Energy Matters

musings on the new grid

Wells to wheels: electric car efficiency *February 22, 2013*

Posted by Maury Markowitz in electric cars.
Tags: electric cars
trackback

One common argument against electrifying the car is that all it really does is move the engine from one place to another – from your car to a power plant. There's an advantage to moving that exhaust away from people, but overall, it's argued, the effect is pretty limited.

Guess what, it's math time!

If we're going to compare electrics to conventional internal combustion engine ("ICE") cars, we need to get our measurements right.

With conventional fuel cycles we often want to know about two primary numbers, the "tank to wheel efficiency" which tells you how efficiently your engine turns fuel into movement, and the "well to wheel efficiency" which adds the energy it took to get that fuel to your gas tank.

For conventional cars you can just Google those numbers in seconds. So if we want to do a straight up comparison, we want to develop similar numbers for electric cars.

So, let's start with tank to wheel

One of the nice things about electric motors is that they operate efficiently over a wide range of speeds. An ICE varies between 0%, when idling, to something in the low to mid 30% range. An electric motor runs somewhere in the low 80's to high 90% range over its entire RPM band.

There used to be a running debate about whether EV's should have gears, generally two. That keeps the motor in the mid-to-high 90's, but adds complexity. That debate is now over; no modern EV has more than a single fixed speed gear.

So in an EV there's no major transmission system, driveshaft components, and in some designs, you don't even have axles or differentials. A modern electric drivetrain is much simpler than a modern gasoline one, with parts counts that are tens or hundreds of times smaller.

Over on the right is an image of the Tesla Model S (from Rides with Chuck) and that's basically the entire car – the motors are placed between the wheels (the big cylinder mid-image) where the front and rear axle/transaxle would be, and a battery pack in the floor of the car (the light-silvery part at the top-left).

This is the drivetrain in a Tesla S. It's a motor between two wheels.

In a typical car, the drivetrain eats up about 5 to 6% of the energy from the engine, in an electric design it's close to 0%.

The motor itself is fantastically efficient, but that's in terms of the electricity being delivered to it from the batteries. That conversion is not direct – the batteries provide DC power but the motor uses AC, so you need to use an "inverter" to change it from one to the other. Modern inverters are about 95% efficient.

In a gasoline car, the fuel that's pumped into your tank is used directly in the engine. That's not the case in an electric car, where the "fuel" is AC power from your home, and the tank is a battery full of DC power. So we have to convert from AC to DC using a charger which is also about 95% efficient.

That's right – we start with AC, turn it into DC, back into AC, and then into motion. That doesn't sound great, does it?

And finally, we need to consider leakage. When I charge the battery, not all of the power ends up stored, some of it is used up pushing the electrons through the battery. Typical numbers here are about 85 to 90% efficient.

So, a rough estimate of the total round-trip tank to wheel efficiency is:

0.90 (motor and drivetrain) x 0.95 (inverter) x 0.90 (battery) x 0.95 (charger) = 73%

This number jives quite well with the claims of Tesla, which quotes a 75% round-trip efficiency. Tesla and Leaf owners report slightly lower real-world charging numbers, with the charger and battery portions of the cycle on the order of 80 to 85%. If we use those numbers we get:

0.90 (motor and drivetrain) x 0.95 (inverter) x 0.8 (battery and charger) = 68%

This isn't a huge difference, so we'll split it and call it 70%. How does this compare to a conventional car? Quite well in fact. A normal gasoline car has a tank-to-wheel efficiency of 16%.

That's right, an electric car is ***over four times*** as efficient at turning energy into motion.

But then there's well to wheel

This comparison is not apples to apples because it doesn't account for where that electricity comes from.

You'll get your electricity from a mix of generation sources, likely including a proportion of coal, natural gas, nuclear, and a bunch of renewables like hydro, wind and solar. Right now the grid in North America is undergoing a massive switch from coal to natural gas. There's still a lot of coal out there. But then there's also a lot of hydro and nuclear. When you average everything out, it's like we get 100% of our power from NG. Actually, that's only true in the US, up here in Canada we get over half our power from hydro, so the power mix is considerably cleaner.

NG is burned in large turbines, basically jet engines, which spin generators. A turbine is about the same overall efficiency as a gas engine running at its peak, turning about 30% of the energy in the fuel into rotating shaft power. The rest, 70% of the energy, is lost as heat. But turbines have one additional trick… in your car that extra heat blows away through your radiator or out the tailpipe. But in a power plant, we can capture it. We use it to heat up water, boil it into steam, and then use the stream to drive another turbine. These "combined cycle" generators can be up to 60% efficient. When you factor in things like throttling and load following these numbers go down, but average numbers on the order of 50% are very common, and most modern plants are closer to 55%.

