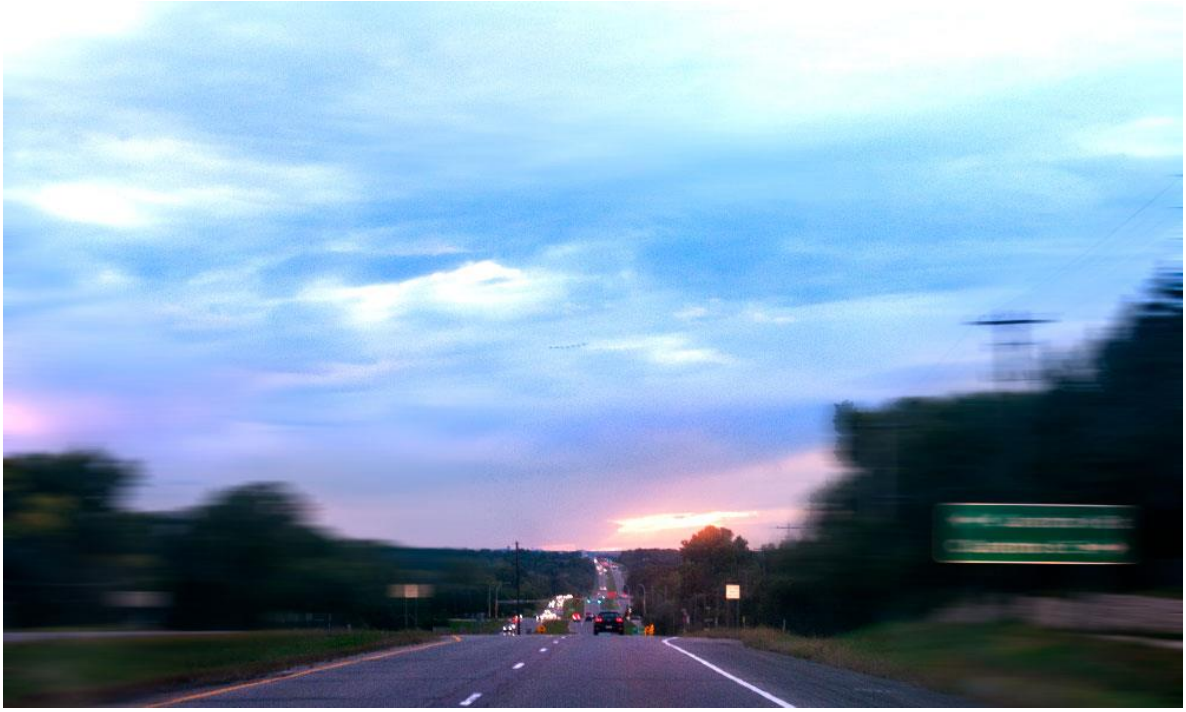
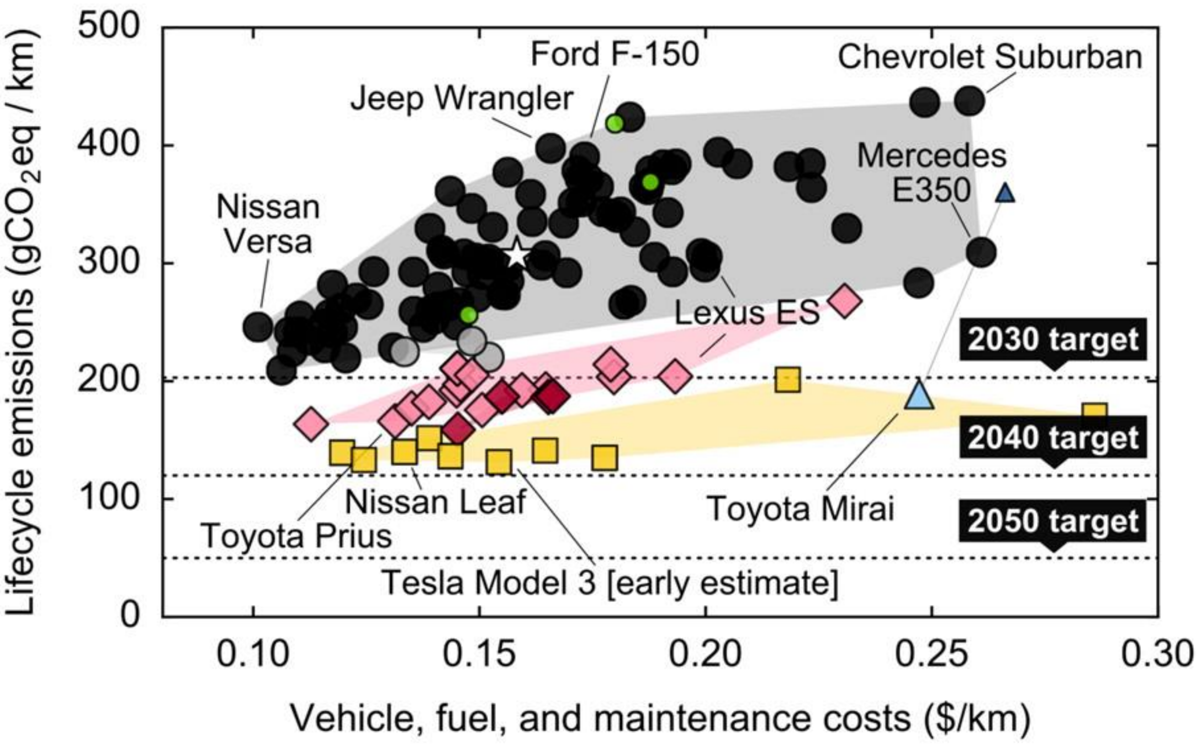
MIT Study: Electric vehicles are cheaper and emit less GHGs

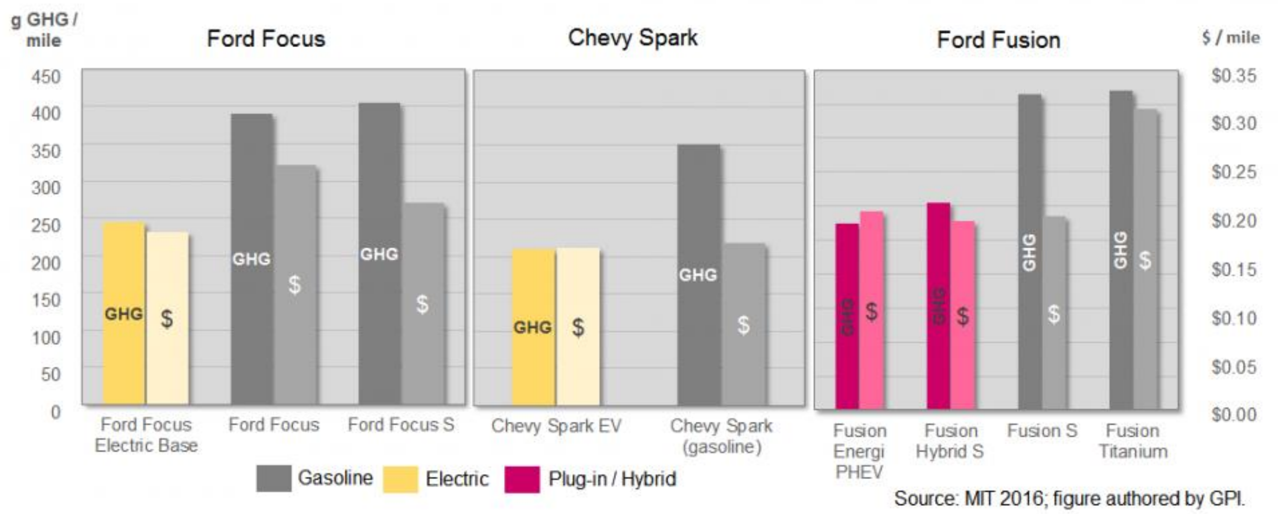
November 28, 2016 | Dane McFarlane | Education



A new study released this fall by the Massachusetts Institute of Technology (MIT) has found that electric vehicles provide a significant cost savings to the consumer, in addition to a large reduction in greenhouse gases (GHGs). The MIT team expanded the breadth of their research compared to previous studies in order to "reflect the diversity of personal vehicle models available to consumers" and analyzed 125 vehicle models on the market today. Their findings show that alternative powertrain vehicles such as plug-in hybrids (PHEVs) and battery electric vehicles (BEVs) are most often cheaper than their fossil fuel counterparts over the lifetime of the automobile



