

ELECTRIC VEHICLES: MORE ANSWERS THAN QUESTIONS

*Will high speeds reduce my range?
Answer: Yes. However, the longer range of newer EV models does not make this as much of a problem as shorter-range models from a few years ago.*

The average fuel efficiency of any vehicle is determined by testing the cars on a "course" that includes both slow city driving and fast highway driving, as well as heating and air conditioning use that can reduce efficiency in winter and summer. Internal combustion engines typically have lower efficiency in city driving and higher efficiency in highway driving, averaging a 32% increase in miles per gallon at highway speeds.

*Can electric vehicles save energy? Can they save you money?
Can they save the world?*

It has been a decade since the first modern electric vehicle (EV) – the Chevrolet Volt in 2010 – was introduced by a major auto manufacturer. A great deal of product evolution has occurred since then, but EVs are still relatively new. There are a lot of questions and misconceptions that the general public and even some proud EV owners have about the technology, the best way to use it, how EVs can change society, and their potential to ameliorate environmental problems.

I am a big supporter of EVs because of their ability to reduce carbon and air pollutant emissions, their elimination of onsite (in-traffic) toxic combustion fumes, their mechanical longevity, and their long-term national security implications for reducing oil consumption.

However, some EV supporters have exaggerated expectations of what these vehicles can achieve. At the same time, some EV detractors have made unsubstantiated (some would say desperate) attacks about the vehicles' alleged problems.

The point of this article is to give an overview of the progress and challenges associated with the technology, and how individuals can become a part of this new and growing trend.

EVs: The Basics

How fast can I go?

Answer: Fast, but it depends on the vehicle.

All EVs sold in the U.S. in 2020 were designed to go at least minimal highway speeds. The slowest of 2019 / 2020 is the Chevy Bolt at 90 mph. The fastest is the Tesla Model S Performance LM at 163 mph, going from 0 to 60 mph in 2.4 seconds. Some models may have a speed limit engineered into them to conserve range.

EVs are the reverse. An analysis of all Battery (only) Electric Vehicles sold in the U.S. in 2019 showed a 16% average decrease in efficiency between City and Highway driving. That said, most newer EVs typically have ranges between 124-259 miles per charge. Since the average daily travel distance in the U.S. is 30 miles per vehicle, these new models will accommodate the vast majority of daily auto needs, highway or not. In 2017, less than 2% of passenger vehicles in the U.S. traveled more than 100 miles in a day; less than 0.7% traveled more than 150 miles a day.¹

Do EVs cause more fires in accidents, and are they as safe as conventional vehicles?

Answer: EV fires are so rare that no accurate statistics exist at this time for comparison, but some do have excellent overall safety ratings.

According to the National Fire Protection Association, in 2018, there were approximately 181,500 vehicle fires (497 per day) causing about 490 deaths, 1,300 injuries, and \$1.4 billion in damage (2018 dollars).² In 2009, the year before the first modern EVs were marketed, there were 190,500 vehicle fires causing 260 deaths, 1,455 injuries, and \$1.4 billion in damage (2018 dollars).³

Almost all fatal fires are due to flammable liquids. Lithium EV batteries are flammable under certain conditions, but battery fires are so rare that separate statistics are not tallied to compare them with internal combustion engine vehicles at this time.

However, since EVs are still new, these rare EV fires provoke controversial news coverage when they occur.

Any vehicle fire is alarming, but there is no evidence to date that EV fires occur at the same or higher rates than conventional vehicles.



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Other safety characteristics in many EVs include improved front crumple zones because there are no engines under the hood, and reduced rollover accidents because the placement of batteries creates a low center of gravity.

Several EV models have earned the Insurance Institute for Highway Safety's ratings of Top Safety Pick (*) or Top Safety Pick+ (**). These are listed below. (Some models have both electric and conventional versions, but the crash tests do *not distinguish* between the same model that uses different fuels.)

Top Safety Picks for Battery Electric Vehicles (BEVs)

2019 Audi e-tron**
 2019 Chevrolet Bolt*
 2019 Hyundai Kona** w/safety option
 2020 Hyundai Kona* w/safety option
 2019 Kia Niro** w/safety option
 2019 Kia Soul* w/safety option
 2020 Kia Soul* w/safety option
 2019 Mini Cooper 2-Door Hatchback* w/safety option
 2019 Tesla 3**
 2020 Tesla 3**

Top Safety Picks for Plug-In Hybrids (PHEVs)

2019 Chrysler Pacifica Minivan* w/safety option
 2019 Hyundai Ioniq* w/safety option
 2019 Hyundai Sonata** w/safety option
 2020 Hyundai Sonata* w/safety option
 2019 Kia Niro** w/safety option
 2019 Kia Optima** w/safety option
 2019 Subaru Crosstrek** w/safety option
 2020 Subaru Crosstrek** w/safety option
 2020 Volvo S60* w/safety option
 2019 Volvo S90* w/safety option
 2018 Volvo V60* w/safety option
 2019 Volvo XC60* w/safety option
 2020 Volvo XC60* w/safety option
 2019 Volvo XC90* w/safety option

What can I do to charge when I am not at a single-family or duplex residence?

Answer: Use public charging stations or find a multifamily complex that offers charging in its parking lot/garage.

There were at least 913 Level 2 public charging plugs located in the Austin Energy service area at various commercial, governmental, and apartment community locations as of December 2019. A "Plug-In Everywhere" card for sale from Austin Energy will allow unlimited charging from these stations for \$4.17/ month (2020 costs). However, as of early 2020, there were only 62 local multifamily complexes that had publicly available chargers.



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You can locate public charging stations in the Austin area at: austinenergy.com/ae/green-power/plug-in-austin/charging-station-map

You can locate public charging stations nationwide at: www.plugshare.com

How long do batteries last?

Answer: New vehicles sold at the time this article was published were warrantied for at least 8 years/100,000 miles, but you also have to consider capacity (range) loss over time.

For 2019/2020 models, EV batteries sold in the U.S. were guaranteed for at least 8 years/100,000 miles. In 2020, Hyundai and Kia BEV (Battery Electric Vehicle) batteries were warrantied for 10 years/100,000 miles. In the same year, Hyundai's PHEV (Plug-In Hybrid Electric Vehicle) batteries were warrantied for 10 years / 150,000 miles, while Kia PHEVs were warrantied for 10 years/100,000 miles.

However, the warranty does not guarantee 100% of original mileage range. Though different for every vehicle model, capacity can fall to as little as 60% of original range before the manufacturers will replace them. As examples: Tesla and Hyundai will replace their batteries if the capacity falls below 70% of initial capacity; Nissan will replace Leaf batteries if they fall to 9 (out of 12) "bars," roughly 70%; Chevrolet will replace Bolt batteries if they fall below 60%.

When buying a used EV, how do I assess battery capacity?

Answer: If it is not apparent, ask an authorized dealer to measure it.

Many EV batteries often retain considerably more than 60–70% capacity at the end of warranty. Pooled self-reported data from hundreds of Tesla owners claim batteries with over 155,000 miles still retain 90% of original range.⁴ Another survey of 6,300 EVs with varying models, climate conditions, and charging circumstances estimated only 2.3% average degradation per year.⁵ Still, capacity erosion is a big concern if you are buying a used vehicle.

