cooled systems (e.g. Tesla and Bolt EV) are better than air-cooled systems (e.g. Nissan LEAF).
- There is no transmission in most BEVs; the motor’s rotation transfers directly to the wheels’ rotation through fixed reduction gears. (The gear ratio for the LEAF is 7.9377.)(Ref. 18)
- BEVs usually have a 12-volts auxiliary battery, which is usually lead acid. It is used to start the BEV system and to provide power for the lights, audio, etc. It must be kept above a minimum voltage in order that the BEV system can be started. It is charged by the propulsion battery and when charging the propulsion battery in most cases. Some BEVs have a small solar panel on the roof to trickle charge the auxiliary battery when the vehicle is in sunlight.

- Most mechanical parts (e.g., steering and windshield wipers) are powered by small electric motors. Some BEVs have electric-actuated parking brakes and some have foot-actuated parking brakes similar to ICEs; the later may be safer in the case of an electrical failure. Of course, a brake cable for foot brakes can fail, also.
- The best BEV cabin heaters/air-conditioners are highly efficient heat pumps. The best cabin-heating systems have heated steering wheels and heated seats, since they use less energy than is needed for space heating.
- Electric motors can have efficiencies as high as 95%; gasoline engines have efficiencies of ~25-35% and diesel engines have efficiencies of ~40%. The transmission and other devices in an ICE cause energy losses. Therefore, the fuel usage (MPGe = 33.705 miles/kWh) for a BEV is about 1/4th of ICE fuel usage (MPG). A typical BEV runs at 3-4 miles/kWh = 101-135 MPGe; whereas a [typical ICE runs at 25 MPG](#).
- A motor in a BEV acts as a generator to recharge the battery when the BEV is slowing down, including braking (regeneration). Therefore, the mechanical brakes of a BEV are used only in emergency stops and at low speeds; therefore, brakes usually do not need to be repaired for 100,000 miles or more. (This is the case for gas-electric hybrids, also.)
- The electricity to drive electric motors can come from solar energy or wind energy, allowing truly zero emissions.
- Electric motors are much quieter than gasoline engines. Most BEVs have a sound maker at low speed and when backing up to warn pedestrians.
- The battery in electric vehicles is usually under the seats, which provides a very low center of gravity for exceptional handling while driving. Here is the battery under the Tesla S:



It has a titanium plate under it for protection from road debris.

- The bodies of BEVs are usually designed to have very low drag.

	TOYOTA PRIUS	MERCEDES-BENZ CLA250	TESLA MODEL S P85 (2012)	NISSAN LEAF SL (2012)	CHEVROLET VOLT
DRAG COEFFICIENT	0.26	0.30	0.24	0.32	0.28
FRONTAL AREA	23.9 ft ²	23.2 ft ²	25.2 ft ²	24.5 ft ²	23.7 ft ²
DRAG AREA (Cd x FRONTAL AREA)	6.2 ft²	7.0 ft ²	6.2 ft²	7.8 ft ²	6.7 ft ²

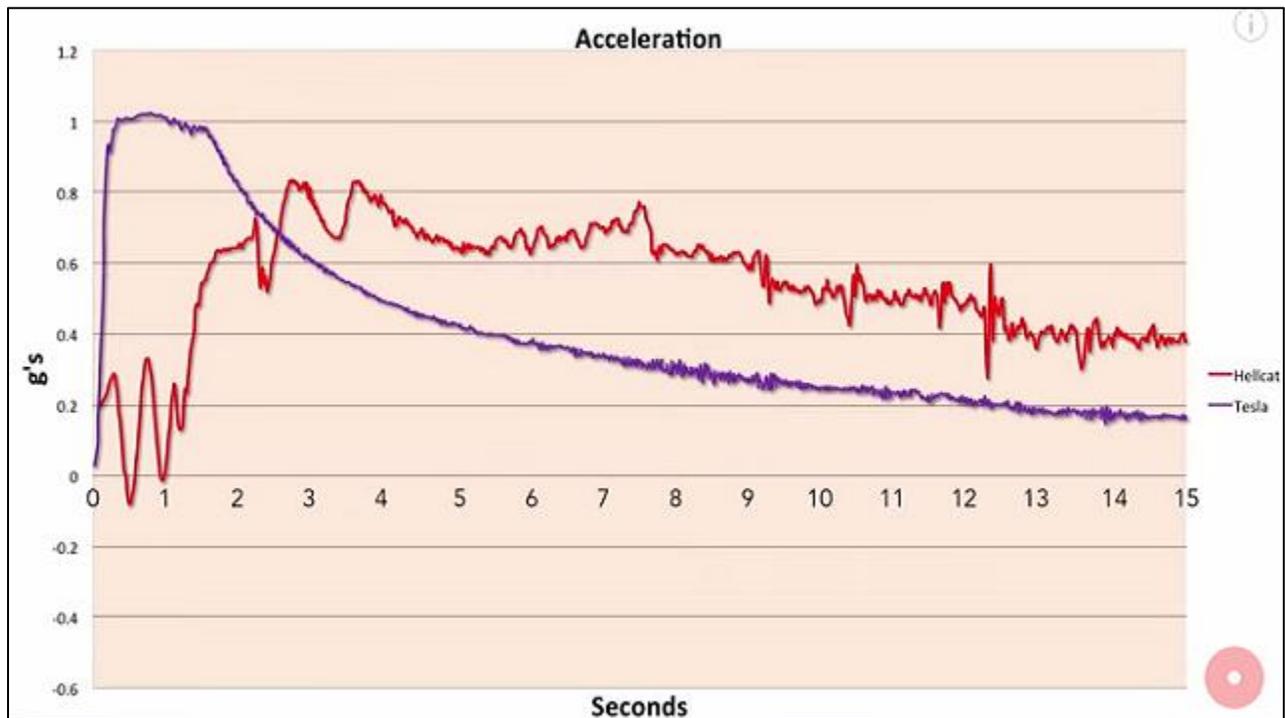
<http://insideevs.com/car-driver-aero-comparo-tesla-model-s-versus-volt-leaf-prius-video/>

- Manufacturing of plug-Ins, often called “electric cars”, is ramping up. They are selling faster than the Toyota Prius did when it was first introduced to the U.S. in year 2000. (“plug-Ins” includes plug-in hybrids (PHEVs) as well as BEVs.) (Ref. 20)

Positive Aspects of Electric Vehicles

- When the electricity comes from solar and wind energy, there are no particulate or greenhouse-gas emissions. Personal transportation is possible without using fossil fuels for power.
- The cost of “fuel” is about 1/4th of gasoline costs for an equivalent vehicle.
- The cost of maintenance is very small; e.g., there are no oil changes or tune ups. And brakes are only used for emergency stops and at low speeds; therefore, they usually do not need to be repaired for 100,000 miles or more. (This is true for brakes on gas-electric hybrids, also.) Usually a regular visit to a dealer is only to rotate the tires, which the driver could do.
- The first thing that impressed me about the LEAF was the high instantaneous acceleration. I have never found a gasoline car that I could not out accelerate at a red light with my LEAF or Bolt EV! And it does so extremely quietly. I like being first position at a red light, because then I can move far away from the gasoline pack quickly. Comparison of the acceleration of a Tesla Model-S P85D+ with a Dodge Hellcat:

<http://www.streetlegaltv.com/news/consumer-reports-take-an-in-depth-look-at-hellcat-vs-tesla/>