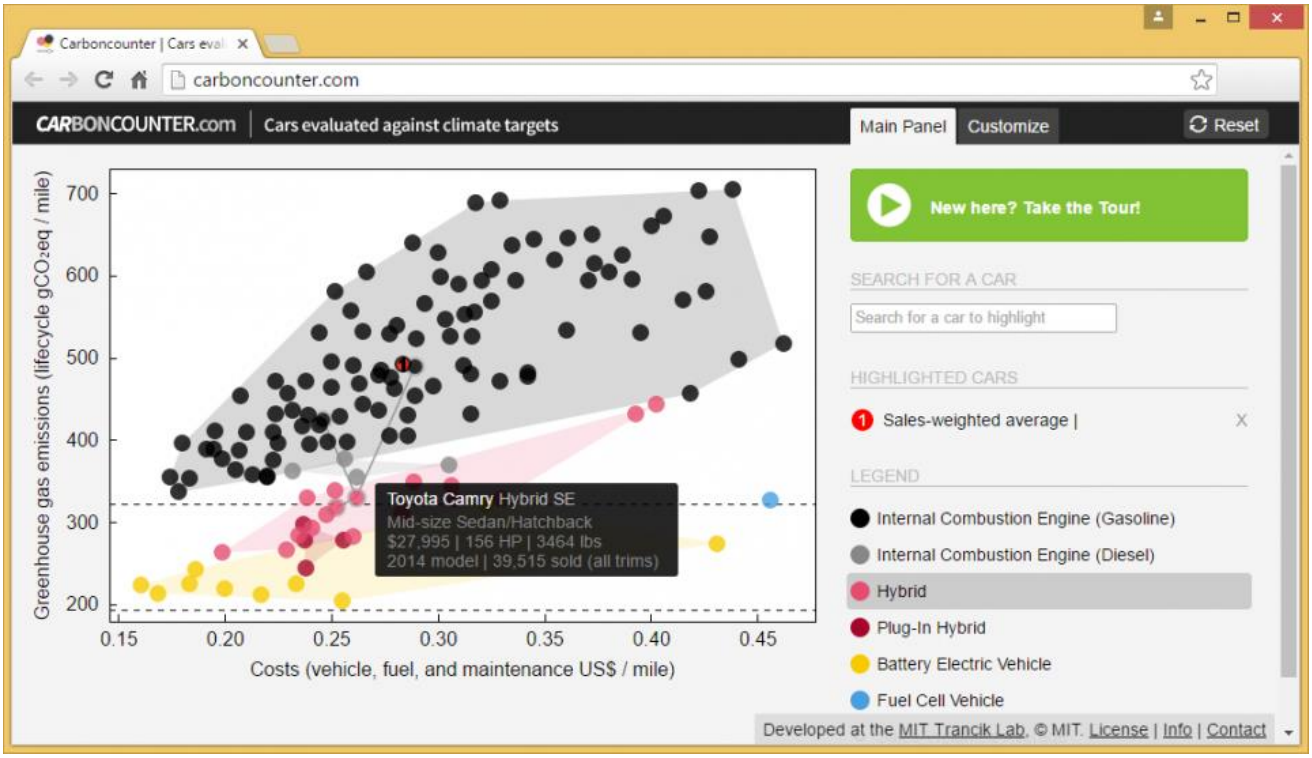
Results of MIT's EV Cost Study



Cost and GHGs per mile of alternative cars and their gasoline counterparts

A new tool to compare vehicle costs

Alongside their research paper, MIT has published a new online tool called the *Car*boncounter that allows anyone to select a car and compare its lifetime cost and carbon intensity to similar alternatives. When you select a vehicle, leader lines appear to visually connect that vehicle to the fossil fuel or electric counterpart made by the same manufacturer. Cars that are lower down and further to the left on the chart are cheaper and more environmentally friendly. As you can see in the graph below, the colored dots representing hybrid and battery electric vehicles are generally both lower and to the left of the black and gray dots representing gasoline and diesel vehicles.



[MIT's CarbonCounter App]

EVs essential to GHG reduction goals for Transportation Sector – even in coal country

The study authors point out that the transportation sector accounts for 28% of US GHG emissions, and that passenger vehicles are the source of over 2/3rds of GHG emissions in this sector. By using Argonne National Laboratory's GREET Lifecycle GHG model and by including emissions from vehicle and battery manufacturing (just like GPI did in its analysis earlier in 2016), MIT found an almost universal reduction in

GHGs from EVs when compared to their fossil fuel counterparts. This reduction is primarily due to increased engine or motor efficiency and an average U.S. electricity mix that is generally less GHG intensive than gasoline or diesel fuel.

To put this into a larger context, the MIT team surveyed GHG reduction goals around the country and identified GHG targets for the years 2030, 2040, and 2050. According to the report, "even in regions of the U.S. with very high carbon intensities of electricity, many BEVs and (P)HEVs meet the 2030 target." This means that, in the near term, even areas in the US that are still heavily dependent on coal for electricity will benefit by expanded sales of EVs. Beyond 2030, the authors point out that the US will need to continue its trend of decarbonizing the electric grid.

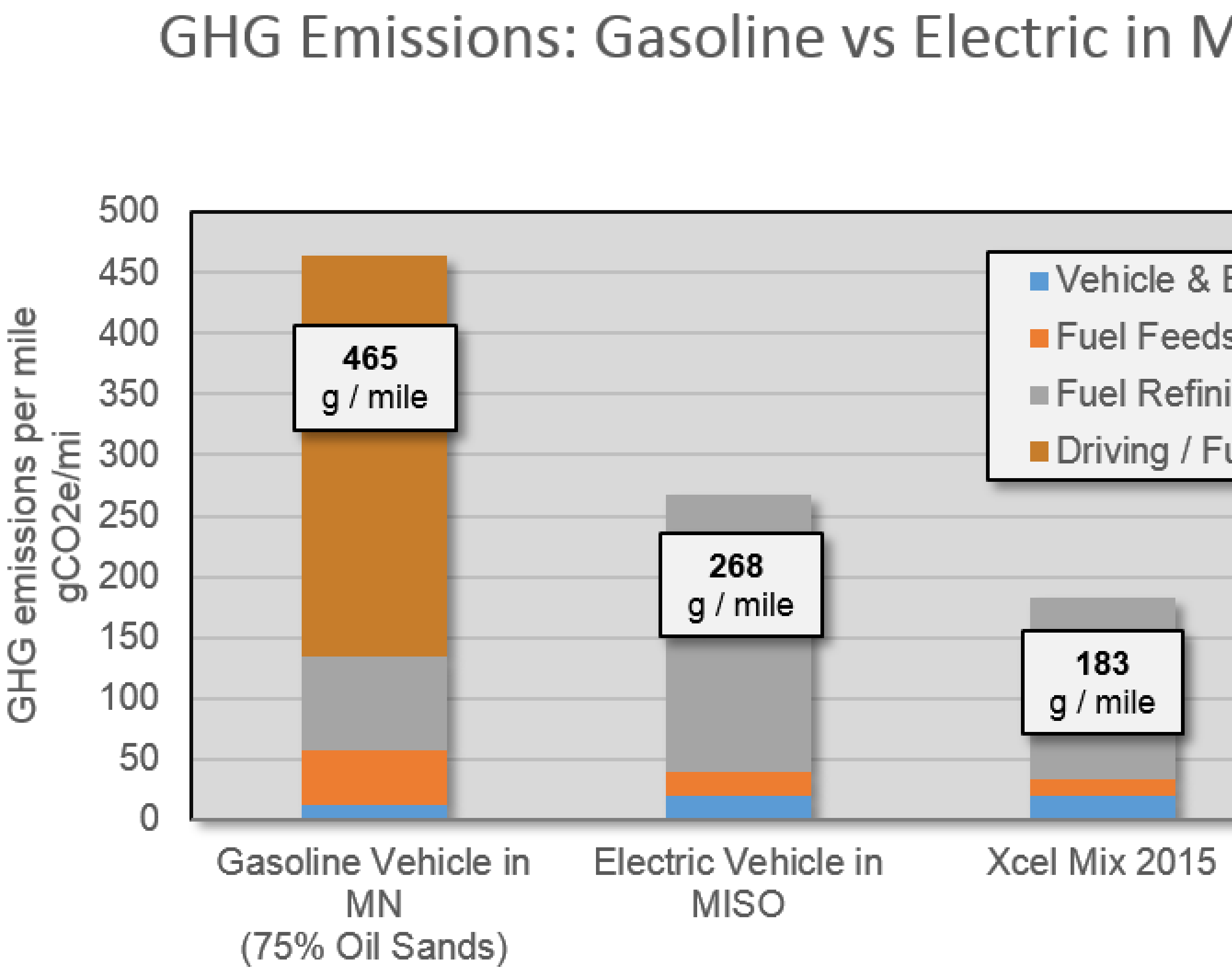
Upfront price remains a barrier to some despite lower total cost

The study report points out that, despite a significantly lower total cost of ownership for EVs, many fossil fuel vehicles have the advantage of a smaller price tag at the time of purchase. Although many rebates and tax credits exist at both the state and national level, many consumers are still swayed by the base cost advertised at the vehicle lot or online. Additionally, anxieties about driving range still persist as EVs are beginning to exceed 100 miles in most models (and over 200 miles for the Chevy Bolt and Tesla vehicles).

These factors currently present barriers to mass market penetration for EVs. And yet, with battery manufacturing costs declining, purchasing discounts occurring frequently, and charging infrastructure set for rapid expansion, EVs will continue to become even more consumer friendly than they already are.