Mass-produced EVs have been on the market since 2011, and used EVs can be had for as little as \$5-10,000. (I observed



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one on sale for \$3,600!) Contrary to the cynical way that many people view normal cars' "planned obsolescence" due to old mechanical equipment, electric motors on EVs can last indefinitely. However, the eroding capacity of EV batteries has become the weak link.

Owners can compensate by: 1) buying used EVs with low mileage (there are some); 2) only driving used EVs for short trips; 3) buying a new battery pack.

This last option is a challenge for lower-income people. For example, according to auto industry press, the cost of a new battery for a 2011 Nissan Leaf was \$8,500 plus installation in 2019. If you get a used Leaf for \$8,000 and install this new battery, it would be more than many people can afford. As another example, the Chevy Bolt, with a larger battery, has a replacement cost of over \$16,250 plus labor.

The Leaf has a battery "bar" meter located on the dashboard that rates capacity. Other models may need a technician at a dealership to analyze range loss.

How can I extend battery life?

Answer: Energize them to the proper State (percentage) of Charge, preheat the cabin in the winter and pre-cool it in the summer, and avoid fast charging when possible.

Since the condition of the EV storage battery is pivotal to range and utility, great care should be taken to make their capacity last as long as possible.

1. Keep in optimum charge range. While it is technically feasible to charge to 100% capacity and drive until there is no electricity left, this should be avoided whenever possible. Batteries generally last longer if they are neither completely emptied or topped off. The optimum range is between 20% and 80% State of Charge.

2. If you do charge to 100% capacity, do this just before driving. Rather than topping off and then storing the charge overnight or several days, store the top 20% (above the 80% optimum) for as little time as possible.

3. Pre-heat the vehicle in winter and pre-cool the vehicle in summer with the car plugged into charger before you travel to limit the vehicle's battery use when you travel. To the extent that you can save your vehicle from the parasitic losses of temperature control, it extends your range, and better allows you to be in the optimum 20% / 80% charge range more often.

Other ideas to reduce losses from temperature control in any vehicle include: 1) parking in shade in summer; parking in a garage in winter if it is warmer than outdoor temperature; 2) maintaining proper tire pressure; and 3) opening windows to air out the cabin in hot weather, which pre-cools the cabin, before turning on the AC.

4. If available, warm yourself with steering wheel and

seat heaters rather than less efficient blown air.

5. Avoid "superchargers" when possible. Under normal ambient temperatures, Level 3 quick-charging stations, also known as superchargers, can generally charge EV batteries from 20% to 80% State of Charge in 30 to 120 minutes, instead of needing 4 to 10 hours typically required by Level 2 (220 volt) chargers or a much longer period required by Level 1 (110 volt) chargers. (A long-range EV of 260 miles on a simple wall plug can literally take almost 3 days to fully charge.) However, repeated supercharging has been shown to cause more battery degradation.

The problem is minimal but noticeable. One study showed a 3 to 9% decrease in battery capacity when EVs exclusively used fast chargers compared to vehicles that were never fast charged, and this was after heavy cycling in a stressful desert climate after 50,000 miles of use.⁶

6. When operating Plug-In Hybrids in hilly or mountainous terrains, switch to 'mountain mode' driving. This switches off dedicated battery use and hoards the electric power for necessary applications such as passing.

7. If storing an EV for an extended period (weeks or months), keep the battery charged at a minimal level. Batteries sitting idle may lose a bit of their charge every day. This attrition can lower the State of Charge to levels that cause stress. A smart charger or cell-phone app that can keep the battery charged to about 50% of capacity would be optimal for these situations. Also, storing in cooler temperatures will prolong battery life compared to hotter ones.

Caley Johnson / NREL



Will cold and hot weather affect EV driving range?

Answer: Yes, particularly if the heating and air conditioning are used.

EVs operate less efficiently in winter because electron mobility in batteries is reduced by the cold. Conventional vehicles also have a winter range handicap because engine fluids do not work as well at preventing friction, and because engines do not work as efficiently. And both EVs and conventional vehicles have a winter handicap because of physics: colder air is denser, creating more aerodynamic drag, and tire pressure decreases, increasing rolling resis-



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tance. Conventional vehicles have an advantage though. They can be heated by the waste heat of the engine, while EVs must use batteries for heat.

Vehicle air conditioning can also result in noticeable range loss in both EVs and conventional vehicles.

A 2019 study by the American Automobile Association compared 5 popular EV models in cold (20°F) and hot (95°F) weather against a moderate temperature (75°F).⁷ It found only a 12% decrease in range in cold weather and a 4% decrease in range in hot weather. However, when parasitic losses of the heater and air conditioner were factored in, there was an additional 41% loss in range in cold weather and an additional 17% loss in range in hot weather.

Cold temperatures can also reduce range in internal combustion vehicles by 15% (24% on short trips).⁸ Similarly, conventional vehicle air conditioning can reduce range; one study showed a 12 to 32% decrease in range from air conditioning, with the reduction varying at different speeds.⁹ However, given the increased time to charge plug-in vehicles compared to fueling gas vehicles, temperature-control range reductions have a larger practical adverse effect.

But ironically, countries with the world's highest percentages of EV sales are in Northern Europe, so weather-affected range limits are not always a formidable obstacle.

EV Economics

Can EVs save money?

Answer: *When the total cost of the vehicle, fuel, and maintenance is considered, EVs are still marginally more expensive for small and mid-sized vehicles without incentives. But they are getting closer to parity with conventional vehicles through falling battery costs.*

Due to still expensive battery packs, the first cost is higher than conventional vehicles, but there are large savings on fuel and maintenance. In round numbers, EVs on the market in early 2020 save 60-70% on fuel and 35-66% on maintenance. Over the life of a vehicle, this will lend considerably to equalizing the total cost of ownership.

U.S. data showed that in 2017, the top 10 repair costs, which made up 40% of all auto maintenance expenses, were specific to internal combustion engines (e.g., replacing spark plugs, ignition coils, fuel injectors, and catalytic converters).¹

Following is a simple comparison of a 10-year total cost of ownership for various small and mid-sized EVs and their conventional counterparts.²

This does not include financing, value of money, federal, state, or dealer incentives, or inflation for fuel and maintenance. Maintenance savings here are conservative, as some studies and reports predict much greater differences. It

should be noted that many EVs will probably be in better condition at the end of 10 years than their fossil-fuel rivals. There are fewer moving parts in an EV, and the motors can last indefinitely.

10-Year Cost of EVs and Conventional Vehicles		
	VW eGolf	Golf
First Cost	\$37,607	\$25,017
Home EV Charger	\$600	\$0
Annual Fuel/yr.	\$438	\$1,158
Annual Maintenance/yr.	\$619	\$949
Ten-Year Cost	\$48,779	\$46,083
	Hyundai Kona EV	Hyundai Kona
First Cost	\$43,483	\$28,337
Home EV Charger	\$600	\$0
Annual Fuel/yr.	\$438	\$1,372
Annual Maintenance/yr.	\$619	\$949
Ten-Year Cost	\$54,655	\$51,547
	Kia eSoul	Kia Soul
First Cost	\$37,134	\$20,974
Home EV Charger	\$600	\$0
Annual Fuel/yr.	\$485	\$1,323
Annual Maintenance/yr.	\$619	\$949
Ten-Year Cost	\$48,776	\$43,693
	Leaf	Average Mid-Size Car
First Cost	\$35,163	\$26,563
Home EV Charger	\$600	\$0
Annual Fuel/yr.	\$516	\$1,195
Annual Maintenance/yr.	\$619	\$949
Ten-Year Cost	\$47,118	\$48,002
First cost includes Texas tax; other costs rounded		

Battery costs have fallen dramatically since the first modern EVs were sold in 2010 and are now estimated to be between \$156 and \$210 per kwh of storage. There is general consensus that when batteries reach \$100 per kwh, EVs will reach parity with fossil-fueled vehicles.^{3,4}

Are there incentives that allow me to afford a new EV?