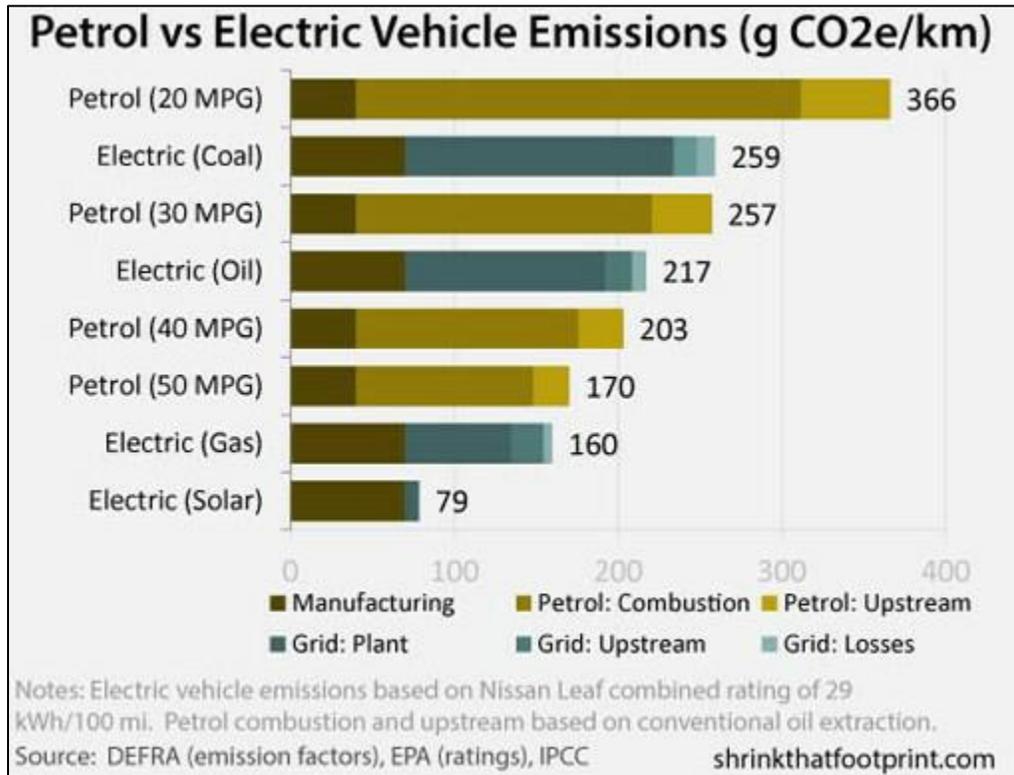
1 g acceleration in less than ¼ second is incredible!

- I charged the LEAF about 98% of the time in our garage. (How many owners of gasoline vehicles can fuel their vehicles 98% of the time in their garages?!) Having a Level-2/240-volts charging station in our garage allows charging the vehicle several times during the day as needed, thereby effectively extending the daily range by a large amount. Usually I charge it to 100% at night when power plants are underutilized. When I went to Roanoke I charged at a CHAdeMO fast charger downtown or behind my daughter's house where she installed a 240-volts level-2 charging station. With the 238-miles Bolt EV I can make several trips to Roanoke without charging there. All new apartment houses should be required to install conduit in their parking lots to make it easy to install charging stations as needed in the future. All new houses should be required to have wiring installed in garages to make it easy to install a charging station as needed in the future.
- The low center of gravity of electric vehicles, due to the battery located under the seats, makes electric vehicles handle extremely well.
- The Nissan LEAF and the Tesla Model S have achieved 5-star safety ratings.

- After their vehicle life time lower capacity BEV batteries can be used for renewable-energy storage. (Ref. 10)
- BEV batteries are designed for very high recycling of the various materials in them. The large-format batteries, such as the 192 batteries in the Nissan LEAF, should be easier to recycle than the small-format batteries, such as the ~7000 ones in the Tesla S since they are surrounded by a goo (Ref. 26). The Nissan LEAF has 48 modules with 4 batteries per module, thus a defective module can be easily replaced at a reasonable cost.

Negative Aspects of Electric Vehicles

- Current batteries have a range less than gasoline tanks. That is likely to change over the next few years.
- Charging batteries currently takes longer than filling gasoline tanks. That is likely to change over the next few years.
- Batteries lose energy capacity with time. The % loss depends on age of battery, average air temperature, average % of charging, average charging current, average rate of acceleration, whether battery cooling occurs and perhaps other factors. Nissan gives the following average numbers for the LEAF: ~20% loss in 5 years, ~30% loss in 10 years. Research is underway to reduce capacity loss of BEV batteries due to high temperatures and charging. (Ref. 6)
- BEVs are constructed with a small amount of rare minerals. Reducing the use of rare minerals in BEV construction is happening.
- In areas where most electricity is generated by burning coal the carbon emissions caused by electric cars is sizeable, but still smaller than the carbon emissions caused by most gasoline cars. Fortunately, generating electricity by burning coal is declining and will stop eventually. When a house or an area gets all its electricity from renewable energy sources, no carbon emissions will occur by driving a BEV.

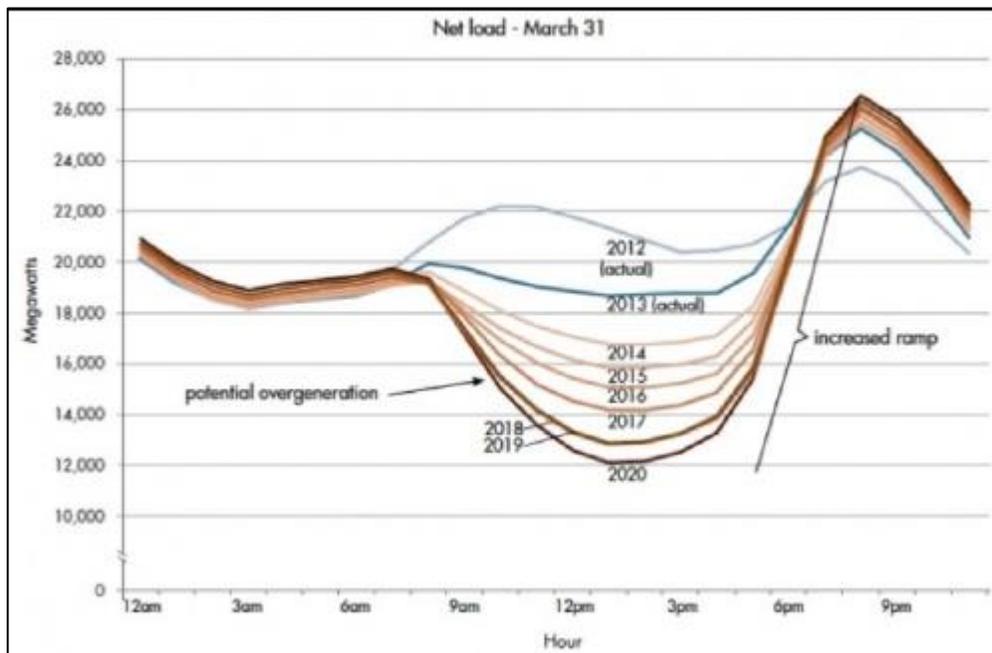


- Electric vehicles cost more than equivalent gasoline vehicles, but less or no more than most large gasoline/diesel vehicles. That is likely to change over the next few years.

- Electric vehicles have a large mass, the battery, below the seats, which mass pushes forward during a frontal crash. Thus, for safety the front end needs to have a better crumple zone than an ICE vehicle to minimize damage to passengers. The battery cases are designed such that damage to batteries during crashes is minimal.
- There are three charging standards for fast charging:
 - CHAdeMO
 - CCS
 - Tesla Supercharger