Analysis: Electric Vehicles Reduce GHGs by At Least 42%

October 20, 2016 | Dane McFarlane | Education



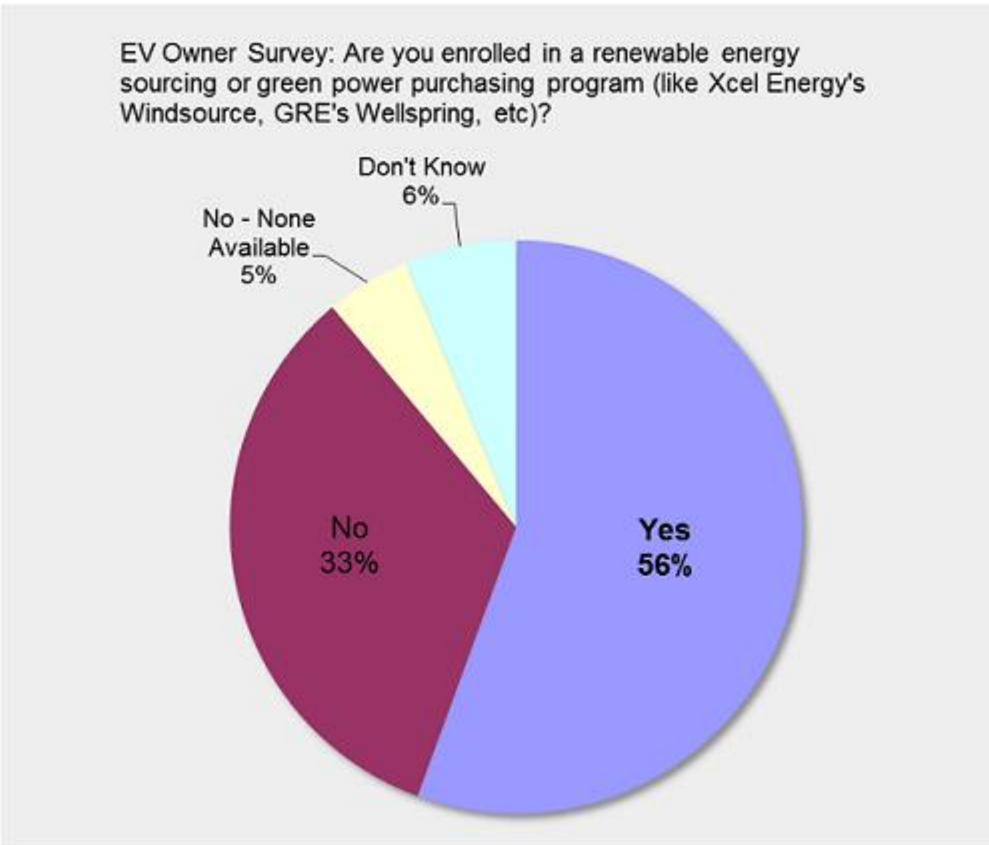
Recent analysis done by the Great Plains Institute (GPI) has found that electric vehicles in Minnesota provide a greenhouse gas (GHG) reduction of at least 61% in most cases (Xcel Energy electric mix) and 95% in many cases (for vehicle charging on renewable energy subscription programs).

GPI utilized Argonne National Laboratory's GREET Lifecycle Model, which collects the results of peer-reviewed science on GHG emissions, to calculate well-to-wheels carbon intensity under a number of automobile driving scenarios in Minnesota. The GREET model is one of the foremost authorities on the measurement of GHGs and includes exhaustive data on every aspect of energy production and use – including fuel extraction and refining, vehicle and battery manufacturing, and fuel distribution and combustion during automobile use.

GPI used data on the energy landscape in Minnesota as inputs into the GREET model to calculate a more accurate picture of the GHG intensities of gasoline and electric vehicles under the most likely scenarios happening within the state. The graph above displays the results.

Gasoline vehicles in Minnesota emit an average of 465 grams of GHGs per mile (g/mile) when accounting for the full fuel lifecycle, which includes energy used for fuel extraction and refining. In comparison, full lifecycle accounting of **an electric vehicle (EV) in Minnesota results in only 183 g/mile of GHGs** on Xcel Energy's 2015 fuel mix. It is interesting to note that because EVs have no tailpipe emissions, all emissions take place *upstream*, aka at the power plant and during vehicle manufacturing. And although it currently takes more energy to manufacture an electric vehicle and its battery than to build a gasoline automobile, as you can see in the above graph, the emissions from combusting gasoline vastly outweigh those from vehicle manufacturing.

To calculate emissions outside of Xcel's service territory, GPI used an average snapshot of electricity production on the Midcontinent Independent System Operator (MISO) system, which manages electric distribution **across most of the Midwest.** Because MISO includes many states that use a higher portion of fossil fuels than Minnesota, **an EV that charges on the MISO grid would result in 268 g/mile GHGs, which still marks a 42% improvement over gasoline**.



Source: GPI Survey of EV Owners, 2015

Figure authored by Great Plains Institute. April, 2016.

In many cases, however, EVs offer even better GHG reductions. In a 2015 survey, GPI and Drive Electric Minnesota asked Minnesota electric vehicle owners about their participation in electric utility customer programs such as Xcel Energy's Windsource or Great River Energy's Wellspring. These programs allow customers to to purchase renewable-sourced electricity to account for their home energy use. **According to the survey, 56% of EV owners participate in these renewable energy programs, resulting in carbon-free EV battery charging.** With 100% renewable energy, EVs only result in an average of 21 g/mile of GHGs, coming solely from vehicle and battery manufacturing.

Full GHG Lifecycle Assessment Results

		GHG Emissions		Change
	Fuel	Per Mile (grams / mile)	Lifetime (tons)	from MN Gasoline
Gasoline	US Gasoline	422.0	67.5	-9%
Gasoline	MN Gasoline	464.6	74.3	--
Electric	MISO Grid	267.9	42.9	-42%
Electric	Xcel Mix 2015	183.1	29.3	-61%
Electric	Xcel Mix 2030	150.6	24.1	-68%
Electric	100% Renewables	21.4	3.4	-95%
		Lifetime: 160,000 miles		

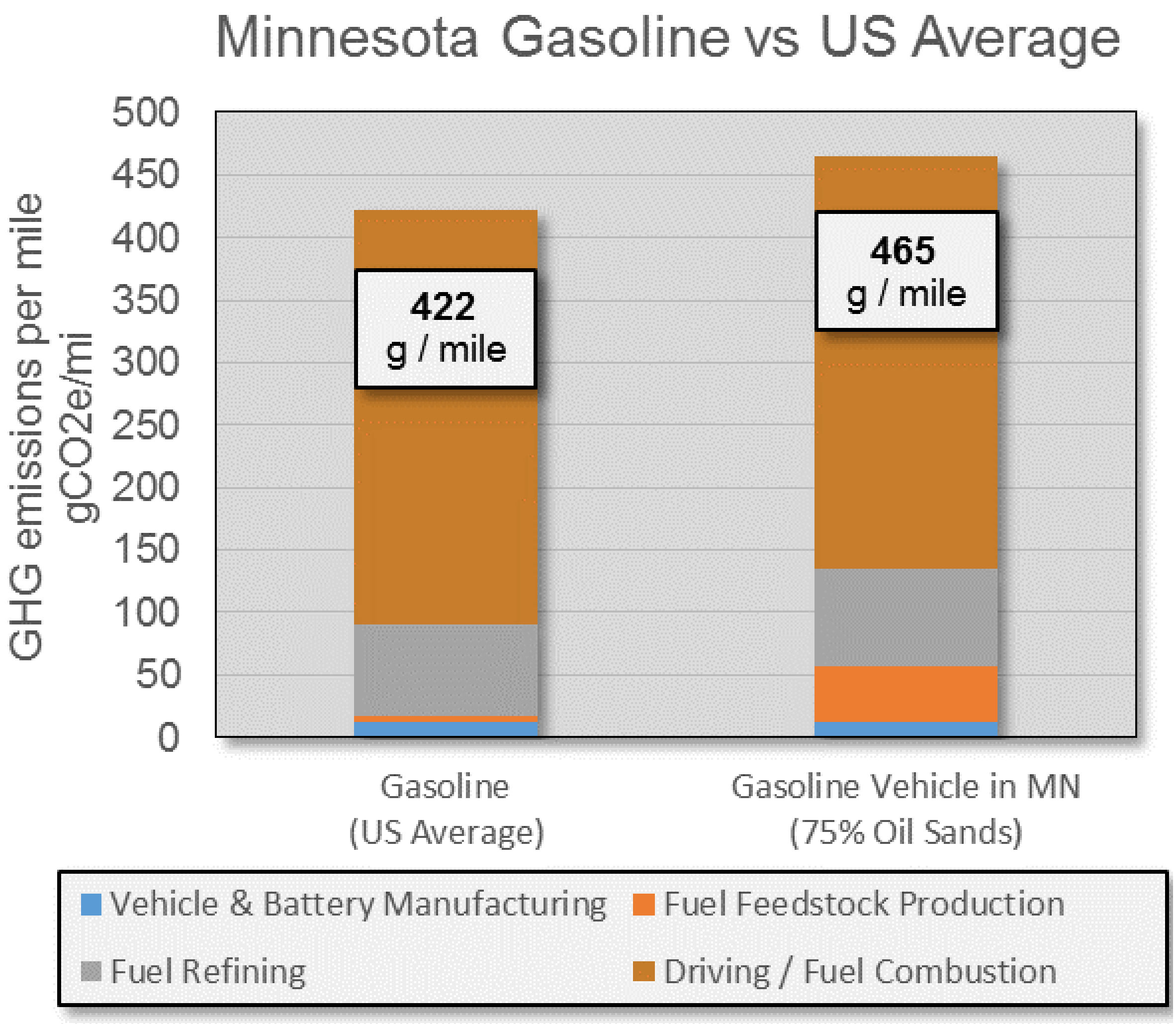
Source: Argonne National Laboratory; MN House Research Dept.; Xcel Energy; MISO.

Figure authored by Great Plains Institute. April, 2016.

Over the lifetime of each vehicle (about 160 thousand miles), a gasoline vehicle will emit about 75 tons of greenhouse gases, while most EVs in Minnesota will result in only 29 tons, and many will result in only 3.4 tons of GHGs (from vehicle manufacturing).

Other Findings

During this analysis, GPI's research found that gasoline that is refined in Minnesota has a higher than average carbon intensity than the rest of the US. According to a 2013 information brief by the Minnesota House of Representatives Research Department titled Minnesota's Petroleum Infrastructure: Pipelines, Refineries, Terminals, nearly all in-state petroleum refining is done with high carbon intensity oil from Alberta oil sands and North Dakota shale oil. This results in gasoline that is almost 10% more greenhouse gas intensive than U.S. average gasoline.