Answer: *Yes: federal, state, and local.*

National: Federal tax credits of \$7,500 were developed to help drive mass production of EVs, which would bring the cost down. They are applied to the first 200,000 vehicles sold in the U.S. from any manufacturer. After that, the tax credits will ramp down and eventually be removed for each automaker. By the end of 2019, both Chevrolet and Tesla EVs hit these limits and no longer have any federal tax credit applicable to any of their models. However, full EV tax credits from other vehicle manufacturers will probably still be available through the end of 2020. It is always possible that tax credits will be renewed in the future for all manufacturers, but this is speculative.

A problem inherent in federal EV tax credits is that they can only be used in one tax year; they are a 'use-it-or-lose-it' opportunity. Many car buyers with low- and moderate-incomes do not pay this amount of income tax (exclusive of social security) in a year, and these EV credits do not roll



Kona Electric



Tesla Model X



Volkswagon eGolf



Nissan Leaf

Battery Electric Vehicles (BEVs)					
		Estimated MSRP	Range in Miles	Miles/Kwh	Class
2020	Audi e-tron	\$77,400–\$88,495	218	2.3	SUV 4WD
2020	BMW i3	\$47,650	153	3.3	Subcompact
2020	Chevrolet Bolt EV	\$36,620–\$41,020	259	3.4	Small Station Wagon
2019	Honda Clarity EV	\$36,620	89	3.3	Midsize
2020	Hyundai Ioniq Electric	\$33,045–\$38,615	170	4.0	Midsize
2020	Hyundai Kona Electric	\$37,190–\$45,400	258	3.7	Small SUV 2WD
2020	Jaguar I-Pace	\$69,850–\$80,900	234	2.3	Small SUV 4WD
2020	Kia Niro Electric	\$39,090–\$44,590	239	3.3	Small Station Wagon
2019	Kia Soul Electric	\$33,950–\$35,950	111	3.2	Small Station Wagon
2020	Nissan Leaf (40 kW-hr battery)	\$31,600	149	3.3	Midsize
2020	Nissan Leaf (62 kW-hr battery)	\$38,200	226	3.2	Midsize
2020	Nissan Leaf SV/SL (62 kW-hr battery)	\$34,190–\$43,900	226	3.1	Midsize
2020	Tesla Model 3 Standard Range Plus	\$37,990	250	4.2	Midsize
2020	Tesla Model 3 Long Range	\$46,990	322	3.6-3.8	Midsize
2020	Tesla Model 3 Long Range Performance	\$54,990	299	3.3-3.6	Midsize
2020	Tesla Model S Long Range Plus	\$74,990	402	3.2-3.3	Large
2020	Tesla Model S Performance	\$94,990	348	3.1	Large
2020	Tesla Model X Long Range Plus	\$79,990	351	2.9	SUV 4WD
2020	Tesla Model X Performance	\$99,990	305	2.6	SUV 4WD
2020	Tesla Model Y Long Range	\$52,990	316	NA	Midsize SUV
2020	Tesla Model Y Performance	\$60,990	315	3.6	Midsize SUV
2019	Volkswagen e-Golf	\$31,895–\$38,895	125	3.6	Compact
2020	Porsche Taycan	\$103,800–\$185,000	192	2.1	Large
2020	MINI Cooper	\$29,900	110	3.2	Subcompact

Not all models are sold in every state. Check for local availability.

Plug-In Hybrids (PHEVs)					
		Estimated MSRP	Miles of Range EV • Gas	Efficiency Miles/Kwh • Miles/Gal	Class
2020	Audi A8 L	\$85,200	17 • 420	1.6 • 23	Large
2020	Audi Q5	\$43,300	20 • 390	1.9 • 27	Small SUV 4WD
2020	BMW 530e	\$53,900	21 • 350	2.1 • 27	Compact
2020	BMW 530e xDrive	\$56,200	19 • 330	1.9 • 25	Compact
2020	BMW 745e xDrive	\$95,550	16 • 290	1.6 • 22	Large
2020	BMW i8 Coupe	\$148,500	18 • 320	2.0 • 27	Subcompact
2020	BMW i8 Roadster	\$164,300	18 • 320	2.0 • 27	Two-Seater Car
2020	Chrysler Pacifica Hybrid	\$39,995–\$46,540	32 • 520	2.4 • 30	Minivans
2020	Ford Fusion PHEV Titanium	\$35,000	26 • 610	3.0 • 42	Midsize
2020	Ford Escape SE PHEV	\$33,040	38 • 492	3.0 • 41	Small SUV 4WD
2020	Honda Clarity PHEV	\$33,400–\$36,600	48 • 292	3.2 • 42	Midsize
2020	Hyundai Ioniq	\$26,500–\$32,950	29 • 601	3.6 • 52	Midsize
2020	Hyundai Sonata	\$33,400–\$39,000	28 • 558	2.9 • 39	Midsize
2020	Karma Revero GT (21-inch wheels)	\$135,000	61 • 330	2.1 • 26	Subcompact
2020	Kia Niro Plug-in Hybrid	\$28,500	25 • 560	3.1 • 46	Small Station Wagon
2020	Kia Optima Plug-in Hybrid	\$36,090	28 • 630	3.0 • 41	Midsize
2020	Land Rover Range Rover PHEV	\$95,950	19 • 480	1.3 • 19	SUV 4WD
2020	Land Rover Range Rover Sport PHEV	\$79,000	19 • 480	1.3 • 19	SUV 4WD
2020	Lincoln Aviator PHEV AWD	\$51,100	21 • 460	1.7 • 23	SUV 4WD
2020	MINI Cooper SE Countryman All4	\$38,750	18 • 300	2.2 • 29	Midsize
2020	Mitsubishi Outlander PHEV	\$36,095–\$41,495	22 • 310	2.2 • 25	Small SUV 4WD
2020	Porsche Panamera 4 e-Hybrid	\$103,800	14 • 490	1.5 • 23	Large
2020	Porsche Panamera 4 e-Hybrid ST	\$107,800	14 • 490	1.5 • 23	Large
2020	Porsche Panamera Turbo S e-Hybrid	\$187,700	14 • 450	1.5 • 20	Large
2020	Porsche Panamera Turbo S e-Hybrid Ex.	\$198,100	14 • 450	1.5 • 20	Large
2020	Porsche Panamera Turbo S e-Hybrid ST	\$191,700	14 • 450	1.5 • 20	Large
2020	Subaru Crosstrek Hybrid AWD	\$35,145	17 • 480	2.6 • 35	Small SUV 4WD
2020	Toyota Prius Prime	\$27,600–\$33,500	25 • 640	4.0 • 54	Midsize
2021	Toyota RAV4 Prime	\$38,100–\$41,425	42 • 558	2.8 • 38	Small SUV 4WD
2020	Volvo S60 AWD PHEV	\$55,400–\$64,800	22 • 510	2.1 • 30	Compact
2020	Volvo S90 AWD PHEV	\$63,200	21 • 490	2.0 • 30	Midsize
2020	Volvo V60 AWD PHEV	\$67,300	22 • 510	2.1 • 30	Small Station Wagon
2020	Volvo XC60 AWD PHEV	\$53,950–\$69,500	19 • 520	1.8 • 27	Small SUV 4WD
2020	Volvo XC90 AWD PHEV	\$67,000–\$73,800	18 • 520	1.7 • 27	SUV 4WD

over into successive years. So these taxpayers will not see the full amount of price reduction.