When to Charge Electric Vehicles

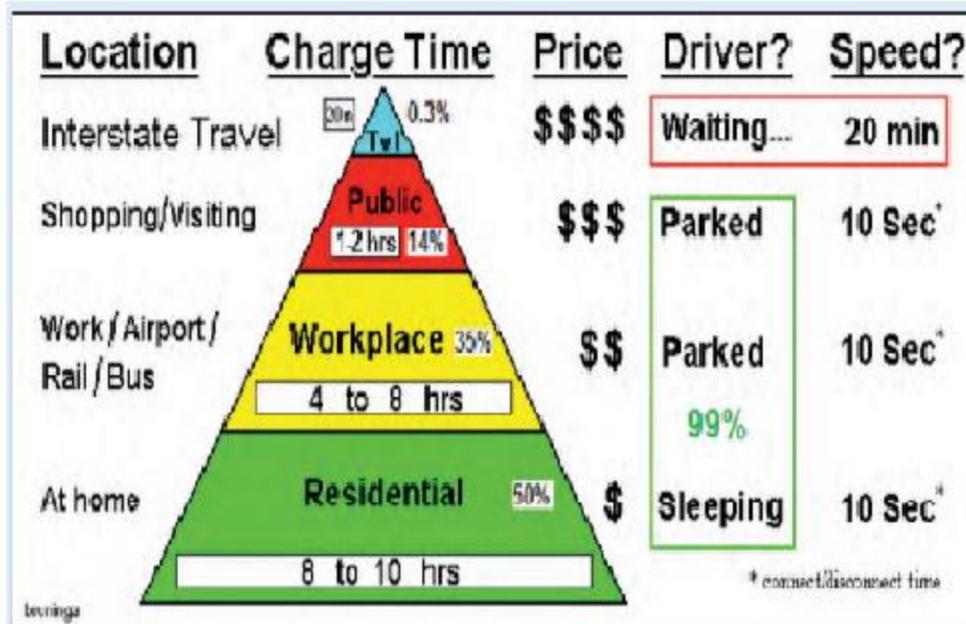
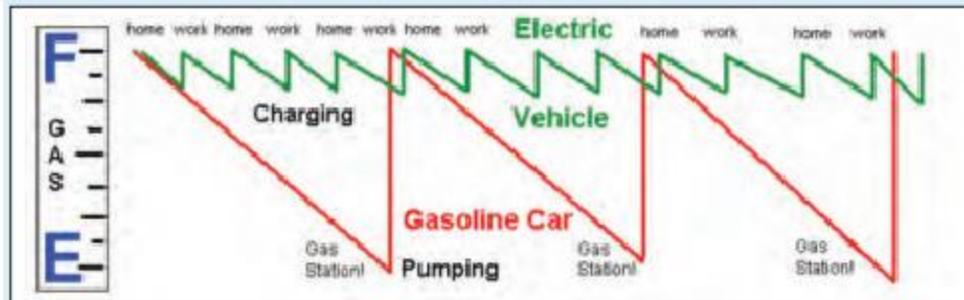
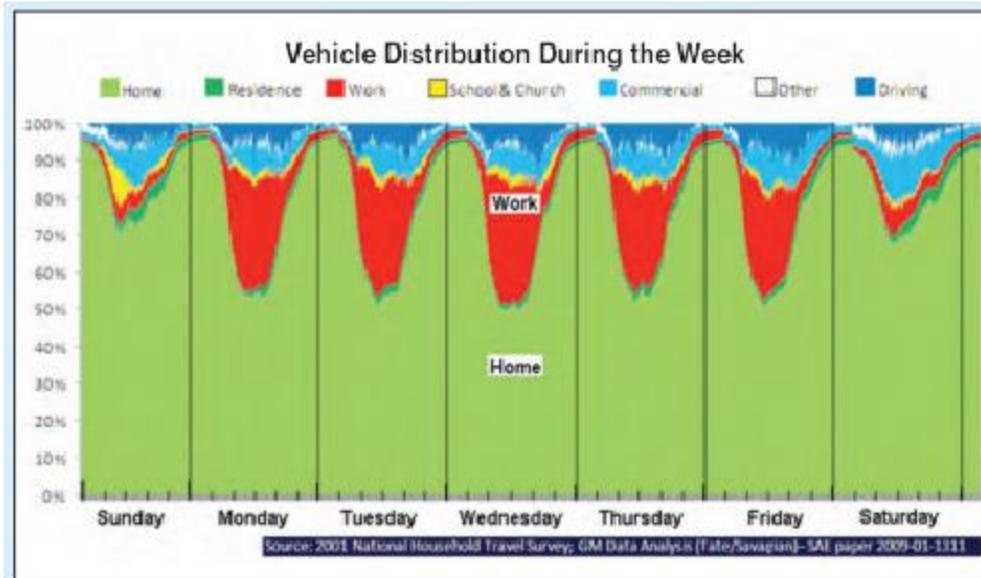
- The “Duck Curve” for non-solar electric generation in the US versus time of day
http://www.greencarreports.com/image/100465172_duck-curve-of-energy-generation-image-greentech-



media): The daytime usage will increase with time as more solar energy becomes available. This shows that it will be best to charge electric cars between 3 AM and 6 PM as the Duck Curve deepens in daytime.

- Modern BEVs have timers which should be set to start after 3 AM at home.
- Employees’ cars should be charged during working hours: 8 AM to 5 PM.
- Charged vehicles could be used for storage of renewable energy during late afternoon, ~3 PM to 6 PM, and then feed the electricity back into the grid between 6 PM and 11 PM and earn money for services as electrical storage.

 SAE Charging Configurations and Ratings Terminology			
AC level 1 (SAE J1772™) 	PEV includes on-board charger	*DC Level 1	EVSE includes an off-board charger
	120V, 1.4 kW @ 12 amp 120V, 1.9 kW @ 16 amp		200-450 V DC, up to 36 kW (80 A)
	Est. charge time:		Est. charge time (20 kW off-board charger):
	PHEV: 7hrs (SOC* - 0% to full)		PHEV: 22 min. (SOC* - 0% to 80%)
	BEV: 17hrs (SOC – 20% to full)		BEV: 1.2 hrs. (SOC – 20% to 100%)
AC level 2 (SAE J1772™) 	PEV includes on-board charger (see below for different types)	*DC Level 2	EVSE includes an off-board charger
	240 V, up to 19.2 kW (80 A)		200-450 V DC, up to 90 kW (200 A)
	Est. charge time for 3.3 kW on-board charger		Est. charge time (45 kW off-board charger):
	PEV: 3 hrs (SOC* - 0% to full)		PHEV: 10 min. (SOC* - 0% to 80%)
	BEV: 7 hrs (SOC – 20% to full)		BEV: 20 min. (SOC – 20% to 80%)
	Est. charge time for 7 kW on-board charger	*DC Level 3 (TBD)	EVSE includes an off-board charger
	PEV: 1.5 hrs (SOC* - 0% to full)		200-600V DC (proposed) up to 240 kW (400 A)
	BEV: 3.5 hrs (SOC – 20% to full)		Est. charge time (45 kW off-board charger):
	Est. charge time for 20 kW on-board charger		BEV (only): <10 min. (SOC* - 0% to 80%)
	PEV: 22 min. (SOC* - 0% to full)		
BEV: 1.2 hrs (SOC – 20% to full)			
*AC Level 3 (TBD)	> 20 kW, single phase and 3 phase		
<p>*Not finalized Voltages are nominal configuration voltages, not coupler ratings Rated Power is at nominal configuration operating voltage and coupler rated current Ideal charge times assume 90% efficient chargers, 150W to 12V loads and no balancing of Traction Battery Pack</p>			
<p>Notes: 1) BEV (25 kWh usable pack size) charging always starts at 20% SOC, faster than a 1C rate (total capacity charged in one hour) will also stop at 80% SOC instead of 100% 2) PHEV can start from 0% SOC since the hybrid mode is available.</p>			
Developed by the SAE Hybrid Committee			<i>ver. 031611</i>
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http://www.electrictauto.org/global_engine/download.asp?fileid=1F6E3055-3811-4687-A0E0-BE762C5F603D&ext=pdf

Batteries for Electric Vehicles

- Modern electric vehicles use lithium-ion batteries. The anodes are usually solid carbon or graphite. The cathodes

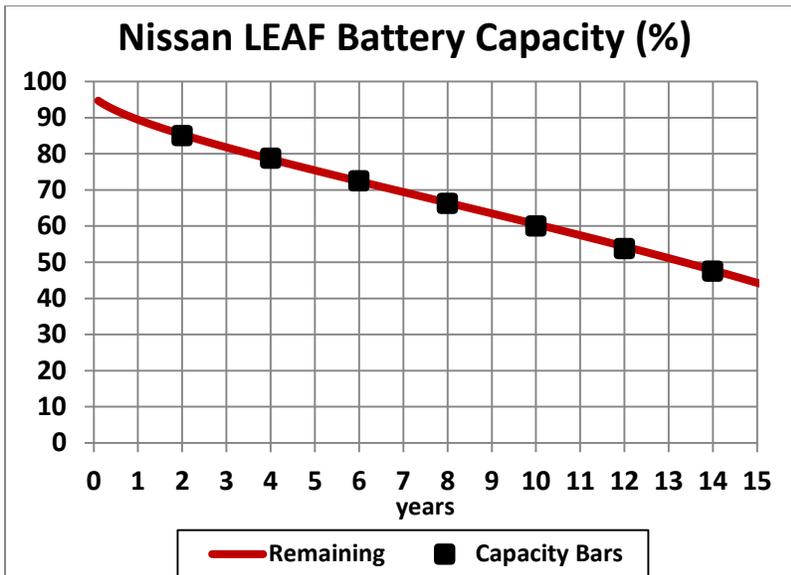
Table I. Characteristics of some positive electrode materials.¹⁸

Material	Specific capacity mAh/g	Midpoint V vs. Li at C/20	Comments
LiCoO_2	155	3.9	Still the most common. Co is expensive.
$\text{LiNi}_{1-x-y}\text{Mn}_x\text{Co}_y\text{O}_2$ (NMC)	140-180	~3.8	Capacity depends on upper voltage cut off. Safer and less expensive than LiCoO_2
$\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ (NCA)	200	3.73	High capacity. About as safe as LiCoO_2
LiMn_2O_4 (Spinel)	100-120	4.05	Poor high temperature stability (but improving with R&D). Safer and less expensive than LiCoO_2
LiFePO_4 (LFP)	160	3.45	Synthesis in inert gas leads to process cost. Very safe. Low volumetric energy
$\text{Li}[\text{Li}_{1/3}\text{Ni}_{1/3}\text{Mn}_{2/3}]\text{O}_2$	275	3.8	High specific capacity, R&D scale, low rate capability
$\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_2$	130	4.6	Requires an electrolyte that is stable at high voltage

are variable:

	Cell Maker	Chemistry	Capacity	Configuration	Voltage	Weight	Volume	Ener dens	Spec Ener	Used in:	
		Anode/Cathode	Ah		V	Kg	liter	Wh/liter	Wh/kg	Company	Model
1	AESC	G/LMO-NCA	33	Pouch	3.75	0.80	0.40	309	155	Nissan	Leaf
2	LG Chem	G/NMC-LMO	36	Pouch	3.75	0.86	0.49	275	157	Renault	Zoe
3	Li-Tec	G/NMC	52	Pouch	3.65	1.25	0.60	316	152	Daimler	Smart
4	Li Energy Japan	G/LMO-NMC	50	Prismatic	3.7	1.70	0.85	218	109	Mitsubishi	i-MiEV
5	Samsung	G/NMC-LMO	64	Prismatic	3.7	1.80	0.97	243	132	Fiat	500
6	Lishen Tianjin	G-LFP	16	Prismatic	3.25	0.45	0.23	226	116	Coda	EV
7	Toshiba	LTO-NMC	20	Prismatic	2.3	0.52	0.23	200	89	Honda	Fit
8	Panasonic	G/NCA	3.1	Cylindrical	3.6	0.045	0.018	630	248	Tesla	Model S

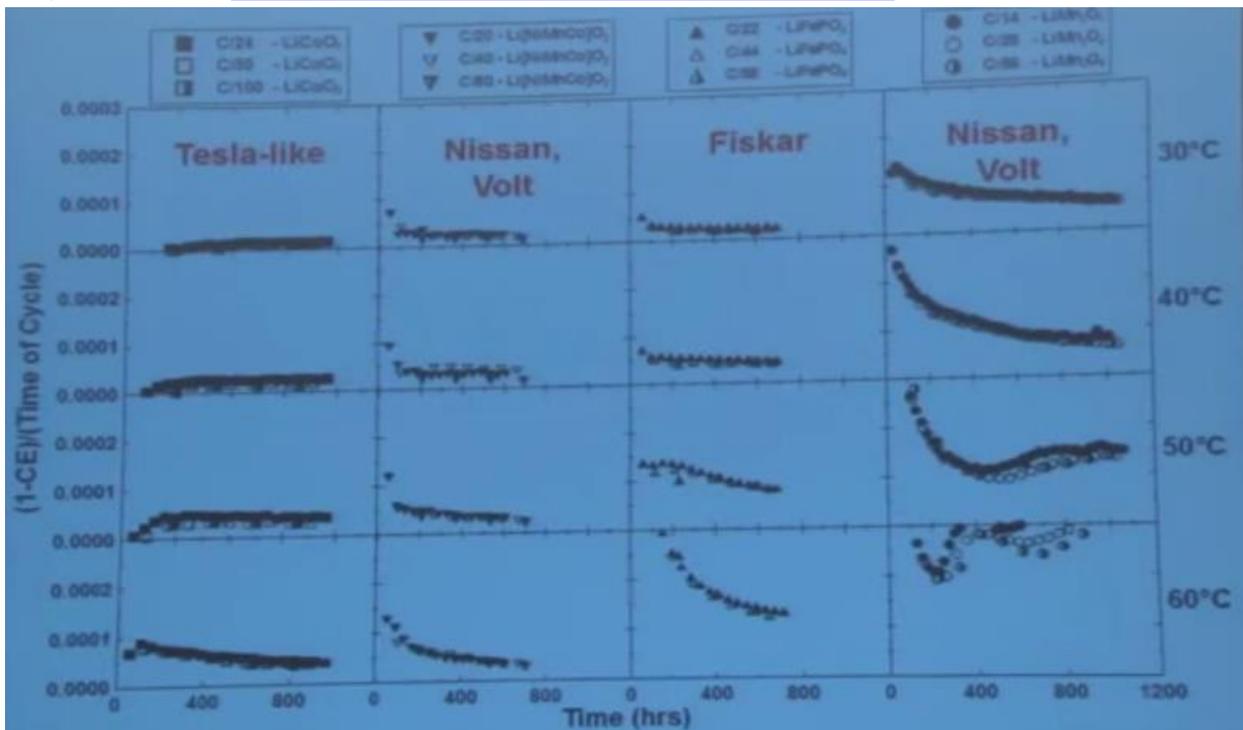
- Batteries lose capacity with usage: The major cause for constant temperature is miles driven or, equivalently the amount of charging. High temperatures accelerate capacity loss, so BEV batteries must be cooled, preferably by liquid rather than by air. (Ref. 27)
- The Nissan LEAF has 12 battery-capacity bars that disappear as the battery loses capacity according to the following graph, which shows the capacities at which the first seven bars disappear:



The assumption is that the LEAF is driven

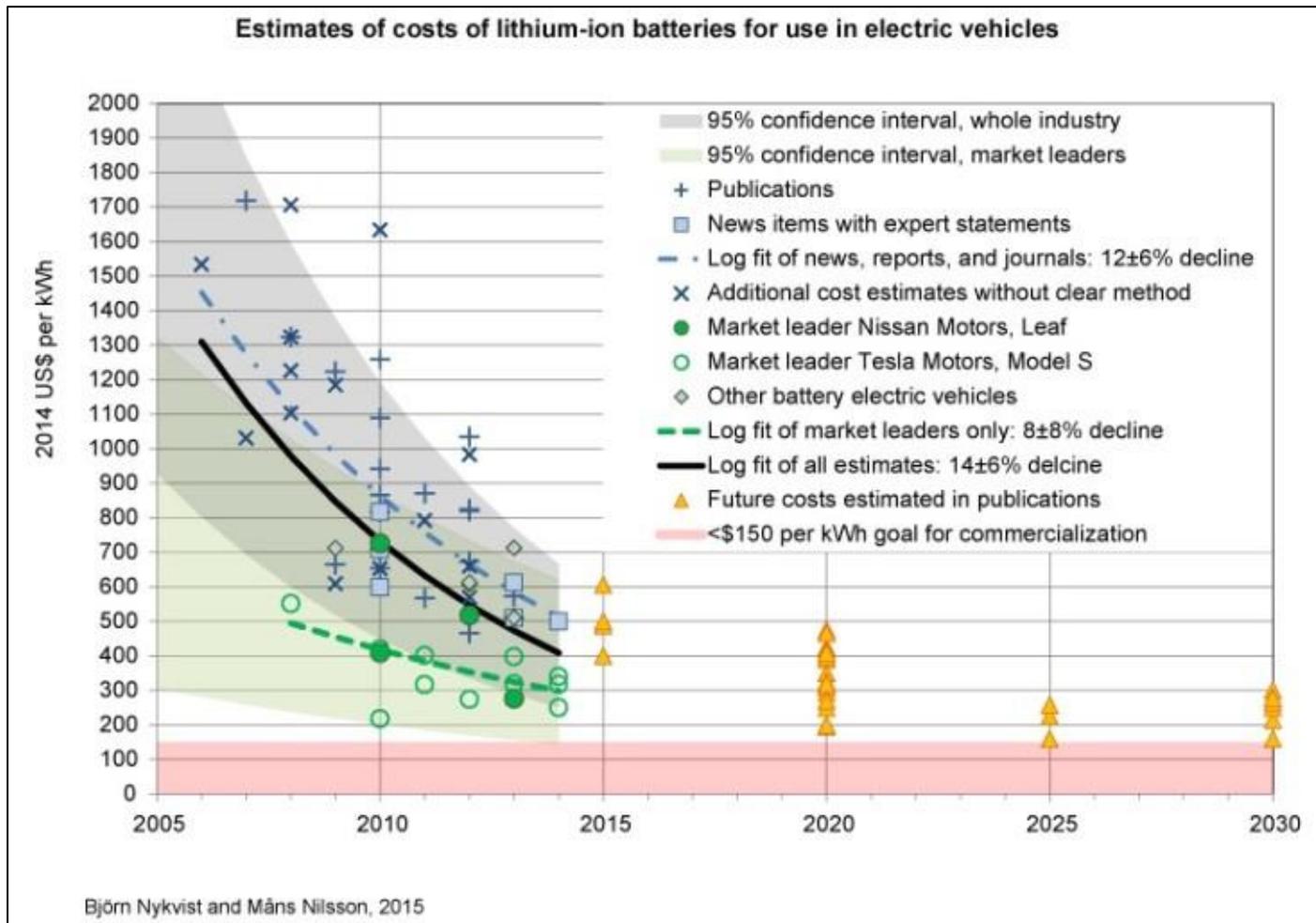
12,000 miles/year. Other electric cars probably have a similar capacity-loss curve as the red curve. (Ref. 31) Nissan has a battery warranty for the LEAF that deals with battery-capacity loss and a battery-replacement program. (Ref. 32) Car dealers who sell electric cars need to provide a curve similar to the one above to prospective buyers so that they understand that batteries will lose capacity as they are driven.