Then we have to get that power to you. Contrary to what you may have heard, the electrical grid is *very* efficient. The *total* losses in the US grid are only about 7%. This number keeps going down as we improve the systems.

So that means the real tank to wheel comparison is:

0.5 (generator) x 0.93 (line losses) x 0.7 (entire car side) = 33%

Now we also have to get that gas to the NG power plant. The drilling and extraction requires energy equivalent to about 9% of the fuel, and shipping it in a pipeline is extremely efficient, accounting for about 1.5% of the energy. So that means the total cycle end-to-end is:

0.91 (extraction) x 0.985 (shipping) x 0.33 = 29%

And that estimate is definitely on the conservative side, most academic papers put it closer to 35 to 40%, 5 to 10% better than what I've calculated here.

So now we have a number that we really can compare directly to a gasoline car – we're accounting for everything from the well to the wheel, and that number is around 30%.

So what's a typical number for well-to-wheel for a conventional car? About 14%.

The case for electric

Very basically, if we took the gasoline you put into your car and burned that in a turbine, then sent that power to your electric car, the overall efficiency of the system would double.

Double.

And that's the *dumb* way to do things. The beauty of an "electric economy" is that batteries can be charged up at any time. They're not soaking up coal and NG power, which are peaker supplies run during the day. They're charging up at night when it's mostly nuclear and wind. As more and more sources of energy come into the mix, invariably more efficient and less polluting than existing generators, your car gets better and better. You can't do that with your existing car, who's efficiency and emissions are fixed at the moment it was built, and generally get worse over time.

There are people who say that we should "burn" hydrogen in fuel cells, for instance. But I can do that at a power plant and ship it to my car for a total loss of only 30%. Other people say we should use more biofuels. But I can burn them at a power plant and ship it to my car for a total loss of only 30%. Want a nuclear powered car? Burn it at a power plant and ship it to my car for a total loss of only 30%.

A nuclear powered car. Yes, really.

You see how this works? Electric cars burn *anything.* They are the ultimate flex fuel vehicles. No matter what new fuel we invent in the future, your car will burn it, without changing a thing.

And in the meantime…

While we wait for the inevitable conversion to electrics, we have problems we'd like to solve in the shorter term. And the quick solution is plug-in hybrids, or PEHs. This gets us all of the advantages of electrics on the vast majority of trips, and gives you a fail-safe option for long trips. The difference between a PEH and a full electric vehicle is that you're hauling around an engine everywhere you go, even when you don't need it. But if you pull that out you need more batteries, so the difference isn't as much as you might think. And since PEHs have less battery, say 1/4 that of a full electric, so as long as batteries remain as expensive as they are now, this is a much lower cost option.

So I'm saving up for my PEH. I'm really loving the Ford Fusion…

Update 2016: As my Civic Hybrid refuses to die, my choices keep getting better. The Fusion Hybrid currently lists at ~$26k for the base model, but I can get a Tesla 3 for about $40k. The Bolt will be available here soon, and rumor has it that Subaru is doing an electric Forester or Outback by 2019.

Comments»

1. ivanchowashere - March 16, 2013
Maury, what is your take on this flashy new tech:
http://lightsailenergy.com/tech.html

Reply

Maury Markowitz - March 16, 2013

70% round-trip efficiency isn't particularly great, as the numbers above demonstrate. Storage lifetime is likely short, as some of the stored energy is in the form of heat, which will leak away. Plus, it has moving parts. Certainly workable and even usable for storage times on the order of hours, but beyond that it's not very useful. There are other teams working on zeolite-based storage that captures the heat energy permanently in chemical form, but many practical problems remain.

The "problem", if you call it that, is the amount of research being put into compressed-air systems are a tiny fraction of the amounts going into lithium based systems. If li-zinc, li-air or any of the other systems currently in the lab work, the game's up.

Reply

2. **mycarquotes.net - January 7, 2014**

Could someone please explain this post like I'm 5?
🙂

Reply

Maury Markowitz - January 7, 2014

Electric cars good. Even if you make the electricity with gas.