State of Texas: At the time of publishing, the “Light-Duty Motor Vehicle Purchase or Lease Incentive Program” administered by the Texas Commission on Environmental Quality offered rebates of \$2,500 to the first 2,000 qualified applicants in a given year.

Austin: As of early 2020, Austin Energy offered a 50% rebate for installed cost of Level 2 charging equipment, up to \$1,200 for Wi-Fi-enabled charging stations and \$900 for non-Wi-Fi-enabled charging stations. In 2019, it was the only utility in Texas to do this.

What about two-wheel vehicles?

Answer: Electric bicycles, mopeds, and motorcycles have been on the market a long time.

There were 130,000 electric bicycles sold in the U.S. in

2015.⁵ The same year, there were 14 million sold in China. Two-wheel electric vehicles are proliferating.⁶ There are three basic types.

- **1) Electric Bicycles:** max speed of 20-30 mph; 19-125 mile range in EV mode, longer with more pedal assist; costs range from less than \$1,000 to as high as \$10,000; no drivers license or vehicle registration required.
- **2) Electric Mopeds:** 30 mph or less; 20-40 mile range; cost of \$2,500-\$7,000; Class M license and vehicle registration required.
- **3) Electric Motorcycles:** max speeds of 50-218 mph; 53-205 mile range; costs of \$9,000-\$48,000; Class M license and vehicle registration required. Many of these are ridden for recreation as opposed to city driving. (218 mph?!)

As of 2020, two-wheel electric vehicles with over 2.5 kwh of battery storage (certain motorcycles) were eligible for federal tax credits of 10% of the cost of the vehicle up to \$2,500.



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It is not completely accurate to compare the efficiency of electric four-wheeled vehicles to electric two-wheeled transportation. Four-wheeled vehicles are calculated on a strictly monitored course of driving, the vehicles can carry several passengers and have cargo capability, and they are temperature controlled.

However, an evaluation of specs provided by a two-wheel manufacturer allows an estimate that e-bikes travel 12 to 67 times as far on the same amount of electricity (depending on the percentage of pedal assistance). Kick scooters (e.g., Segway) can travel about 25 times as far. Electric mopeds can travel roughly 5 times as far, and electric motorcycles can travel approximately 2-1/2 times as far.

EVs and the Environment

How will EVs affect U.S. national energy use? (What if everybody did it?)

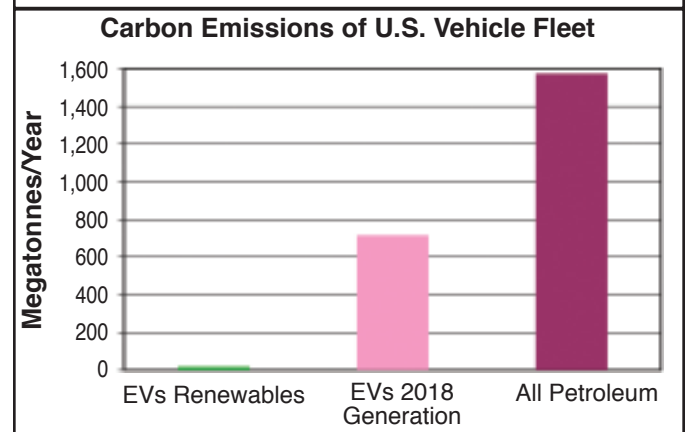
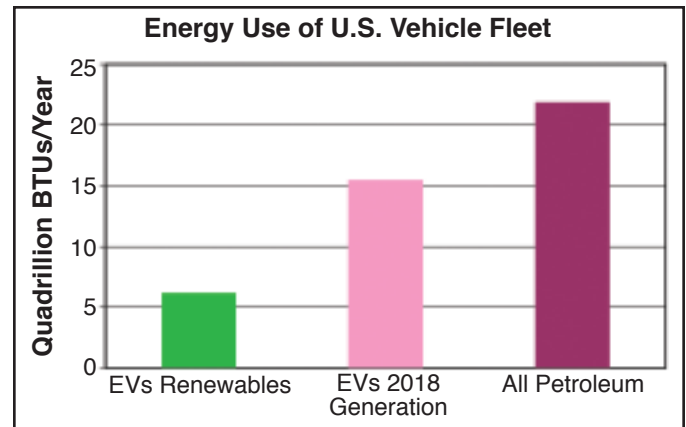
Answer: If the entire vehicle fleet were switched to EVs, it would increase overall electricity use markedly, but dramatically lower overall energy use.

In 2016, the U.S. had a fleet of over 267 million vehicles. 95% of these were light-duty cars and trucks, and motorcycles.¹ Though heavy trucks made up only 5% of actual vehicles, they represented 28% of petroleum energy consumption on the country's highways.²

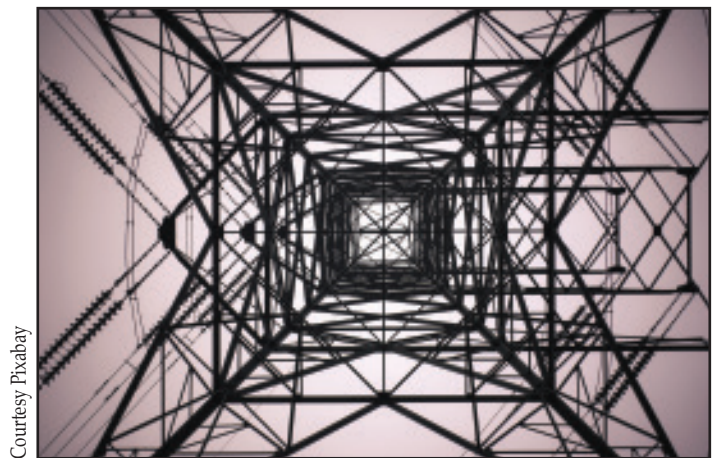
If every one of these vehicles operated on electric power, it would raise the electricity used in the U.S. by 43% over 2018 levels.³

However, if this electric fleet operated completely on renewable electricity, overall energy use would be only 28% of current energy use on highways.⁴ This is because electric motors are more efficient at using energy than combustion engines, and because there are no fossil-fuel thermal power plant losses from solar and wind energy.