- After BEV batteries have lost sufficient capacity that they are not useful for BEVs they can be used by power companies and off-grid buildings as storage for solar and wind energy. (Ref. 29) After they have lost sufficient capacity that they are not useful for storage they will be recycled. (Ref. 30)
- Why batteries fail (<http://www.youtube.com/watch?v=9qi03QawZEk#t=24>):



The curves are the inefficiency of charging divided by the charging-cycle time, a universal curve. The higher the curve the more the battery capacity decays with time. Nissan LEAF and the Chevy Volt use 50% of the 2nd battery type and 50% of the 4th battery type. The Volt is thermally managed by a liquid coolant and the LEAF is not. Tesla has chosen the best battery for high charging efficiency. (60°C = 140°F, 50°C = 122°F, 40°C = 104°F, 30°C = 86°F)

- Battery prices are declining (<http://insideevs.com/declining-battery-prices-boost-electric-car-market/>);



Cooling Batteries

- <http://insideevs.com/tesla-or-gm-who-has-the-best-battery-thermal-management-bower/>
- <http://www.technologyreview.com/view/429282/are-air-cooled-batteries-hurting-nissan-leaf-range/>

Other Considerations

- In the future I plan to lease or buy BEVs with reflective exteriors and interiors because of the faster battery capacity loss with heat.
- BEVs need to come into common use as soon as possible because extraction of [fracked tight crude oil](#), to make gasoline and diesel, and [fracked shale natural gas](#) will peak soon. Those hydrocarbons will need to be reserved for making useful items and for fuel for large trucks and airplanes. Eventually biofuels will need to be reserved for trucks and airplanes, not used in cars. (I believe the best biofuel is biodiesel, preferably made from algae and/or bacteria.)(Ref. 17)
- The source of electricity for BEVs needs to switch to solar and wind as soon as possible because of illnesses and climate change caused by emissions from fossil-fuel power plants and the dangers and high costs of nuclear energy.
- Traffic will change considerably when a large fraction of personal cars are BEVs. The higher BEV acceleration will separate out the BEVs from the clumps of gasoline vehicles (ICEs) on roads. Drivers of BEVs will be aggravated

when they are held back behind slowly-accelerating ICEs. Will traffic-lights' synchronization be set for BEVs or for ICEs, as they are now? Will special lanes at traffic lights be restricted to electric cars?

- Communities will become intolerant of the noise made by ICEs after they get used to the low noise of BEVs.
- Many Level-2/240-volts charging stations provide free electricity to users because transaction costs are more than reasonable prices for the electricity used. Shopping centers, hotels and other businesses view them as incentives for their customers to shop there. Businesses view them as benefits for their employees. In my home town of Blacksburg VA seven of the nine public Level-2 charging stations did not charge a fee for usage in 2017.
- Fast charging stations are being established at a fast rate across the U.S., especially Superchargers for Tesla's.
- After a long time driving a BEV it is very aggravating to drive an ICE with its noise, heat, pollution, slow acceleration and knowing that one is burning a valuable hydrocarbon. When one thinks about it, it seems very strange to explode a hydrocarbon in an engine to convert linear motion to rotational motion to provide linear motion of the vehicle!
- Several of my friends have driven my Nissan LEAF and Bolt EV and they have all been surprised at how well they handle, their high acceleration and level of comfort.
- There are ethical issues about using public charging stations. See Ref. 34 for a discussion of Public Charger Protocol.

Buying/Leasing an Electric Car

I leased a 2012 Nissan LEAF for three years and a 2015 Nissan LEAF for 2 years because the technology, especially for batteries, used in electric vehicles was changing rapidly. Also, batteries lose capacity with time; it is better to have the car manufacturer take care of that when a leased car is turned in at the end of a lease. Consumer Reports recommends leasing BEVs for the same reasons, the first time they have recommended leasing a car. (Ref. 3)

Returning a leased car to a car company will force companies to devise battery exchange programs faster than they would otherwise. (See the section below about battery exchanges.) After robust battery exchange programs are in place and the technology settles down, buying might become a better way to drive an electric car.

Buying a Used Nissan LEAF

Here is a web page that contains advice for prospective buyers of used Nissan LEAFs:

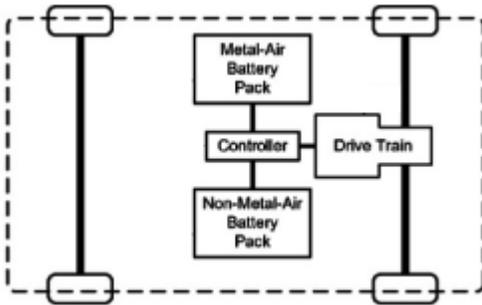
<http://www.roperId.com/Science/NissanLEAFUsed.htm>

AWD Electric Car

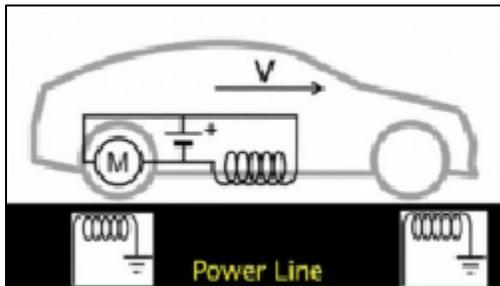
Tesla started selling an AWD Tesla Model X in 2015 (Ref. 34). In later years several other car companies are planning AWD BEVs.

Future Possibilities for Electric Vehicles

- **Battery-battery hybrids:** Tesla has patented the concept of using a lithium-ion (LI) battery (medium energy density and high power density) with a lithium-air (LA) battery (high energy density and medium power density). The LI battery would be used to provide energy during brief driving periods requiring high power (accelerating and climbing hills) and the LA battery would be used to provide energy during periods requiring low power (cruising). The LA battery also can recharge the LI battery. (Ref. 7)



- **Battery Exchange:** Nissan and Tesla have mentioned future plans for battery exchange programs. There are two versions: temporary battery exchange during a trip and permanent battery exchange when the original battery energy capacity gets too low. (Low-capacity batteries will be used as energy backup for renewable energy, such as solar and wind.) The auto companies need a battery exchange program to refurbish leased BEVs when they are returned with partially depleted batteries. Eventually, they will design BEVs so that batteries of larger capacity can replace batteries of lower original capacity. (Ref. 8, 9 & 10)
- **Wireless Charging.** Garages and parking lots can have wireless charging stations under the floor to wirelessly send energy to the charger in a vehicle. A few of these already exist. (Ref. 21)
- **No-Stop Charging:** A charging station can be continuous in the pavement to charge BEVs while they are moving. This would allow unlimited range! (This is already being done for buses on short repetitive routes.) (Ref. 12 & 13)



- **Vehicle-To-Grid (V2G):** Electric vehicles can be used to provide power to the grid when they are not being driven (e.g., employees' cars at jobs during afternoons when power demand is high) and receive power from grid when electricity demand is low. AnBEV owner can earn money from such a system because electricity rates are much higher during peak demand times than during low demand times. (Ref. 11)
- **Home power backup (V2H):** Electric vehicles' batteries can be used for home electric-power backup when the grid is down. Nissan has developed such a system for the LEAF. If a fast charging station on grid power is available within a few miles, the BEV can be charged as necessary. (A company in New Hampshire makes such backup systems for Toyota Prii, the world's most efficient, clean and quiet portable "generator".) (Ref. 14)
- **Business electricity-cost Savings (V2B):** Electric cars of employees can be used as storage devices during low-demand times to supply electricity for the business during high demand times. (Ref. 25)
- **500-miles Range Battery:** Research on several new battery chemistries are aiming for a 500-miles or longer range. (Ref. 15)

- **Light-Weight BEV Bodies:** Carbon-fiber reinforced plastics can be used to greatly reduce the weight of BEV bodies, thereby increasing the range of a given battery. BMW is the first car manufacturer to do this for a BEV, the BMW i3. (Ref. 22)
- **Automated Driving:** BEVs are natural vehicles for autonomous vehicles because of the high-power electronics. Nissan, Tesla and other auto companies have been experimenting with automated driving. Tesla already markets an Autopilot (Ref. 24, 33)