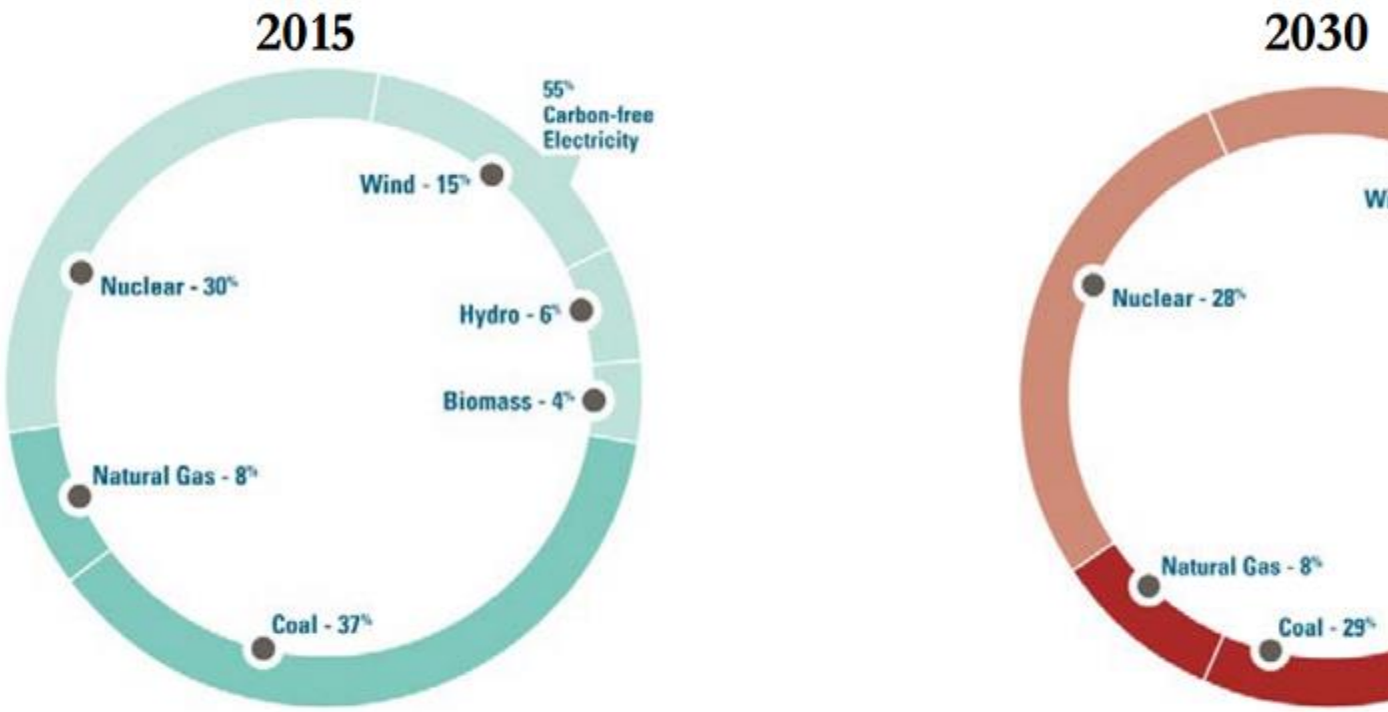


Source: Argonne National Lab; MN House Research Dept.

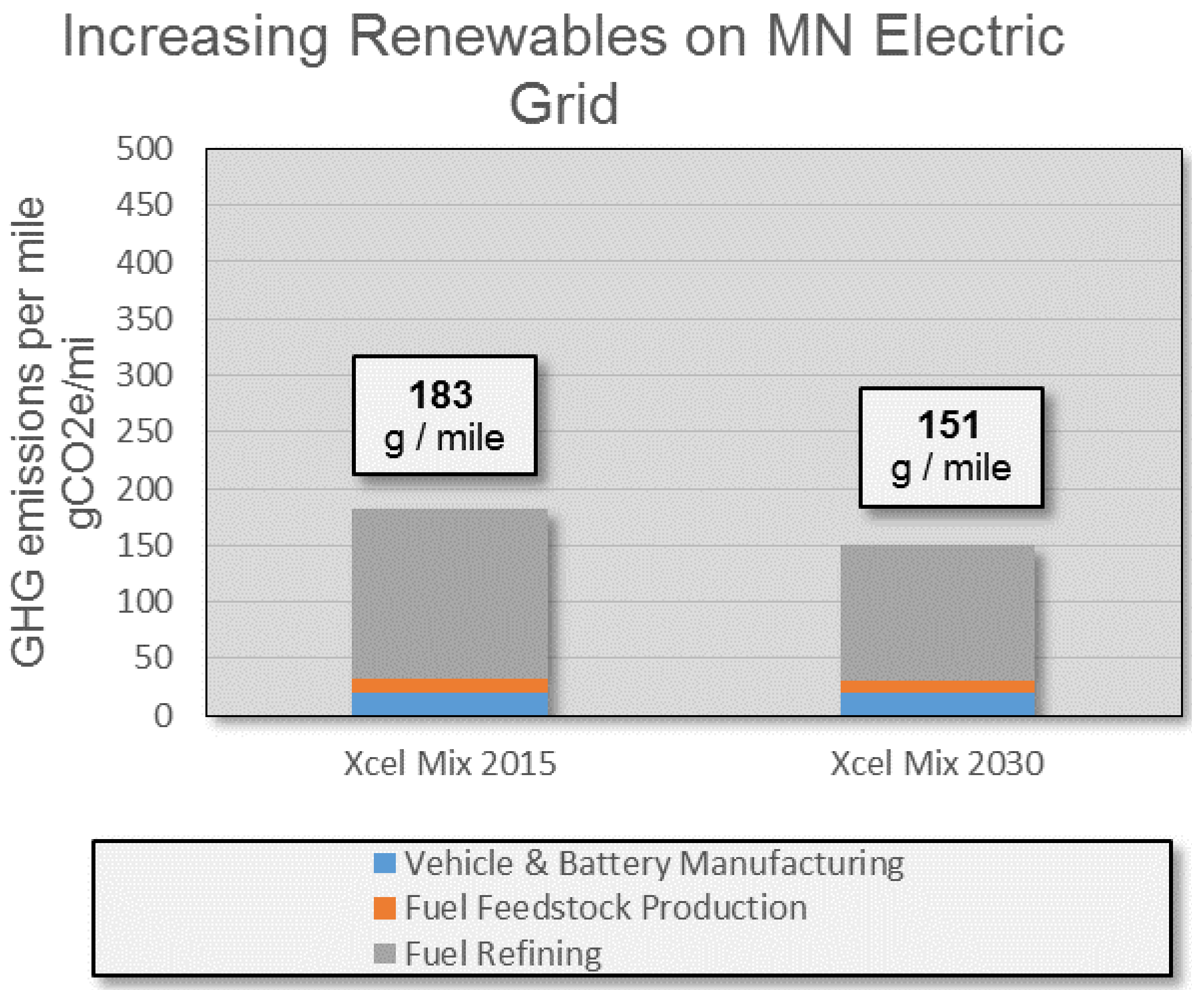
Figure authored by Great Plains Institute. April, 2016.

In contrast, Minnesota's electric grid has a relatively high penetration of renewable and zero carbon energy. Xcel Energy's Upper Midwest Resource Plan 2016 – 2030, recently filed with the Minnesota Public Utilities Commission, lays out its "Preferred Plan" to increase the rate of carbon-free electricity in its service territory from 55% in 2015 to 63% in 2030. This results in an almost 20% drop in GHG intensity for electric vehicles in Xcel's service territory by 2030.

Xcel Energy's "Preferred Plan" Upper Midwest Fuel Mix – 2015 to 2030



Source: Xcel Energy, 2015. Figure authored by Great Plains Institute. April, 2016.


Increasing Renewables on MN Electric Grid
GHG emissions per mile
gCO2e/mi
500
450
400
350
300
250
200
150
100
50
0
183
g / mile
151
g / mile
Xcel Mix 2015
Xcel Mix 2030
Vehicle & Battery Manufacturing
Fuel Feedstock Production
Fuel Refining