Reply

3. **Dries Dokter - February 12, 2014**

There is a couple of things missing here:
The energy used to create a battery and electro motor so you can run the car. (taking into account total lifetime, including battery)
against the energy used to create a fuel tank and a combustion engine (again taking into account total lifetime). Also taking into account the waste at the end of the lifetime…

I am still trying to understand: does well to wheels presume that for all energy sources the amount of miles obtained is the same? Does one litre of gas, amount to the same miles per litre of gasoline? Or is that part of the efficiency number? (weight of the car included etc etc)

Reply

Maury Markowitz - February 12, 2014

> The energy used to create a battery and electro motor so you can run the car. (taking into account total lifetime, including battery) against the energy used to create a fuel tank and a combustion engine (again taking into account total lifetime).

These factors turn out to be vanishingly small, much smaller than even the most minor day-to-day issues, like driving style. The advantage is *slightly* in favour of gas engines, generally because the materials are easy to come by. But basically this is so tiny to be ignored.

> Also taking into account the waste at the end of the lifetime…

Some good news here is that cars are *amazingly* recyclable. Even the plastics are getting re-used these days. Electrics don't change that much, lithium recycling systems are being built out now.

> energy sources the amount of miles obtained is the same? Does one litre of gas, amount to the same miles per litre of gasoline? Or is that part of the efficiency number?

It's the efficiency number. All other things considered, the basic amount of energy you need to move a car is based almost entirely on three factors; loaded weight, frontal area, coefficient of drag. If you take the same car, say the new Fusion Energi, the second two are the same for the gas and electric versions. However, the electric version is heavier because its carrying around the engine, motor and batteries. So from a strict energy perspective, the Energi version is worse off. Yet because of the inherent efficiencies of the electric motor, especially at "launch", it averages well over 50 mph in hybrid mode.

It's almost as if it shouldn't work, everything is working against the electric. The fuel (batteries) are heavier, more energy is used up getting the "fuel" in and out of the tank, and there are losses all along the chain from production to you. Yet in spite of this the motor is so efficient it just blows all of that out of the water.

Reply

Dries Dokter - February 12, 2014

oh and what about the amount of energy used to create fuel from oil.. etc etc

Reply

Maury Markowitz - February 12, 2014

Read it again 🙂

4. Alan Wells - August 23, 2014

As I read your reference http://www.asahi-net.or.jp/~pu4i-aok/cooldata2/hybridcar/hybridcare.htm about hybrids, I see the driveline losses at 2%, not the 5-6% you state early in your article. A manual transmission and drivetrain doesn't produce much heat, so I'm interested in where you came up with 6%. You might also present the data in a less prosaic manner such as a table. I believe that would help comprehension.

And the reference also notes that a hybrid diesel has a well to wheel efficiency of 42-46%, the same as an electric car if not better. And engineers continue to coax additional inefficiencies and continued cleanliness from traditional approaches. Now add in a mature assembly industry with low capital costs, high range and it starts to look like electric cars will be a niche player for awhile longer.

I think we're looking at the wrong solution. In my opinion, we should be looking at mature diesel hybrids in the US along with much smaller mass footprints in the cars such as they have in Europe (and illegal in the states and Canada). I would suggest our real problems will be solved by eliminating 3 ton trucks driven as cars everyday and Cadillac Escalades. I don't see a lot of technical improvements in pure electrics in the future. The batteries are still not dense enough, charge/discharge cycles limited, and the cost to manufacture is high. Electric motors are hugely more expensive than mechanical drivelines, although they have advantages (diesel locomotives for instance).

Reply

Maury Markowitz - August 23, 2014

Excellent points Alan, especially the table concept. Sadly wordpress makes it much more difficult to work with tables than it should, it's all manual essentially (still better than the wiki mind you).

The end of the article focuses on this point a bit. In the short term, hybrids are definitely the way to go. The cost of a hybrid is much lower than the equivalent all-electric, and that is very important. But I don't see that lasting. There doesn't seem to be any inherent limit to the cost of li-ion, prices appear to be what the market will bear. When the gigafactory comes online we'll have a better idea.

But over the long term, all-electric wins every time. The well-to-wheel of an electric is about 70% or better in theory, something a hybrid can't touch. It's only if you burn hydrocarbons upstream that that drops. Here in Canada where over 50% of our power is hydro and about 25% of what's left is non-hydrocarbon of one sort or another, the total efficiency is on the order of 50 to 60%. And unlike a hybrid, that improves every time a new wind turbine comes online.

Reply

Maury Markowitz - August 23, 2014

I see I missed one point, about drivetrain losses. The situation is complex. Losses in the transmission itself are, as you note, quite low. However, there are significant losses in the differentials and similar components. I'm certainly no expert on this, but it seems losses of 5 to 10% are not uncommon in RWR differentials. Added to this are dynamic losses, when the car is accelerating, which can be significant. The number in the paper is effective only when the car is driving steady-state. The same is not true of an all-electric drivetrain, where dynamic losses end to be much smaller.