Plug-In Vehicles

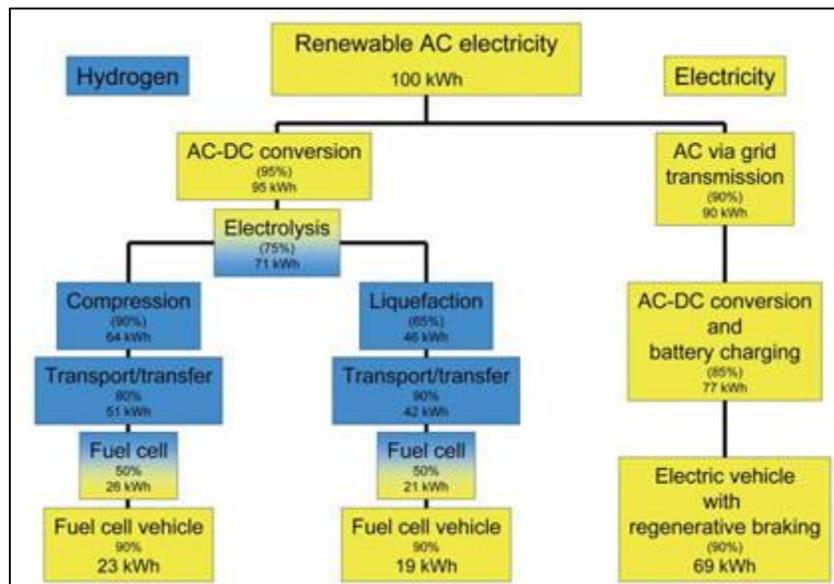
To get a rough estimate for the electric range for a plug-in car multiply the kWh for the battery by 3 or 4.

- BEV: Battery Electric Vehicle has no petroleum engine to help provide motive power. Examples: Nissan LEAF has a 30-kWh battery, Tesla Model S has a 75-kWh, 85-kWh or 100-kWh battery, BMW i3 has a 33-kWh battery, and Chevrolet Bolt EV has a 60-kWh battery).
- REx: Range-extended electric vehicle. Examples: BMW i3/Rex has a 33-kWh hour battery and small gasoline generator, Chevrolet Volt has a 18.4-kWh battery and medium-sized gasoline generator.
<http://www.roperId.com/Science/BMWi3.htm>
- Plug-In Hybrid: A gasoline-electric hybrid with a medium-sized battery. Examples: Ford C-MAX Energi has a 7.6-kWh battery, Toyota Prius Plug-In has a 8.8-kWh battery.

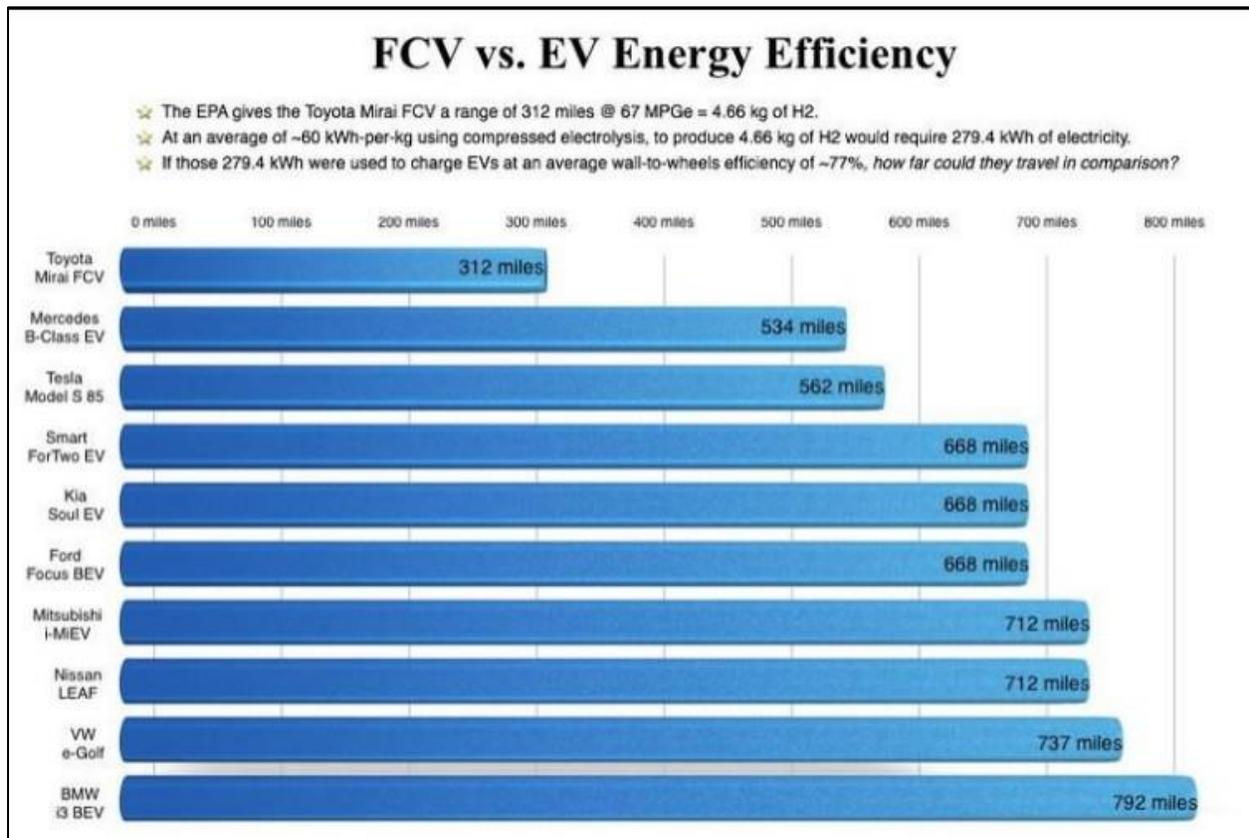
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Fuel-Cell Electric Vehicles

Why a hydrogen economy doesn't make sense: <http://phys.org/news85074285.html>



How a fuel cell works: <http://insideevs.com/toyota-mirai-explained-engineering-explained-video/>