Even using the mix of conventional and renewable energy sources that powered the U.S. electric grid in 2018, total energy use of an all-electric fleet would be 71% of current highway use.⁵



Carbon dioxide emissions would be even more dramatically affected. Using the 2018 generation mix to power this fleet would only release 46% of the emissions from petroleum highway use, while renewable energy would obviously create no emissions from the generation at all.⁶



Courtesy Pixabay

How will EVs affect peak demand on the electric grid? (What if everybody did it?)

Answer: EVs will increase electricity demand at peak times, though it is speculative as to how much.

A sweltering Texas summer afternoon at 5 PM can use 3 times the electric capacity demanded on a balmy spring morning before dawn. EVs might require that more generation and distribution capacity be built to accommodate conversion.

A considerable amount of potential peak load from vehicles can simply be deferred through “managed charging” (incentive rates and prohibitions that shift peak use to off-peak hours). However, supercharging stations for long-distance driving and special situations are not as easily controlled. These stations currently use between 50 to 350 KW (10 to 70 times the summer peak demand of an average Texas home). Superchargers can provide the majority of a vehicle’s battery capacity in 30 minutes to 120 minutes, as opposed to more common overnight charging operations that take place in homes.

Superchargers will become more common, and it is inevitable that they will be used during peak demand. It would cause some drivers considerable inconvenience if superchargers were prohibited from operating at peak hours, and this could discourage wider adoption of EVs.

It is hard to predict the long-term needs for accommodating superchargers with generation capacity. Fortunately, it is not yet a worrisome matter, and there is at least one interesting twist to solving the problem: using batteries to charge other batteries.

As electric vehicles age, the vehicles will not be able to travel as far as they used to on a charge. By the time batteries have lost 25-30% of their capacity, the units are often considered worn enough to be replaced.

However, the batteries can have a second life in stationary applications, including EV supercharging stations. They could operate from batteries during peak demand while charging at off-peak hours, saving the grid from expensive upgrades and their charging clients from higher on-peak prices.

Do EVs eliminate air pollution?

Answer: For average emissions from the fuel mix of U.S. electric plants in 2018, EVs will have lower emissions for criteria air pollutants, with the exception of sulfur dioxide.

Unless EVs are Plug-In Hybrids, there are obviously no tailpipe emissions. In contrast, a 2020 model of a gasoline light-duty vehicle driving average mileage will emit 1.66 pounds of nitrogen oxides and non-methane organic gases (including Volatile Organic Compounds) that cause ozone, and 26 to 107 pounds of carbon monoxide annually. Most of these pollutants are concentrated in metropolitan areas where they can cause more harm to more people.⁷

If the entire U.S. highway vehicle fleet converted to electric vehicles from fossil fuels (using the 2018 generation mix of coal, gas, nuclear, and renewable energy), it would lead to dramatic changes in air pollutant emissions.⁸

• 98% reduction of carbon monoxide from vehicle emissions, and a 35% reduction of all emissions (including factories, solvents, etc);

Are EVs more efficient than conventional vehicles?

Answer: Yes. EVs lose less direct energy to waste heat and “upstream” losses such as oil refineries.

EVs are more energy efficient than the average gas-powered passenger car since electric motors are much more efficient than internal combustion engines, even considering losses from a thermal power plant. BEVs can save 28-77% on actual electric use.⁹



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Energy Efficiency of Battery Electric Cars			
Type	Power Source	BTUs/Mile	Savings
Gas Car		4,980	
Electric Car	Coal Plant	3,593	28%
Electric Car	Efficient Gas Plant	2,123	58%
Electric Car	Offsite Wind	1,198	76%
Electric Car	Onsite Solar PV	1,138	77%

Net Energy Use in Vehicles		
Energy Losses	Electric Vehicle	Gas Vehicle
Motor Loss	4%	81%
Power Plant Loss	0-66%	
Transmission Loss	0-7%	
Battery Loss	7%	
Charger Loss	7%	
Refinery Loss		20%
Total Efficiency After Losses	26-83%	15%

• an 86% reduction in ozone-causing nitrogen oxide from vehicle emissions and a 28% reduction of all emissions;

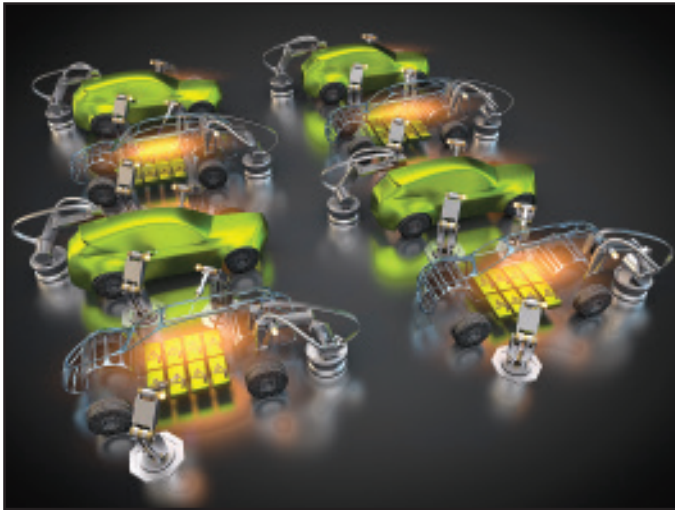
• a 99% reduction in ozone-causing VOC emissions from vehicles and a 14% reduction of all emissions;

• a 19-fold increase in sulfur dioxide from vehicles due to increased coal combustion, and a 20% increase from all emissions.

Criteria Air Pollutants and Sources 2018 (Thousands of Tons)				
	Carbon Monoxide	Nitrogen Oxide	Vol. Organic Compounds	Sulfur Dioxide
Electric Utilities	731	1,114	38	1,306
Highway Vehicles	17,045	3,300	1,993	27
Total All Sources (Excluding Wildfires)	47,668	10,208	13,963	2,664
Savings from Electric Vehicles	-16,738	-2,832	-1,977	+522
Percent Reduction of Highway Use	-98%	-86%	-99%	+1938%
Percent Reduction of All Sources	-35%	-28%	-14%	+20%

This last figure should be viewed in context. Coal power plants contribute half of all sulfur dioxide emissions in the U.S., while the contribution of this pollutant from motor

fuels is barely noticeable. So any increase from electric vehicles would have an exaggerated effect on this pollutant's increase. Coal plants are currently waning in the U.S., with capacity falling 22% between 2008 and 2018.¹⁰ They are being replaced with (low-sulfur) natural gas and renewable energy generation.



Patrick P. Paley/ Stock-Adobe.com

Can batteries in EVs store large amounts of solar energy for the electric grid?

Answer: At this time, this is overly optimistic.

The concept of Vehicle-to-Grid (V2G) storage began in about 1996.¹¹ The brilliantly simple idea is that since not all electric vehicles are on the road at the same time, EVs can act as storage units to supply the electric grid without the need for dedicated stationary storage batteries. At times of low demand, EV batteries can charge from the grid at interconnected ports in locations such as parking garages or grocery stores, and dispatch to the grid when demand is high.

The concept itself has been proven in numerous scientifically studied trials, leading some alternative energy proponents to welcome it as a main solution to storing intermittent wind and solar power and creating a completely clean electric grid.

Take Austin as a (theoretical) example. There were about 833,000 vehicles in Travis County in 2017.¹² If 200,000 of these were EVs, and each one had a 40 KW battery pack, and half of their capacity were used at the highest hour of summer peak demand, that would be 4,000 MW. As a point of comparison, at the time this article was completed, Austin's all-time high summer peak was 2,878 MW (on July 23, 2018). Without further scrutiny, this appears a seamless solution.