Reply

5. **gplusg - September 25, 2014**

Thank you for this article. Can I translate it to Spanish and publish it on my blog? Of course, giving you credit and linking to your blog. I think this MUST be known, and I am not tech-savvy enough to do this calculus myself.

Reply

Maury Markowitz - September 25, 2014

I'd be delighted. I noticed a sudden uptick in traffic to this article lately, and followed the references back to a Spanish re-blogging site. Hundreds of clicks there, so there definitely seems to be some interest!

Reply

gplusg - September 26, 2014

The article was sent to Meneame.net, the Spanish equivalent for reddit. Since the country is in such a deep economic crisis and we have such potential for renewable production*, there's a huge debate about the electric car here. 🙂

*hottest place in Europe, if you want more sun or heat, you have to go to Africa. Plus, second most mountainous European country after Switzerland, so we produce truckloads of electricity by eolian mills. The windmills have the dishonor of producing energy that many times goes to waste, since they normally produce it at night when it isn't used. The fact that most electric cars would recharge precisely at night makes me feel all warm up inside when I read articles like this. I'll send you a link when I finished translating and have done publishing. If there's any update, please tell me so I can check up the data.

And, thanks 🙂

6. **Quincy Scott - July 8, 2015**

You say, "a normal gasoline car has a tank-to-wheel efficiency of 16%." Then you say, "So what's a typical number for well-to-wheel for a conventional car? About 14%." Shouldn't you be comparing well-to-wheel to well-to-wheel, not tank-to-wheel? It takes energy to get the crude oil, refine it, and process it into gasoline. The gasoline then has to be shipped to the gas station. In other words, what's the well-to-wheel for gasoline powered cars? What did I miss?

Reply

Maury Markowitz - July 8, 2015

The page at the other end of that link shows both well-to and tank-to. The missing part is where that 2% difference goes. I'll see if I can find a link that shows the losses. BTW, I understand those numbers are only true for oil from the Middle East, they are supposed to be worse for fracked oil from the US.

Reply

Kieran - June 5, 2018

That page at the other end also doesn't seem to add up to 16% (let alone the 14%). They both state and show in the graphic losses of 72% for the engine, 10% for idle losses, and 2% for driveline. That's a total efficiency of .28 * .9 * .98 = 24.7% Even taking into account aero, braking and rolling losses you still only get down to about 21%. I don't see how they get all the way to 16%. I'm a BEV owner and advocate, but 16% for a typical modern ICE car is too low.

Maury Markowitz - June 6, 2018

The missing factor is the duty cycle. When a car idles it's efficiency is zero, unlike an WV where it doesn't change (or goes infinite, depending on how you count). Since cars spend finite time below maximum throttle, all of it basically, the actual efficiency is well below the theoretical. This is where hybrids come in, they are typically closer to 20% and even higher for PEHs.

Kieran - June 6, 2018

Can't seem to respond directly to your reply so doing it here…
Duty cycle may be the missing factor, but the page you linked to does not explicitly call it out or show for it in their calculations. So you're saying duty cycle reduces the overall efficiency from ~24% to ~16%; that's an additional 35% loss from duty cycle. What literature / source do you have to support that claim?

Kieran - June 6, 2018

Also, what are the 10% "standby / idle" losses if not duty cycle? Same thing, IMO. I'd love to be able to argue that cars are tank-to-wheel only 16% efficient when convincing others of BEV benefits, but I don't see the math adding up here. Would appreciate any guidance on where the missing 35% goes… 🙂

7. Bert - July 10, 2015

I'm curious to know what the efficiency of coal mining is compared to oil mining. I'm guessing that the coal mining efficiency doesn't make a significant difference, (because we would have definitely heard about it from the misleading studies trying to claim that EVs are the most polluting things ever) but I can't recall ever seeing the numbers on coal mining vs oil mining and I'm curious to know what those look like. If anyone has seen a study of these numbers, could you please link me to it? Thanks.

Reply

Maury Markowitz - August 5, 2015

That's an interesting question. Off the top of my head I suspect that coal in the US is far less energy intensive than oil in the US. I seem to recall that new oil wells burn a barrel for every two they produce, whereas coal is blasted out and then picked up by trucks. It goes pretty much directly from there to the power plant.