Here’s How Electric Cars Will Cause the Next Oil Crisis

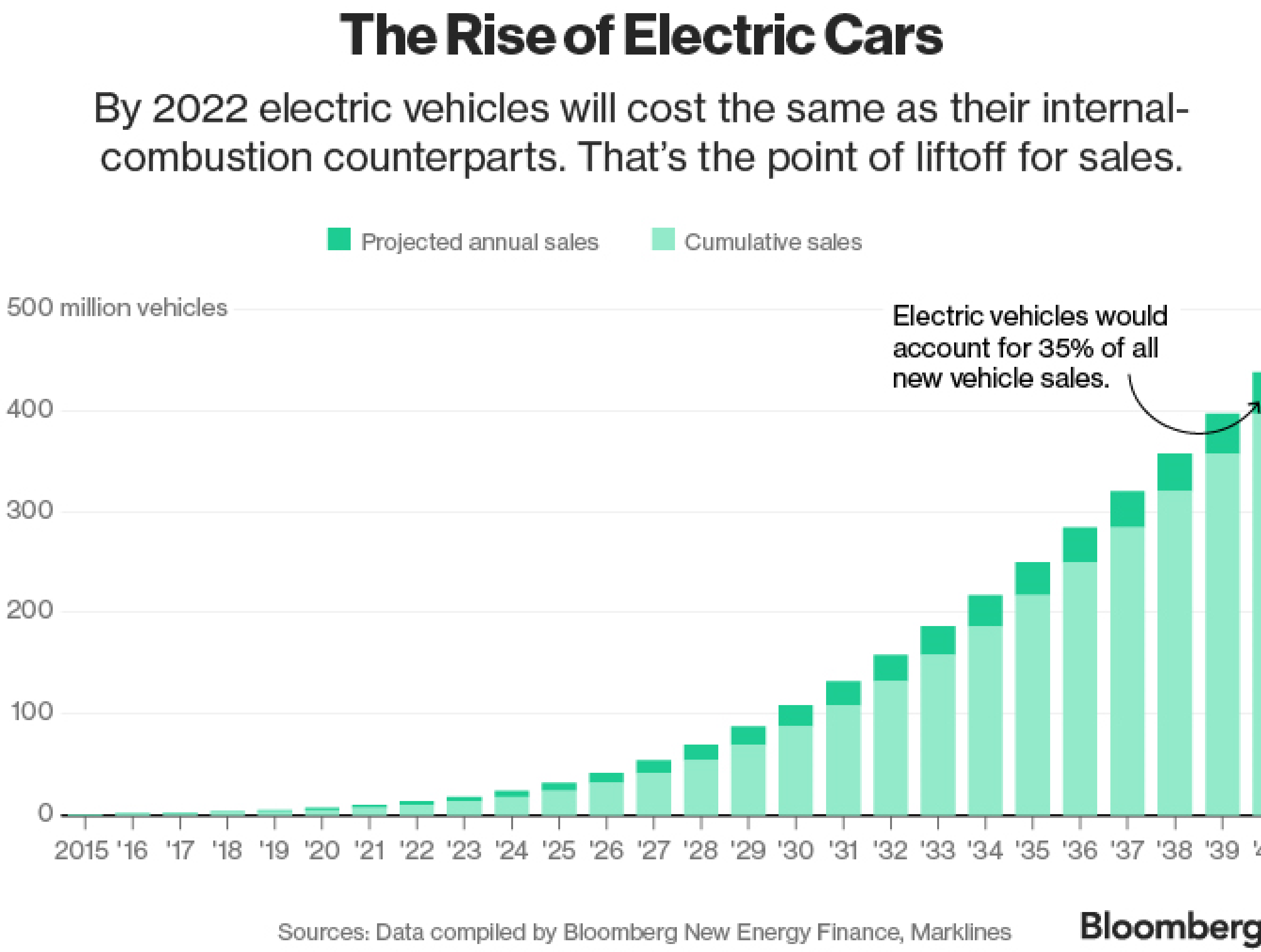
A shift is under way that will lead to widespread adoption of EVs in the next decade.

With all good technologies, there comes a time when buying the alternative no longer makes sense. Think smartphones in the past decade, color TVs in the 1970s, or even gasoline cars in the early 20th century. Predicting the timing of these shifts is difficult, but when it happens, the whole world changes.

It’s looking like the 2020s will be the decade of the electric car.

Battery prices fell 35 percent last year and are on a trajectory to make unsubsidized electric vehicles as affordable as their gasoline counterparts in the next six years, according to a new analysis of the electric-vehicle market by Bloomberg New Energy Finance (BNEF). That will be the start of a real mass-market liftoff for electric cars.

By 2040, long-range electric cars will cost less than $22,000 (in today’s dollars), according to the projections. Thirty-five percent of new cars worldwide will have a plug.



This isn't something oil markets are planning for, and it's easy to see why. Plug-in cars make up just one-tenth of 1 percent of the global car market today. They're a rarity on the streets of most countries and still cost significantly more than similar gasoline burners. OPEC maintains that electric vehicles (EVs) will make up just 1 percent of cars in 2040. Last year ConocoPhillips Chief Executive Officer Ryan Lance told me EVs won't have a material impact for another 50 years—probably not in his lifetime.

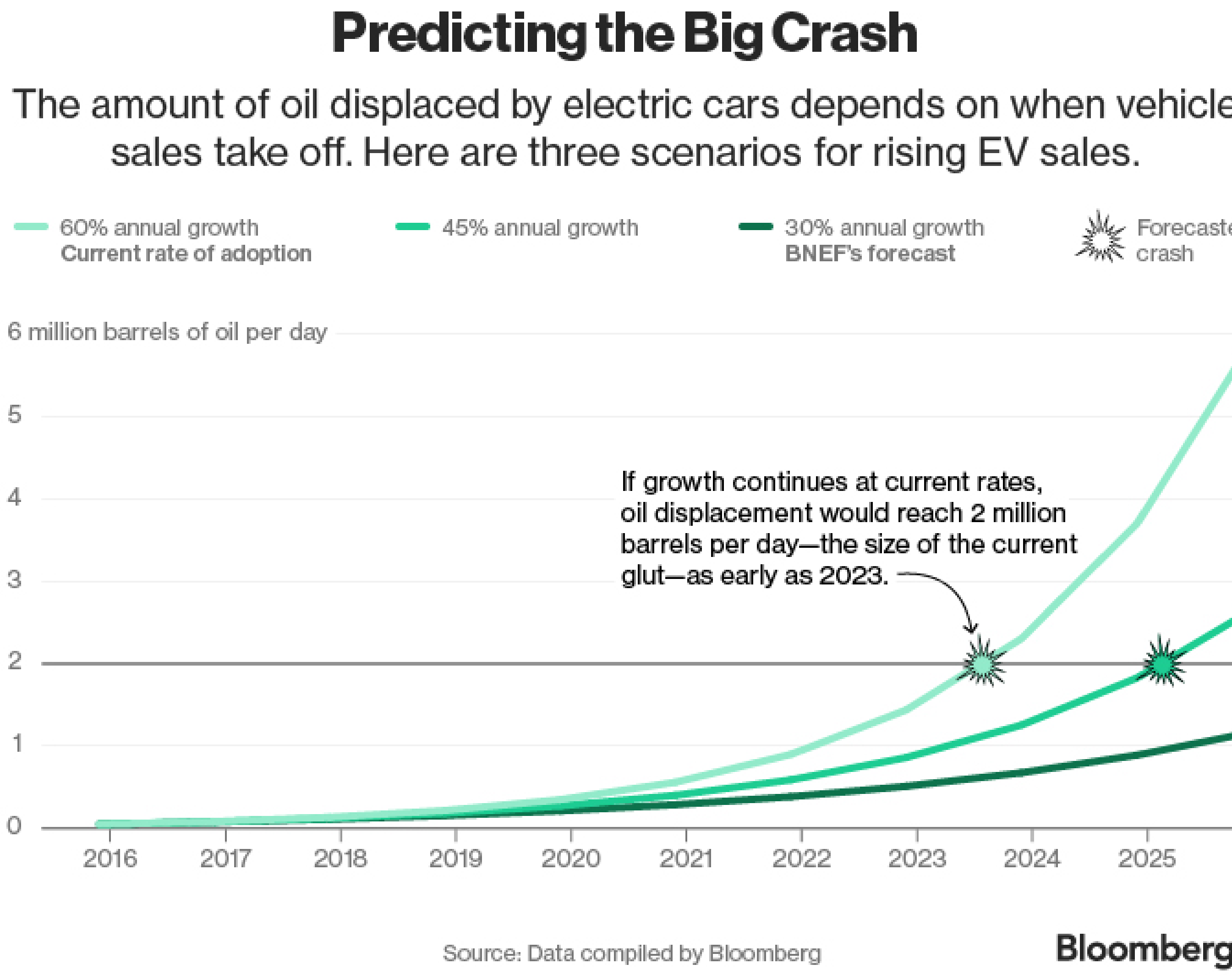
But here's what we know: In the next few years, Tesla, Chevy, and Nissan plan to start selling long-range electric cars in the $30,000 range. Other carmakers and tech companies are investing billions on dozens of new models. By 2020, some of these will cost less and perform better than their gasoline counterparts. The aim would be to match the success of Tesla's Model S, which now outsells its competitors in the large luxury class in the U.S. The question then is how much oil demand will these cars displace? And when will the reduced demand be enough to tip the scales and cause the next oil crisis?

First we need an estimate for how quickly sales will grow.

Last year EV sales grew by about 60 percent worldwide. That's an interesting number, because it's also roughly the annual growth rate that Tesla forecasts for sales through 2020, and it's the same growth rate that helped the Ford Model T cruise past the horse and buggy in the 1910s. For comparison, solar panels are following a similar curve at around 50 percent growth each year, while LED light-bulb sales are soaring by about 140 percent each year.

Yesterday, on the first episode of Bloomberg's new animated series *Sooner Than You Think*, we calculated the effect of continued 60 percent growth. We found that electric vehicles could displace oil demand of 2 million barrels a day as early as 2023. That would create a glut of oil equivalent to what triggered the 2014 oil crisis.

Compound annual growth rates as high as 60 percent can't hold up for long, so it's a very aggressive forecast. BNEF takes a more methodical approach in its analysis today, breaking down electric vehicles to their component costs to forecast when prices will drop enough to lure the average car buyer. Using BNEF's model, we'll cross the oil-crash benchmark of 2 million barrels a few years later—in 2028.



Predictions like these are tricky at best. The best one can hope for is to be more accurate than conventional wisdom, which in the oil industry is for little interest in electric cars going forward.