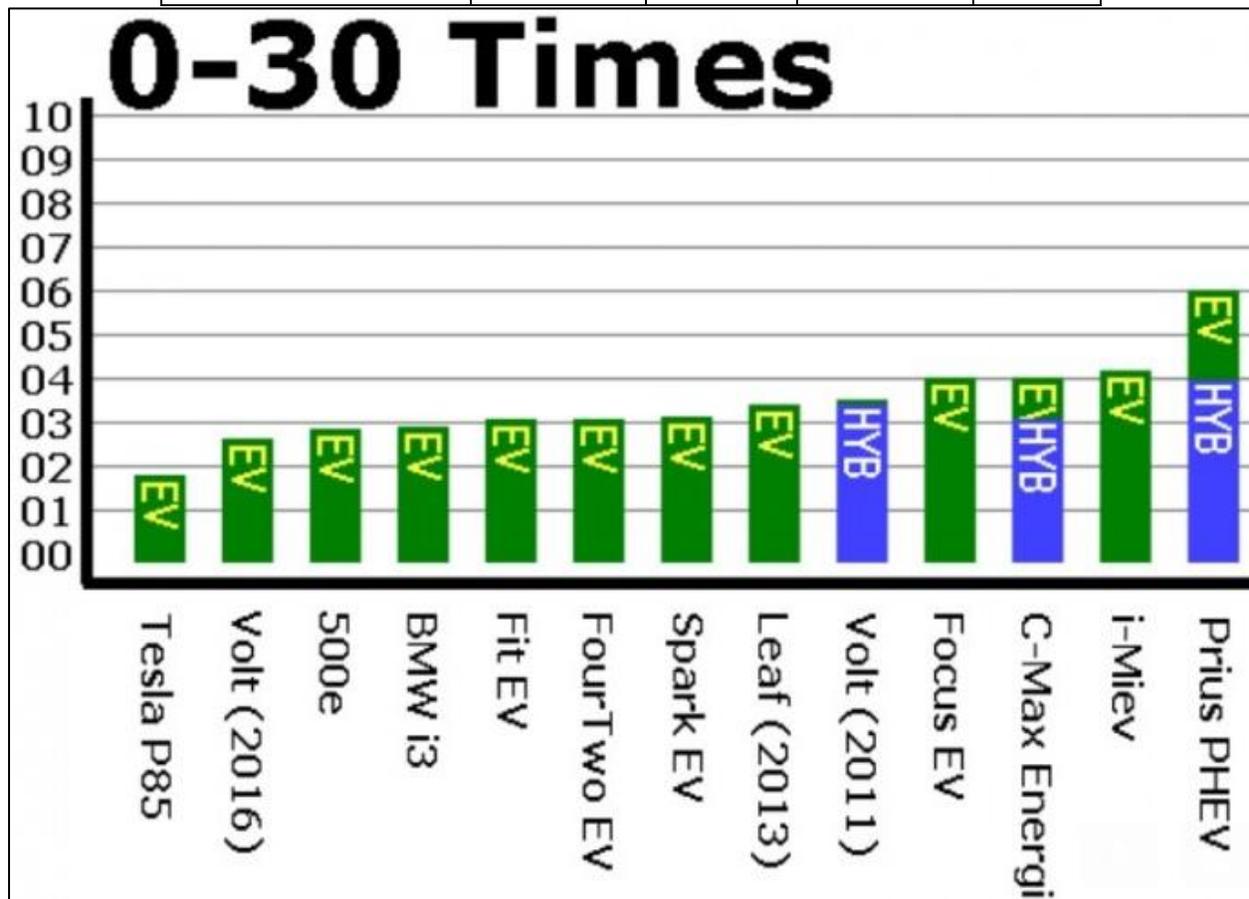


My Future Electric Cars

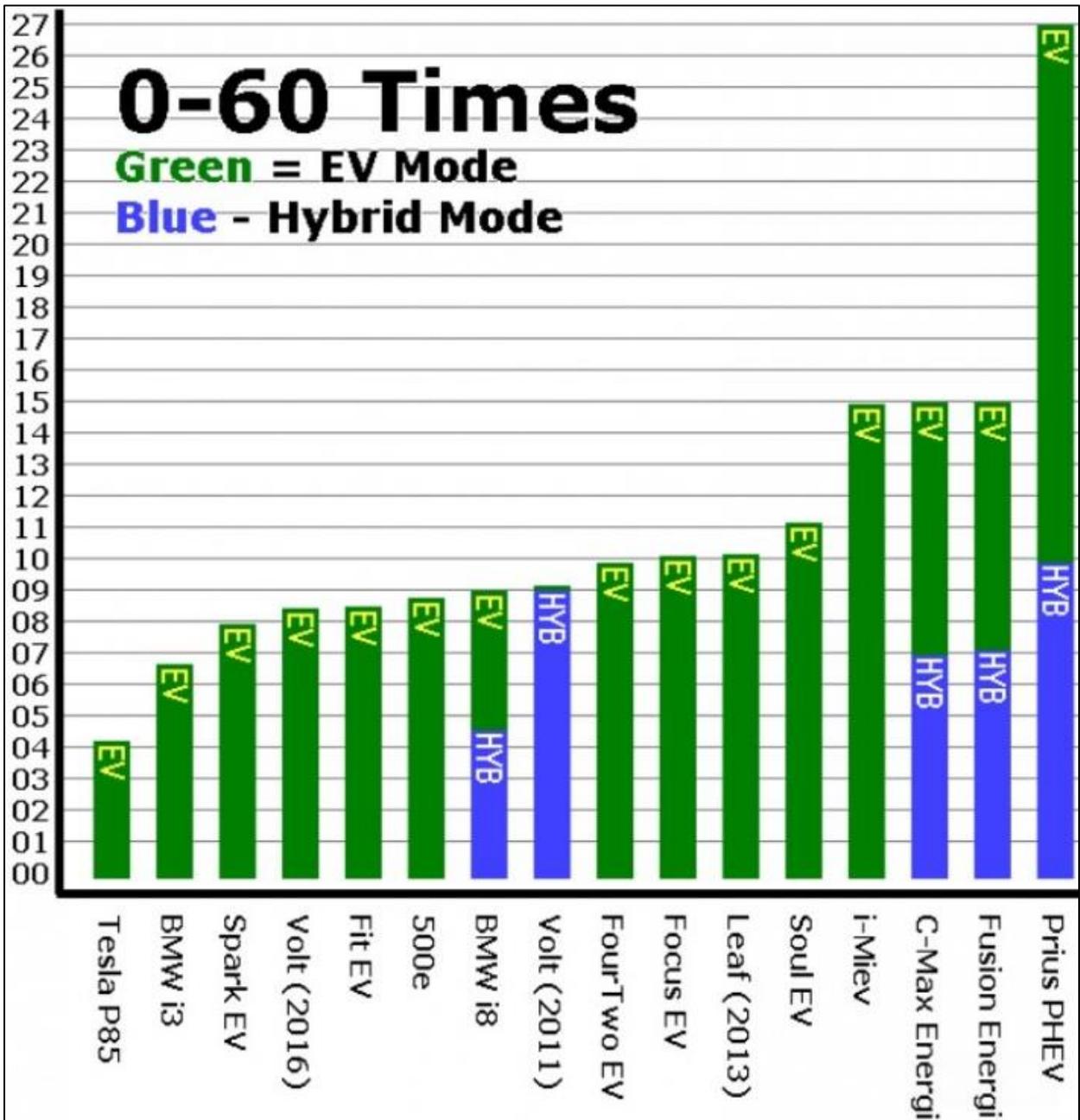
- I leased a 2012 Nissan LEAF SL on 7 May 2012 for three years.
- I leased a 2015 Nissan LEAF SV on 4 March 2015 for two years.
- I bought a 2107 Chevrolet Bolt EV on 11 April 2017.
- I have put a deposit on a Tesla Model 3.
- Eventually I want a BEV with ~400-miles or longer range.

Current Electric Cars (2014)

Make & Model	Miles/Gallon Equivalent	Miles/kWh	Range	Battery Size (kWh)
BMW i3	124	3.62	81	22
Chevy Spark EV	119	3.47	82	20
Fiat 500e	116	3.39	87	24
Nissan LEAF	114	3.33	84	24
Mitsubishi i-MiEV	112	3.27	62	16
Smart Electric	107	3.12	68	17
Kia Soul EV	105	3.07	93	27
Ford Focus EV	104	3.04	80	23
Tesla S 70D	?	?	240	70
Tesla S 85/85D/ P85D	89	2.48	265/270/253	85
Mercedes B250 e	84	2.45	104	36

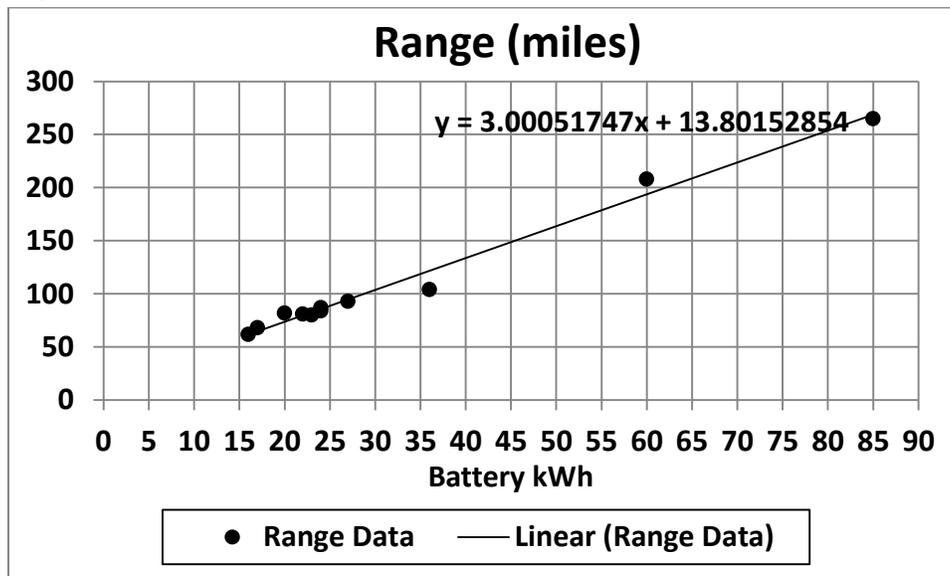


<http://insideevs.com/plug-vehicle-cross-section-acceleration-30-mph-60-mph-ev-mode/>