However, this assumes that all these cars would be at a dispatch port at the precise time of electric-system peak demand, which occurs at about 5 PM in summer and about 7 AM in winter, the exact times for traffic peak demand.

And it assumes a reasonable cost for the charging/dis-

patch port, which does not exist at this time. The Pecan Street research project in Austin recently purchased a 10 KW port for about \$41,000.¹³ A preliminary analysis for this article included equipment amortization, maintenance, charging costs, power losses, and off-line repair time to show that annual revenues from V2G would provide less than a quarter of the revenue necessary to break even.

Of course, mass production and greater co-use with commercial charging in off-peak hours could change this equation. This possibility was also analyzed using recent data from the more than 900 plugs that are part of Austin Energy's "Plug-In Everywhere" charging network. Even in this more optimistic situation, costs of charging stations (per KW) would need to fall by almost 90%, costs for charging customers would need to increase over 20%, and the hours utilization for charging would need to increase by almost 10 times, for the revenues to equal costs.¹⁴ *And these variables would all have to occur simultaneously.*

This analysis also assumes that the battery is "free." However, battery capacity can erode with increased use. So while the vehicle owner may get a payment from the utility for use of the car battery at peak times, this may come at a cost of battery depletion. It is not even assured that all auto manufacturers would honor their battery warranties for vehicles participating in V2G use.

Given these formidable challenges, I do not see small-vehicle V2G implementation as a major grid storage option in the near future. If V2G has a future role in a low-carbon electric grid, it is likely to first be seen in large bus and delivery fleets. Their much larger battery size may better justify the cost of dispatch ports, and their schedules are more predictable. And this is a good thing, just not the panacea that some dreamers hope for.

Will the energy used to make EV batteries cancel out the carbon dioxide savings from the use of electricity?

Answer: The embodied energy of EV batteries is noticeable, but not that significant in the emissions over a vehicle's lifetime.

EV batteries are energy intensive to manufacture, with the main energy draw being electricity. However, the energy and subsequent carbon dioxide emissions are not overwhelming. They are roughly equal to one year of carbon emissions from a gasoline-fueled vehicle. However, over the 15-year life of a vehicle, an EV powered by U.S. electricity (with its 2019 percentage of coal and gas) will still reduce carbon dioxide emission by 56% compared to gasoline.¹⁵ If the EV were entirely powered by renewable energy, it would reduce emissions by 92%.

Can EV batteries be recycled?

Answer: Battery recycling is in its infancy.

The weak link in an otherwise compelling environmental case for conversion from fossil-fuel vehicles to EVs is the disposal of batteries that have lost their capacity.

To date, there have been 2 approaches to the problem: reuse or “repurposing” units that still have useful life after use in vehicles; and breaking down batteries for raw materials to make new batteries or other products.

Repurposing: A vehicle battery is considered obsolete when it has lost 30% of its capacity, since many vehicle owners have range anxiety (though owners of newer EVs with longer ranges may have a greater tolerance for capacity loss). However, a battery that has lost some of its initial storage is quite capable of being used in stationary or alternative applications.

- **Off-Road Vehicle Use:** There have been a number of successful and creative battery repurposing experiments to date. In 2019, car-maker Audi reemployed used electric car batteries from its EVs in forklifts and tow tractors at one of its factories to replace their original lead batteries. The equipment ran better and the new batteries also saved labor, leading to the conclusion that there would be millions of dollars in savings if the practice were implemented company wide.¹⁶

- **EV Charging:** In Hamburg, Germany, a large bank of repurposed batteries will be used to recharge electric buses during peak demand to lower charging costs.¹⁷ In 2018, a charging station in Union City, CA, began using repurposed BMW-i3 vehicle batteries to defer 30 KW of peak demand.¹⁸

- **Electric Utility Use:** A Daimler storage plant in Lunen, Germany uses repurposed batteries totaling 12.8 Mwh. Commissioned in 2016, it initially used 1,000 packs from the Smart electric EV.¹⁹ In 2016, Florida Power & Light installed repurposed batteries from 200 BMWs in Miami for grid resilience.²⁰

- **Onsite Building Use:** In 2018, a major sports arena in Amsterdam, the Netherlands, installed 590 Nissan Leaf battery packs to provide back-up power and grid services in conjunction with its solar array. The system will provide 2.8 Mwh, 3 MW. 41% of these packs were repurposed.²¹

In late 2019, the Japanese company Itochu announced a partnership with Chinese auto maker BYD and Chinese battery recycler Shenzhen Pandpower to provide repurposed vehicle batteries to commercial customers in 1,000 kwh increments. Renewable power storage will be its primary focus. Its initial markets will be in Australia and Southeast Asia, though it plans to sell to the U.S. and Japan. The new company will retain ownership of the units while marketing power services to its customers.²²

In theory, repurposed batteries offer profoundly low first costs compared to new batteries. One source suggests a cost of between \$44 and \$180/kwh in 2018 dollars.²³ This compares to about \$209/kwh for a new unit in 2018.²⁴

However, the life of a new battery, 20 years, would be cut in half using repurposed units. And these estimated prices



"It wasn't hard to track, it left a trail of dead batteries everywhere it went."

do not account for the substantial “balance of system” costs such as housing, inverters, operation and maintenance, and temperature conditioning (not to mention the cost of the electricity itself). Nor will all batteries be reusable. Disparate manufacturers, battery chemistries, and rates of charge degradation may make universal reuse of batteries a challenge.

Recycling: At the time of printing, vehicle battery recycling was not widespread. One reason is that most EV batteries were not even made until 2011 or later. They are typically warranted for 8 years and can last considerably longer with proper care.

This author did not learn of any recycling process where vehicle batteries yielded recycled materials pure enough to be remanufactured into new vehicle batteries without first being sent to a smelting plant.

The current European Union regulation for battery recycling requires 50% recovery of materials by weight.²⁵ New technologies that often rely on chemical and / or mechanical methods of material recycling are generally at the R&D or pilot plant stage. These companies often aspire to recover over 90% of valuable metals, with the goal of providing material directly to battery manufacturers as raw materials instead of being sent to a bridge smelter or refiner for further processing.²⁶ Technologies that do not require smelting have the virtue of energy savings and air pollution reductions since they avoid fuel required to melt metal.

Current commercial plants often or always require a

“tipping fee” or gate charge on battery feedstock to break even, as the reclaimed materials alone usually cannot make the plants economically sustainable. Conversely, plants may offer a credit if valuable metals can be reclaimed. This credit, however, may dwindle in the future as EV battery manufacturers attempt to find chemistries that limit or eliminate certain high-cost ingredients such as cobalt or nickel.

EVs and Market Share

What market share of new sales do EVs have, and what percentage will they have in the future?

Answer: In 2019, EVs represented 1.9% of the U.S. market and 2.5% of the worldwide market. The future will be driven by early adopters and aggressive regulations, but the most optimistic prediction to date is that 57% of passenger vehicles will be electric by 2040.