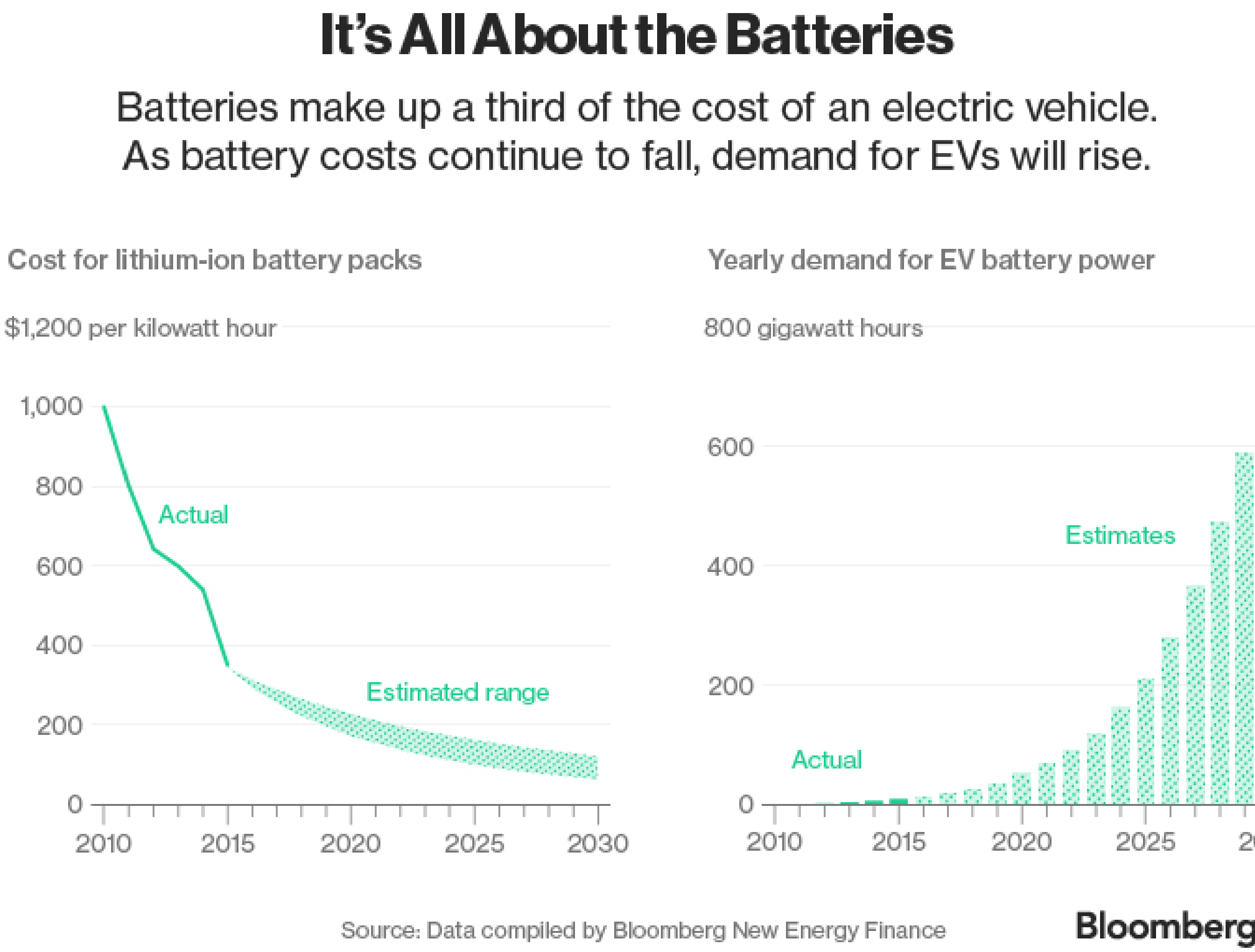
"If you look at reports like what OPEC puts out, what Exxon puts out, they put adoption at like 2 percent," said Salim Morsy, BNEF analyst and author of today's EV report. "Whether the end number by 2040 is 25 percent or 50 percent, it frankly doesn't matter as much as making the binary call that there will be mass adoption."

BNEF's analysis focuses on the total cost of ownership of electric vehicles, including things like maintenance, gasoline costs, and—most important—the cost of batteries.

Batteries account for a third of the cost of building an electric car. For EVs to achieve widespread adoption, one of four things must happen:

1. Governments must offer incentives to lower the costs.
2. Manufacturers must accept extremely low profit margins.
3. Customers must be willing to pay more to drive electric.
4. The cost of batteries must come down.

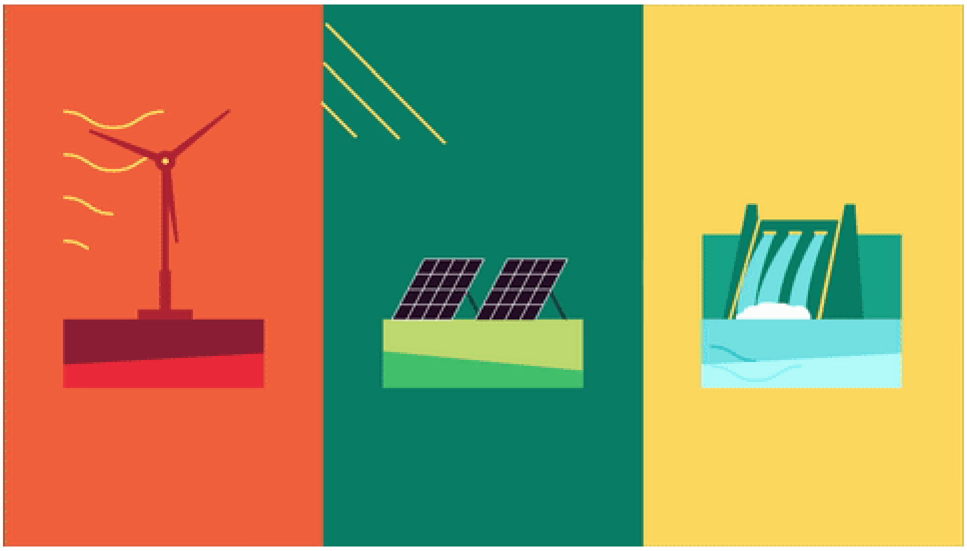
The first three things are happening now in the early-adopter days of electric vehicles, but they can't be sustained. Fortunately, the cost of batteries is headed in the right direction.



There's another side to this EV equation: Where will all this electricity come from? By 2040, electric cars will draw 1,900 terawatt-hours of electricity, according to BNEF. That's equivalent to 10 percent of humanity's electricity produced last year.

The good news is electricity is getting cleaner. Since 2013, the world has been adding more electricity-generating capacity from wind and solar than from coal, natural gas, and oil combined. Electric cars will reduce the cost of battery storage and help store intermittent sun and wind power. In the move toward a cleaner grid, electric vehicles and renewable power create a mutually beneficial circle of demand.

And what about all the lithium and other finite materials used in the batteries? BNEF analyzed those markets as well, and found they're just not an issue. Through 2030, battery packs will require less than 1 percent of the known reserves of lithium, nickel, manganese, and copper. They'll require 4 percent of the world's cobalt. After 2030, new battery chemistries will probably shift to other source materials, making packs lighter, smaller, and cheaper.



Watch the video: The Peak Oil Myth and the Rise of the Electric Car

Despite all this, there’s still reason for oil markets to be skeptical. Manufacturers need to actually follow through on bringing down the price of electric cars, and there aren’t yet enough fast-charging stations for convenient long-distance travel. Many new drivers in China and India will continue to choose gasoline and diesel. Rising oil demand from developing countries could outweigh the impact of electric cars, especially if crude prices fall to $20 a barrel and stay there.

The other unknown that BNEF considers is the rise of autonomous cars and ride-sharing services like Uber and Lyft, which would all put more cars on the road that drive more than 20,000 miles a year. The more miles a car drives, the more economical battery packs become. If these new services are successful, they could boost electric-vehicle market share to 50 percent of new cars by 2040, according to BNEF.

One thing is certain: Whenever the oil crash comes, it will be only the beginning. Every year that follows will bring more electric cars to the road, and less demand for oil. Someone will be left holding the barrel.

Case Study: Battery Types

1. Last updated
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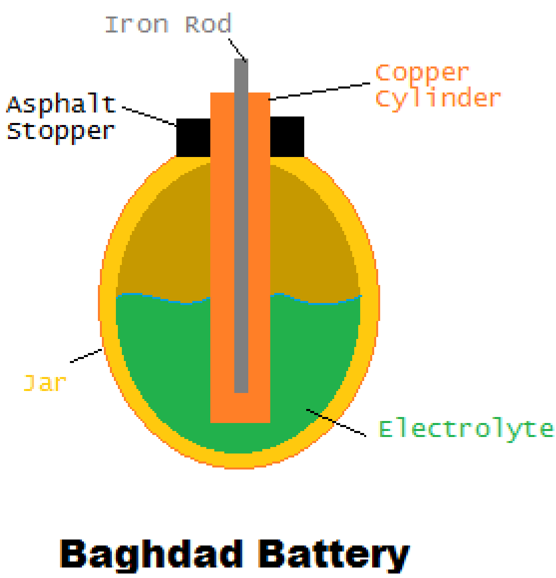
Ranging from the very crude to the highly sophisticated, batteries come in a plethora of variety. Batteries in short are electrochemical cells that produce a current of electricity via chemical reactions. More specifically, batteries produce electrical energy from oxidation-reduction reactions. A collection of electrochemical cells wired in series is properly called a battery. A flashlight battery is really a single electrochemical cell, while a car battery is really a battery since it is three electrochemical cells in series.

Introduction

Electrochemical cells have been in use longer than what was once thought. Discovered in Khujut Rabu of modern day Iraq and dating from the Parthian (250 B.C.-A.D. 224) and Sassanid (A.D. 224-600) periods, the Baghdad Battery is the first known battery in the world. Consisting of a copper cylinder, an iron rod, an asphalt stopper, and a small earthenware jar, the Baghdad Battery was filled with an unknown electrolytic solution and may have been used for electroplating.