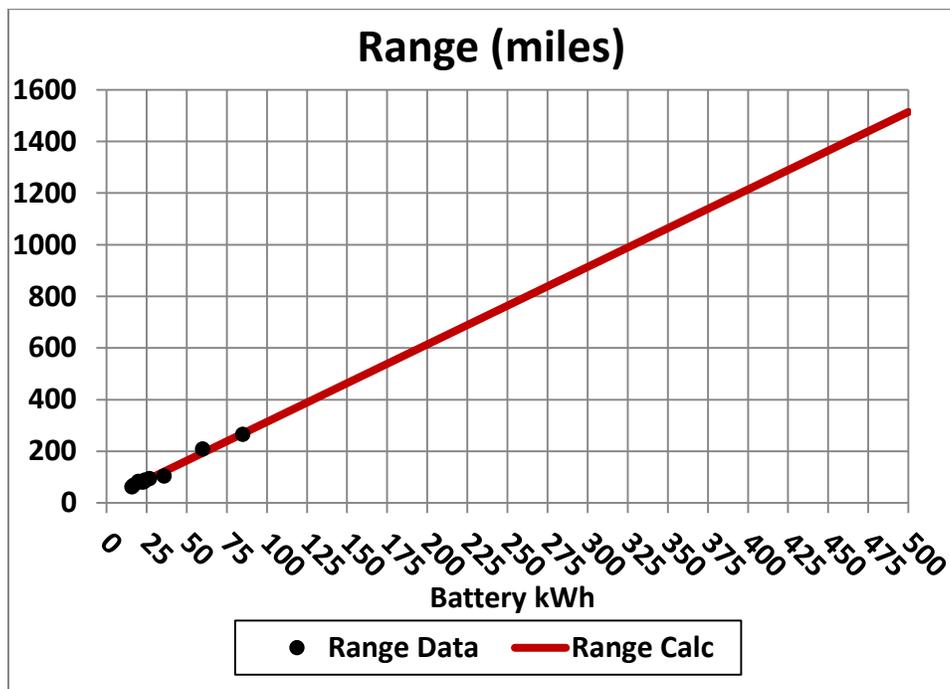
<http://insideevs.com/plug-vehicle-cross-section-acceleration-30-mph-60-mph-ev-mode/>

Range vs Battery Size:



Note that the miles/kWh for the linear fit is ~3.00. All BEVs do not fully charge or fully discharge the battery in order to keep the batteries healthy.

Projected range vs battery size, assuming a linear relationship:



When an affordable 200-kWh battery is ready, say goodbye to the gasoline car.

Education

- <http://evannex.com/pages/evannex-university-evu-draft>

Electric-Assisted Bicycles (Pedelec)

Electric-assisted bicycles (human-electric hybrid, e-bike or pedelec) are becoming very popular worldwide. There are about 120 million of them in China! I have a folding one that I like very much. (Ref. 16)

Electric Motorcycles and Scooters

Electric motorcycles have become very noticeable in motorcycling racing. (Ref. 23)

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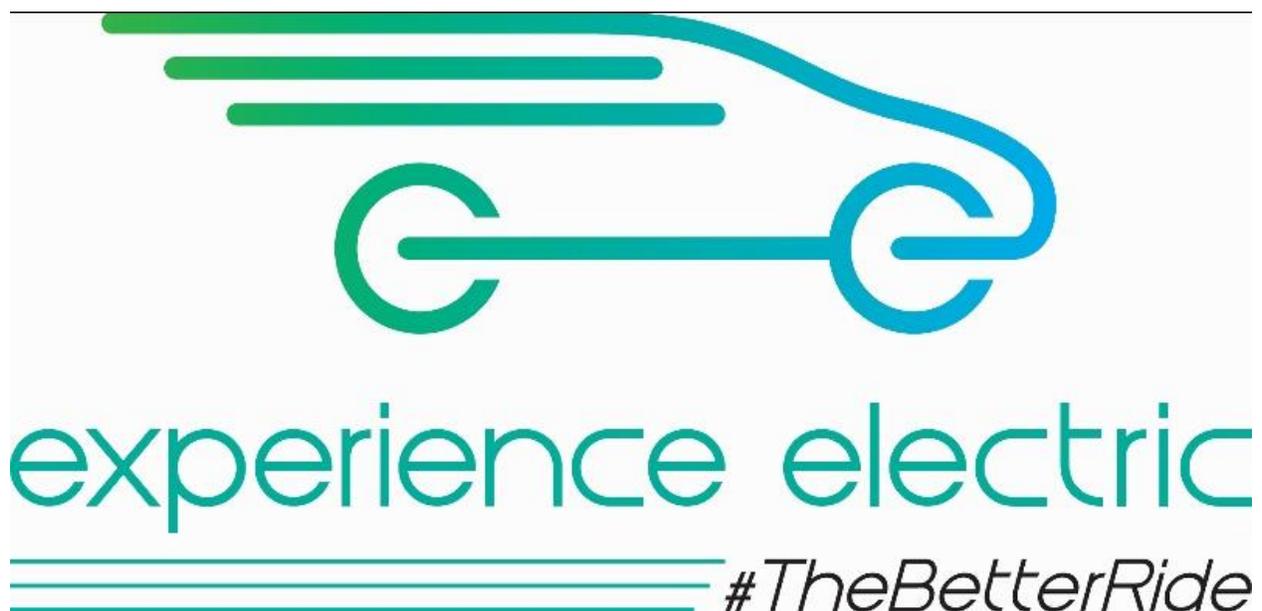
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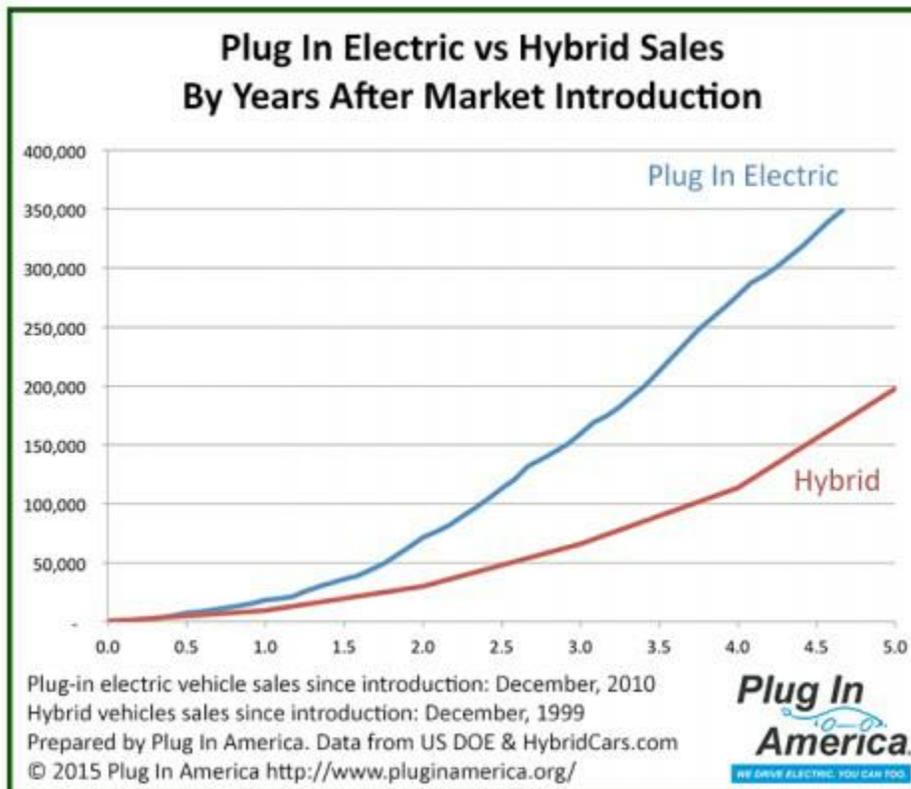
When an affordable 500-miles battery is ready, say goodbye to the gasoline car.

“Jay Leno: “...if it were reversed and electric vehicles were dominant today, who would put up with the noise, pollution, inefficiency, and tremendous maintenance needs of gasmobiles?”



Top 10 Reasons I'd Buy an EV Even If Gasoline Was Free

- 1 Torque is tremendous
- 2 Silence is golden
- 3 Fun to drive 21st century technology
- 4 No need to go somewhere to fill up (home fueling is great!)
- 5 Full 'tank' every morning!
- 6 Use your own 'home grown' solar fuel (no oil imports needed)
- 7 Insurance costs the same as a gas car
- 8 Long term overall cost of ownership is less (cost per mile is lower)
- 9 Less periodic maintenance, no more bi-annual smog checks to waste your time
- 10 EV simplicity always beats ICE complication (same goes for Fool Cells)



When will all cars be electric?: <http://www.roperld.com/science/ElectricCarsTotal.htm>

<http://www.roperld.com/science/ElectricCarsWorkshop.htm>