In 2019, U.S. EV sales represented 1.9% of the market for about 17.5 million vehicle sales. Worldwide, they represented 2.5% of 87.5 million total vehicle sales.¹ These sales, as well as the short-term EV sales growth, are being driven (if you will) by early adopters, but more by state and national governments with the political will to do so.

- The European Union is lowering its 2019 carbon emission standards for vehicles by 21% by 2020, 33% by 2025, and 50% by 2030.² Violations will be fined, and depending on the degree that vehicles are out of compliance, the fines can possibly result in hundreds of dollars in increased cost for every vehicle that is manufactured.

Further, these standards start to require that certain percentages of new vehicle sales be “Zero-Low Emission Vehicles,” that become a de facto requirement for BEVs and PHEVs. By 2025, 15% of all new sales must be from this category, and by 2030, 30% of the new fleet must be in this category. In 2019, 17% of the world’s auto sales took place in this region; it was 20% if you counted the UK, which recently exited the EU but is on record as wanting to keep carbon reduction goals. So the worldwide EV market share can only rise.

- EV sales are further influenced by carbon emission standards in China, which has 30% of the global auto market. By some accounts, the country has the most aggressive efficiency standards in the world. They have risen from 29 mpg in 2010 to 48 mpg in 2020, and will rise again to 60 mpg in 2025. The standards also require that auto manufacturers obtain “credits” that signify that a certain minimal percentage of electric and fuel-cell vehicles are part of their total fleet sales.³

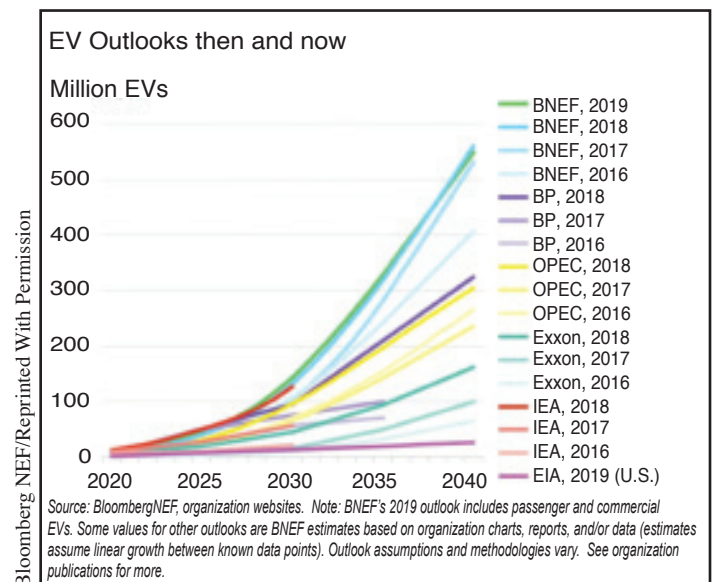
- The state of California also has a fuel efficiency standard that requires electric and fuel-cell vehicles to obtain a certain number of credits, along with 10 other state governments that have adopted its standards. These states represent 30% of all U.S. sales, and 6% of global auto sales. These credits required 3% of new sales to be EVs in 2019, and will rise to require 8% of sales be EVs in 2025.⁴

Due to California’s requirements, state incentives and rebates, and the largest population in the country, almost half of U.S. EV sales in 2019 were within its boundaries.

These major markets do not include smaller countries such as Norway and Iceland, which on a percentage basis, lead the world in EV adoption.

To prepare for this, international auto manufacturers are making large commitments. The top 7 manufacturers (VW, Toyota, Renault-Nissan, GM, Hyundai, Ford, and Honda), which sold 77% of vehicles in the worldwide market in 2019, plan to release more than 160 new electric (BEV, PHEV, or hybrid) models by 2030.⁵ These grand plans and investment strategies may change or adapt because they rest upon the directions of the market. But these markets are based upon government policy and the wish of motivated customers to adopt a low-carbon transportation system.

Where will all this lead? Various companies and organizations have tried to extrapolate trends. The most optimistic came from Bloomberg New Energy Finance. In 2019, it predicted by 2040, 57% of world’s passenger cars, along with 81% of its buses, 56% of its light commercial trucks, 31% of its commercial medium trucks, and even 19% of its heavy trucks, will be electric, for a total EV fleet of 550 million vehicles.⁶ Eyeing EV competition, fossil fuel interests have also predicted large numbers: Exxon at over 150 million; and OPEC and British Petroleum (BP) at more than 300 million, all in 2018 reports.



Is there any country in the world that has come anywhere close to this idealized goal of the 100% EV goal?
Answer: There are certainly countries trying harder than the U.S. They are motivated by the economics of EVs in their specific locales, and by the political will to help the environment.

The approximate 2% EV sales rate in the U.S. pales in comparison to countries in Northern Europe.⁷

- Norway – 56% in 2019, compared to only 3% in 2012;
- Iceland – 25% in 2019, compared to only 3% in 2015;
- The Netherlands – 15% in 2019, compared to only 2% in 2017;
- Sweden – 11% in 2019, compared to 3% in 2015.

There were several reasons for this.

- These 4 countries contain high clusters of population density, which reduces the need for long trips.
- These countries have serious commitments to environmental protection and reducing global warming.
- These nations also have exceedingly high fuel costs. In January 2020, Iceland had the 2nd highest gasoline cost in the world (\$7.29/gallon). Norway and the Netherlands were tied for the 5th highest cost (\$7.20/gallon). Sweden was 15th (\$6.38/gallon). This is compared to the U.S. (\$2.88/gallon). These countries assess high value-added and carbon taxes on these fuels, which discourages their consumption. And Iceland has high fuel import costs.
- In early 2020, all 4 of these countries conferred tax and cost advantages on EVs.

Free marketeers would challenge that these incentives and disincentives direct purchasing towards irrational economic decisions. If they are being honest though, they would have to factor in both the subsidies given to fossil fuels, and the harm to the environment not currently captured in the economic balance.

U.S. federal and state tax incentives and subsidies to the fossil-fuel industry amounted to about \$21 billion annually in 2015 and 2016.⁸ \$2.9 billion of this was in Texas. At least \$100 billion annually was spent to support fossil fuels by the 7 largest “G7” national economies in the same years.⁹ A recent study by the International Monetary Fund estimated that environmental damage such as deaths from air pollution and global heating amounted to \$5.3 trillion globally in 2015.¹⁰

EVs: Buses and Trucks

Are EVs ready for all applications? Can everybody do it? (What about heavy vehicles?)

Answer: Buses are starting to appear in greater numbers. Light- and heavy-duty vans and trucks are either in development or have not been sold in large numbers.

Almost all EVs on the road today are light-duty vehicles, ranging from subcompact “city cars,” to 4WD SUVs.

However, there are also a number of transit buses that are appearing in municipal and school bus fleets. Texas cities have, or shortly will have, small numbers of them. Austin’s Capital Metro, for instance, has purchased 12.

Other U.S. cities and utilities are much more aggressive. King County Metro (Seattle) has ordered 120 electric buses with a nominal range of 260 miles.¹ Los Angeles has ordered 130, with a nominal range of 150 miles, and the batteries carry a 12-year warranty.² Dominion Energy, which provides electricity to parts of VA, NC, and SC, plans to add over 1,000 electric school buses to its service area by 2025.³ However, there were almost 800,000 buses in the U.S. in 2016, so these early adopters are not the norm.