About 2000 years later the Voltaic Pile, a stack of individual cells of zinc and copper disks immersed in sulfuric acid, was created by the Italian Count Volta and effectively replaced the use of the Leyden Jar, an instrument that stored static electricity for future use. Volta's battery is considered the first electrochemical cell and the reaction for which is as follows:

oxidation half-reaction: $Zn \rightarrow Zn^{2+} + 2e^-$

reduction half-reaction: $2H^+ + 2e^- \rightarrow H_2$

Because zinc is higher in the electrochemical series, the zinc anode reacts with sulfate anions and is oxidized whilst protons are reduced to hydrogen gas. The copper cathode remains unchanged and acts only as electrode for the chemical reaction. Because the Voltaic pile was unafe to use and the cell power diminished over time, it was abandoned.

Electrochemical cells typically consist of an anode (the negative electrode where oxidation occurs), a cathode (the positive electrode where reduction occurs), and an electrolyte (the medium conducting anions and cations within a reaction) all contained within a cell. Electrons flow in a closed circuit from the anode to the cathode. Depending on the configuration of the cell and the electrolyte used, a salt bridge may be necessary to conduct ions from one half cell to another as an electric charge is created when electrons move from electrode to another. The difference created would keep electrons from flowing any further. Because a salt bridge permits the flux of ions, a balance in charge is kept between the half cells whilst keeping them separate.

Types of Batteries

The two main categories of batteries are primary and secondary. Essentially, primary cells are batteries which cannot be recharged while secondary cells are rechargeable. The distinction begs the question as to why primary cells are still in use today, and the reason being is that primary cells have lower self-discharge rates meaning that they can be stored for longer periods of time than rechargeable batteries and maintain nearly the same capacity as before. Reserve and backup batteries present a unique example of this advantage of primary cells. In reserve, or stand-by, batteries components of the battery containing active chemicals are separated until the battery is needed, thus greatly decreasing self-discharge. An excellent example is the Water-Activated Battery. As opposed to inert reserve batteries, backup batteries are already activated and functional but not producing any current until the main power supply fails.

Biobatteries

Devices that generate electric energy via the digestion of carbohydrates, fats, and protiens by enzymes. The most common biobatteries are the lemon or potato battery and the frog or ox-head battery better described as a "muscular pile". In a lemon cell, the energy for the battery is not produced by the lemon but by the metal electrodes. Usually zinc and copper electrodes are inserted into a lemon (the electrolyte being citric acid) and connected by a circuit. The zinc is oxidized in the lemon in order to reach a preferred lower energy level and the electrons discharged provide the energy. Using zinc and copper electrodes, a lemon can produce about 0.9 Volts.

While not technically a biobattery, an Earth battery is comprised of two different electrodes which are either buried underground or immersed in natural bodies of water which tap into Telluric currents to produce electric energy.

Dry-Cell Batteries

During the 1860s, a French man named George Lelanche developed the Lelanche cell also known today as the dry-cell battery. A dry-cell battery is a battery with a paste electrolyte (as opposed to a wet-cell battery with a liquid electrolyte) in the the middle of its cylinder and attached are metal electrodes. A dry-cell battery is a primary cell that cannot be reused. In order to function, each dry-cell battery has a cathode and an anode. Some examples of dry-cell batteries used in everyday objects today are remote controls, clocks, and calculators.

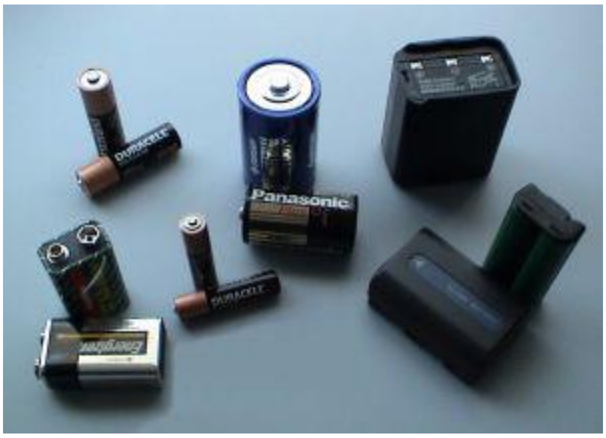


Figure: Modern dry cell batteries. Image used with permission from Wikipedia

Types of dry-cell batteries are zinc-carbon batteries, alkaline-cell batteries, and mercury batteries. Before zinc-carbon batteries were used, mercury batteries were the main resource. It was not until mercury was known to become harmful that zinc-carbon batteries replaced it. Batteries may produce the following potential problems or hazards:

- Pollute the lakes and streams as the metals vaporize into the air when burned.
- Contribute to heavy metals that potentially may leach from solid waste landfills.
- Expose the environment and water to lead and acid.
- Contain strong corrosive acids.
- May cause burns or danger to eyes and skin.

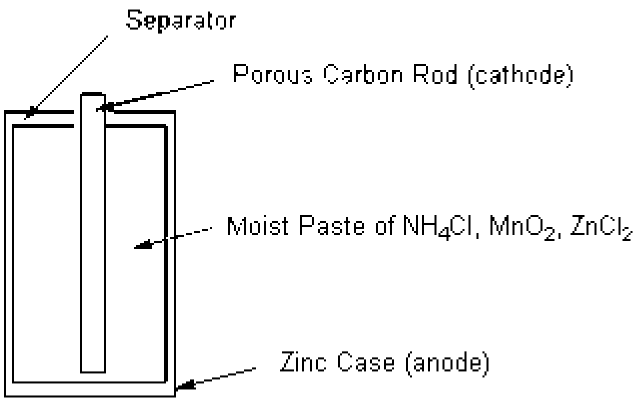
Dry-cell batteries are the most common battery type used today. Essentially, the battery is comprised of a metal electrode (or graphite rod) surrounded by a moist electrolyte paste that is enclosed in a metal cylinder. 1.5 volts is the most commonly used voltage for dry-cell batteries. The sizes of dry-cell batteries vary, however, it does not change the voltage of the battery.

Zinc-carbon cells

Zinc-carbon cells were the first really portable energy source. These cells have a short lifetime and the zinc casings become porous as the zinc is converted to zinc chloride. The substances in the cell that leak out are corrosive to metal and can terminally destroy electronic equipment or flashlights. Zinc-carbon cells produce 1.5 volts.

ZINC CARBON CELL

$$Zn + 2\,MnO_2 + 2\,NH_4Cl \longrightarrow ZnCl_2 + Mn_2O_3 + 2\,NH_3 + H_2O + \text{electrical energy}$$



For a dry-cell battery to operate, oxidation will occur from the zinc anode and reduction will take place in the cathode. The most common type of cathode is a carbon graphite. Once reactants have been turned into products, the dry-cell battery will work to produce electricity. For example, in a dry-cell battery, once Zn^{2+}

has been oxidized to react with NH_3, it will produce chloride salt to insure that too much NH_3

will not block the current of the cathode.

$$Zn^{2+}(aq) + 2NH_3(g) + 2Cl^-(aq) \rightarrow [Zn(NH_3)_2]Cl_2(s)$$

How does the reaction work? While the zinc anode is being oxidized, it is producing electrons that will be captured by reducing Maganese from an oxidation state of +4 to a +3.

- **Reduction of Maganese:** $2MnO_2(s) + H_2O(l) + 2e^- \rightarrow Mn_2O_2(s) + 2OH^-(aq)$
-

The electrons produced by Zinc will then connect to the cathode to produce it's product.

- **Oxidization of Zinc**: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$
-

Alkaline cells

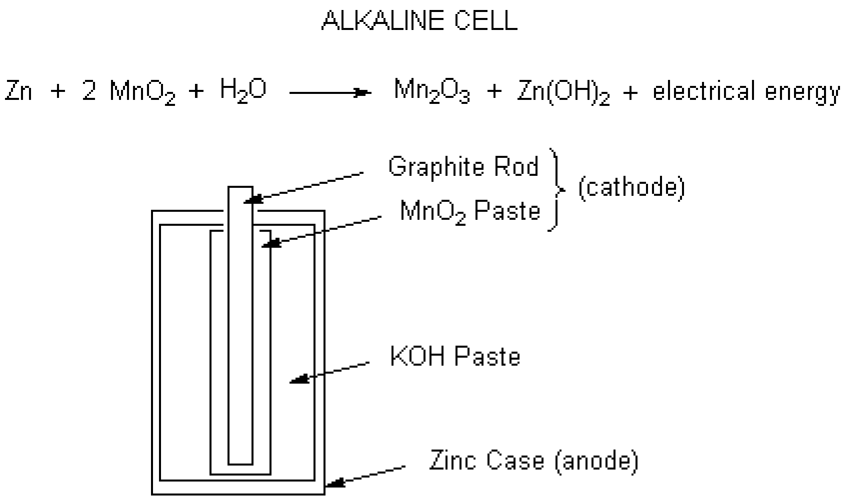
Recently, the most popular dry-cell battery to be used has been the alkaline-cell battery. In the zinc-carbon battery shown above, the zinc is not easily dissolved in basic solutions. Though it is fairly cheap to construct a zinc-carbon battery, the alkaline-cell battery is favored because it can last much longer. Instead of using NH_4Cl

as an electrolyte, the alkaline-cell battery will use $NaOH$ or KOH instead. The reaction will occur the same where zinc is oxidized and it will react with OH^-

instead.

$$Zn^{2+}(aq) + 2OH^{-}(aq) \rightarrow Zn(OH)_2(s)$$

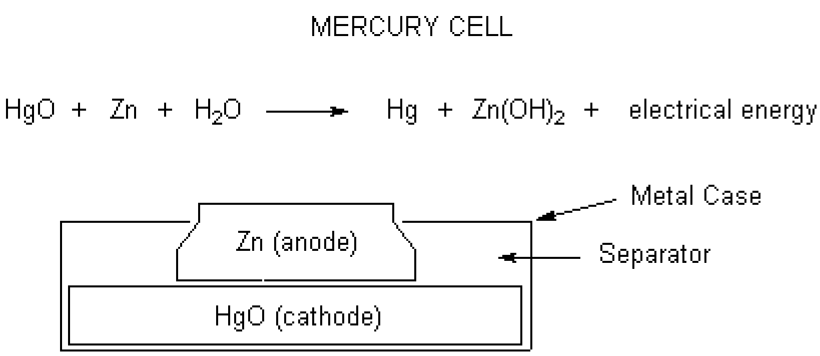
Once the chemicals in the dry-cell battery can no longer react together, the dry-cell battery is dead and **cannot** be recharged. Alkaline electrochemical cells have a much longer lifetime but the zinc case still becomes porous as the cell is discharged and the substances inside the cell are still corrosive. Alkaline cells produce 1.54 volts.



Mercury cells

Mercury batteries are small, circular metal batteries that were used in watches. Mercury cells offer a long lifetime in a small size but the mercury produced as the cell discharges is very toxic. This mercury is released into the atmosphere if the cells are incinerated in the trash. About 90% of the 1.4 million pounds of mercury in our garbage comes from mercury cells. Mercury cells only produce 1.3 Volts.

$$HgO + Zn + H_2O \rightarrow Hg + Zn(OH)_2$$



Mercury batteries utilize either pure mercuric oxide or a mix of mercuric oxide with manganese dioxide as the cathode. The anode is made with zinc and is separated from the cathode with a piece of paper or other porous substance that has been soaked in the electrolyte (which is generally either sodium or potassium oxide).

In the past, these batteries were widely used because of their long shelf life of about 10 years, and also because of their stable, steady voltage output. Also, they had the highest capacity per size. They were popular for use in button-type battery applications, such as watches or hearing aids. However, the environmental impact for the amount of mercury present in the batteries became an issue, and the mercury batteries were discontinued from public sale.

lead-acid batteries

The lead-acid battery used in cars and trucks consists of six electrochemical cells joined in series. Each cell in a lead-acid battery produces 2 volts. The electrodes are composed of lead and are immersed in sulfuric acid. The negative electrodes are spongy lead metal and the positive electrodes are lead impregnated with lead oxide. As the battery is discharged, metallic lead is oxidized to lead sulfate at the negative electrodes and lead oxide is reduced to lead sulfate at the positive electrodes. When a lead-acid battery is recharged by an alternator, electrons are forced to flow in the opposite direction which reverses the reaction.

$$Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$$

Nickel-cadmium cells

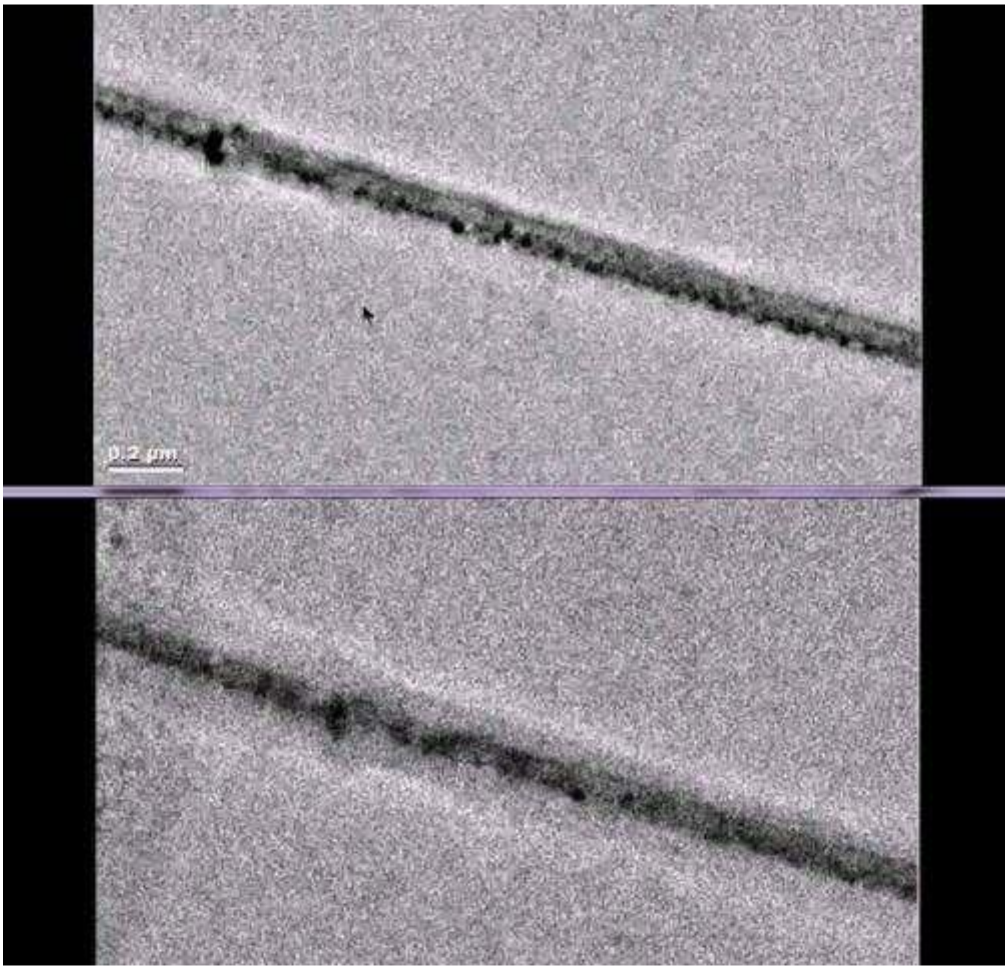
Nickel-cadmium cells can also be regenerated by reversing the flow of the electrons in a battery charger. The cadmium is oxidized in these cells to cadmium hydroxide and the nickel is reduced. Nickel-cadmium cells generate 1.46 Volts.

$$Cd + NiO_2 + 2H_2O \rightarrow Cd(OH)_2 + Ni(OH)_2$$

A Nickel-metal Hyride battery is a secondary cell very similar to the nickel-cadmium cell except that it uses a hydrogen-absorbing alloy in place of cadmium. The Nickel-metal Hyride battery has 2-3 times the capacity of a nickel-cadmium cell.

Researchers develop methods to study battery chemistry in action

February 4, 2014



Liquid battery electrolytes makes this view of an uncharged electrode (top) and a charged electrode (bottom) a bit fuzzy.Credit: Gu, et al., *Nano Letters* 2013

Researchers at a host of national laboratories and universities have developed a way to microscopically view battery electrodes while they are bathed in wet electrolytes, mimicking realistic conditions inside actual batteries. While life sciences researchers regularly use transmission electron microscopy to study wet environments, this time scientists have applied it successfully to rechargeable battery research.

The results, reported in December 11's issue of *Nano Letters*, are good news for scientists studying battery materials under dry conditions. The work showed that many aspects can be studied under dry conditions, which are much easier to use. However, wet conditions are needed to study the hard-to-find solid electrolyte interphase layer, a coating that accumulates on the electrode's surface and dramatically influences battery performance.

"The liquid cell gave us global information about how the electrodes behave in a battery environment," said materials scientist Chongmin Wang of Pacific Northwest National

Laboratory. "And it will help us find the solid electrolyte layer. It has been hard to directly visualize in sufficient detail."

Wang and colleagues have used high-powered microscopes to watch how the ebbing and flowing of positively charged ions deform electrodes in batteries. Metal ions squeezing into the electrode's pores makes the electrodes swell, and repeated use can wear them down. For example, recent work funded through the Joint Center for Energy Storage Research—a DOE Energy Innovation Hub established to speed battery development—showed that sodium ions leave bubbles behind, potentially interfering with battery function.

But up to this point, the transmission electron microscopes have only been able to accommodate dry battery cells, which researchers refer to as open cells. In a real battery, electrodes are bathed in liquid electrolytes that provide an environment ions can easily move through.

So, working with JCESR colleagues, Wang led development of a wet battery cell in a transmission electron microscope at EMSL, the DOE's Environmental Molecular Sciences Laboratory on the PNNL campus, giving scientists a more realistic view of what's happening.

It began with the team building a battery so small that several could fit on a dime. The battery had one silicon electrode and one lithium metal electrode, both contained in a bath of electrolyte. When the team charged the battery, they saw the silicon electrode swell, as expected. However, under dry conditions, the electrode is attached at one end to the lithium source—and swelling starts at just one end as the ions push their way in, creating a leading edge. In this study's liquid cell, lithium could enter the silicon anywhere along the electrode's length. The team watched as the electrode swelled all along its length at the same time.

"The electrode got fatter and fatter uniformly. This is how it would happen inside a battery," said Wang.

The total amount the electrode swelled was about the same, though, whether the researchers set up a dry or wet battery cell. That suggests researchers can use either condition to study certain aspects of battery materials.

"We have been studying battery materials with the dry, open cell for the last five years," said Wang. "We are glad to discover that the open cell provides accurate information with respect to how electrodes behave chemically. It is much easier to do, so we will continue to use them."

As far as the elusive solid electrolyte interphase layer goes, Wang said they couldn't see it in this initial experiment. In future experiments, they will try to reduce the thickness of the wet layer by at least half to increase the resolution, which might provide enough detail to observe the solid electrolyte interphase layer.

"The layer is perceived to have peculiar properties and to influence the charging and discharging performance of the battery," said Wang. "However, researchers don't have a concise understanding or knowledge of how it forms, its structure, or its chemistry. Also, how it changes with repeated charging and discharging remains unclear. It's very mysterious stuff. We expect the liquid cell will help us to uncover this mystery layer."

Read more at: http://phys.org/news/2014-02-methods-battery-chemistry-action.html#jCp