But while only a few hundred electric buses were operating in the U.S. in 2018, about 421,000 were working in China that same year. To deal with the country’s prodigious air pollution and to stem its dependence on imported oil, China has created incentives and mandates that have converted over half of its bus fleet to EVs.

What is missing is any large number of trucks and commercial delivery vehicles that are meant to carry cargo instead of people and groceries. Given the weight of batteries that must be carried in addition to this cargo, most of the first products will have limited range. (However, in 2018, 2/3 of U.S. truck freight was shipped less than 100 miles.⁴) The limited options for EV trucks are beginning to change, albeit slowly.

Daimler, the largest heavy truck manufacturer in the U.S. market, is testing 3 Class-8 models with payloads of 18 to 40 tons.⁵ Commercial sales are expected in 2021/22. Daimler is already selling its eVito delivery van. Amazon is adding 100 of them to its fleet, with at least 10 in service in Germany at the time this story was published.⁶

Mitsubishi Trucks, a division of Daimler, has also been in small series production of its 8-ton, Class-7 electric FUSO eCanter since 2017. It has a payload of almost 5 tons.⁷

In late 2019, Volvo announced European sales of electric refuse trucks.⁸ Mack Trucks, also owned by Volvo, will begin beta testing a refuse truck with New York City in 2020.⁹

Tesla is also planning to sell an electric Class-8 semi in 2021. What distinguishes this new product is range: 300 to 500 miles per charge.¹⁰ The best Daimler model being beta tested is currently achieving 250 miles per charge.

There are also smaller trucks being developed, including models from two mainstream manufacturers. Ford’s F-150 line will market an electric version in 2021.¹¹ In an early promotional commercial, a prototype towed a chain of train cars mounted on their rails that collectively weighed over a million pounds. (Despite this model being the ultimate symbol of American machismo, the driver was a woman.) Ford will also market an electric van in the same year.¹²

The GM Hummer, once considered the paramount symbol of fossil-fuel waste and conspicuous consumption, is making a comeback as the Hummer EV. It is expected to have 1,000 horsepower, go from 0 to 60 mph in 3 seconds, and be sold in model year 2022 for an estimated \$70,000.¹³

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6 Annual vehicle 2018 mileage is 11,576 per *Highway Statistics 2018*, Washington, DC: U.S. Department of Transportation, Federal Highway Administration, Chart VM-1, November 2019.

7 Electricity and gasoline cost are 10-year real price average (2010-2019) from *Short-Term Energy Outlook Real and Nominal Prices*, Washington, DC: U.S. Department of Energy, Energy Information Administration, March 2020. Online at <https://www.eia.gov/outlooks/steo/realprices/>

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3 Assumes 3 miles/kwh for light vehicles, 2.16 miles per kwh for light trucks, 0.5 miles per kwh for buses and heavy trucks, divided into Vehicle Miles Traveled from op. cit., Davis, Stacy, Tables 2.13, 4.2, 5.1, and 5.2.

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8 Petroleum emissions from op. cit. Davis, Stacy, Table 2.7 X Energy

Information Administration Carbon Dioxide Emissions Coefficients for various fuels. Online at https://www.eia.gov/environment/emissions/co2_vol_mass.php

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10 Derived from "Criteria pollutants National Tier 1 for 1970 – 2018," Air Pollutant Emissions Trends Data, Durham, NC: U.S. Environmental Protection Agency, updated on May 3, 2019. This assumes a 43% increase in overall electricity use if the entire U.S. vehicle fleet were electrified.

11 Assumptions:
Gasoline is 125,000 BTUs/gallon;
Refinery losses at 20%;
Gasoline vehicle gets 25 mpg;
BEV gets 3 miles/kwh;
Coal plant is 34% efficient;
Natural gas plant is 57% efficient;
Renewable energy sources are 100% efficient;
Transmission & distribution losses are 5%.

12 10 op. cit. *Electric Power Annual 2018*, Table 4.2.A. Online at <https://www.eia.gov/electricity/annual/pdf/epa.pdf>

13 Patterson, Brittany, "Electric Vehicles Drive to Back Up the Grid," *Scientific American*, July 14, 2015.

14 Derived from U.S. Census, "2017 American Community Survey 1-Year Estimates of Occupied Households in Travis County" (462,632)

15 X vehicles per household estimated from "2017 American Community Survey 1-Year Estimates of Tenure By Vehicle in Travis County" (1.8).

16 Conversation with Karl Popham, Electric Vehicles & Emerging Technologies Manager, Austin Energy, November 2020.

17 **V2G Base Case Assumptions:**
Charging Station
Cost of V2G station is \$41,000.
Average cost of commercial charging station is \$6,600 (per Lindsey McDougall, Electric Vehicle Program Manager, Austin Energy, in phone conversation on November 25, 2019).
Input of charging station is 7.2 KW. Input/Output of V2G station is 10 KW (Ibid.)
Finance cost of charging station is 4%.
Charging station current operational percentage is 3.75% of hours.
Maintenance cost per year per plug of \$175 derived from City of Austin Purchasing contract RFP 1100 EAL3005.
Austin Energy charging cost estimated at 6.2¢/kwh based on 2018 average commercial price.
V2G charging/discharging losses estimated at 81%.
Station outage estimated at 10%.

18 **Cost of Peak Power Plant: 21¢/kwh**
Cost per KW, fixed and variable Operation and Maintenance, and heat rate based on high cost of gas peaking from *Lazard's Levelized Cost of Energy Analysis*, Version 13.0, New York, NY: Lazard, November 2019, PDF p. 19. Online at <https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf>
Plant life is 30 years.
Plant capacity is 5%.

19 Fuel is based on \$4.19/MMBTUs, the 2009-2018 Texas average cost for electric utilities. "Natural Gas Prices," Washington, DC: U.S. Department of Energy, Energy Information Administration.

20 **Assumptions for CO2 from Gasoline Vehicle:**
11,576 miles per vehicle per year (op. cit. Highway Statistics 2018)
÷ 25.1 miles per gallon in MY 2018 per *2019 EPA Automotive Trends Report*, Ann Arbor, MI: U.S. Environmental Protection Agency, EPA-420-S-20-001, March 2020.

21 X 0.0089 Metric Tons of CO2 per gallon per U.S. Environmental Protection Agency, "Greenhouse Gases Equivalencies Calculator - Calculations and References."

22 X 15 year life of vehicle
= 66.9 Metric tons CO2 per conventional vehicle

23 **Assumptions for CO2 from Battery Manufacture:**
64 kwh per battery
X 83.5 Kg of CO2/Kwh per Emilsson, Erik and Lisbeth Dahlöf, *Lithium-Ion Vehicle Battery Production Status 2019 on Energy Use*, Stockholm, Sweden: IVL Swedish Environmental Research Institute Ltd., November 2019, Table 8.

24 **Assumptions for CO2 from EV Fuel With 2018 U.S. Generation Mix:**
3 Miles/Kwh
X 0.9128 pounds CO2/kwh (Total CO2 emissions from electric sector (op. cit. U.S. Greenhouse Gas Emissions and Sinks, 1990-2017) divided by total kwh generated (op. cit. *Electric Power Annual 2018*))
X 15 year life of vehicle
+ Battery CO2 emission (above)
= 29.3 Metric Tons

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