Reply

8. **Introducing a decent carbon tax will reduce our overall spend on fuel | Lance Wiggs - August 15, 2015**

[…] power as electricity to electric cars would halve the fuel needed for transport. Here's a good explanation, using US […]

Reply

9. **Peter Levey's Weblog - May 31, 2016**

[…] https://matter2energy.wordpress.com/2013/02/22/wells-to-wheels-electric-car-efficiency/ […]

Reply

10. **Linwood Hirko - October 31, 2016**

You ought to be a part of a contest for one of the best websites on the net. I most certainly will recommend this website! |

Reply

Maury Markowitz - October 31, 2016

Aww, shucks.

Reply

11. **Gus - January 17, 2017**

A couple of points other than the obivous that modern hybrids, especially that can use E85 (large renewable fuel content), are the low GHG producers.

1st, you can't average power usage because putting all of the cars onto the electric grid to power would create new demand and new demandmeans we can't get rid of the dirties source. So the proper fuel choice is the worst case available which for most of the world means coal.
2nd, real world numbers please not optimal best case technologies. If you simply take into account your data there is a huge drop off in performance.
3rd, the grid loses a TON of power every year because it must be maintained. That generation efficiency is 60%, indeed less than a third of the energy that goes into making electricity is actually consumed.

Electric cars only accomplish one thing and that is moving the GHG from one location to another. Cities love this, especially our east and west coast liberals as they get zero emissions where they live and shift that all onto those evil Republicans living in the heartland.

Reply

Maury Markowitz - January 17, 2017

All of the numbers in the article are real world. There is another article on this site that demonstrates best possible EV uptake is slower that new wind capacity. So, none of your points appear correct. Sources?

Reply

12. **Adam - March 16, 2017**

Hi Maury!

Amazing article that I just came across but I have some corrections:

1. you did tackle the issue of how the electricity "gets" to your car but in the 16% tank to wheel of the ICE car you didn't take into consideration the gas that needs to be transported every couple weeks to

all the gas stations across the world.(of course there massive trucks are very polluting and not so efficient)

2. you didn't address regenerative braking! in the article about the Hybrid they did address it. it improves the efficiency of the vehicle as well!

3. Maintenance, now this one is a little complicated and not very direct but in general EV's are far simple and have far less moving parts so less maintenance of the drive-train and part\oil changes. less pollution.

4. you didn't address car manufacturing.

5. you assumed that the car will be charged with AC source however fast DC chargers are very common and some people actually own solar panels that not only are very clean but are DC as well.

6. Flexability and grid development. EV's need electricity it doesn't matter how you produce it. ICE cars however are stuck with 1 option gasoline.
As the grid evolves EV's are becoming cleaner without changing anything.

Sorry I am really interested in EVs so I'm a bit picky. Cheers!

Reply

Maury Markowitz - March 17, 2017

And I don't want to sound like I'm nitpicking back, but just so its in the record…
1) transport *is* included in the well-to-wheel. It's surprisingly small (a few percent on the fuel side, basically invisible in the car side)
2) regen is slightly more effective on EV than hybrid due to larger storage capacity, but otherwise they are similar
3) indeed, this is *huge* issue. And for hybrids too – my Civic Hybrid has 210,000 on it and I've done one set of tires, one set of spark plugs, oil, wiper blades and windshield fluid. I'm still on the original brakes! EVs are even more crazy in this regard, because the number of moving parts is so small. That said, that's not really about energy, but cost of ownership, a topic for another article (which really I should get around to writing)
4) You are right, I did not. I simply don't know enough to trust myself to write anything useful. And that is an issue. But my gut feeling is that the manufacture and recycling of the batteries pales in comparison to the energy spent by the car actually moving. The rest is too similar to have any real world effect (motor vs. engine manufacture for instance)
5) DC fast chargers don't have the effect you might imagine – "slow charge" takes AC from a wire and converts it to DC in a charger in the car. Fast charge takes AC from a wire and converts it to DC in a box and then ships the DC to the car on a wire. You're doing nothing but moving the box a few feet, and the overall efficiency is the same. A bigger box and relaxed weight limits might allow some design flexibility so they may be *slightly* more efficient, but I doubt it's even 0.1%.
6) Absolutely. But I *do* talk about that at the end.

Reply

Adam - March 17, 2017

Hi Maury,

The transport seems too small for a constent deliveries of gas with huge trucks every couple weeks.

I think they took 1 time of "gas supply" not constent supply as it is in real life scenerios.

I didn't see you take into consideration power restored by regen so i'm not sure what you meant.

about DC i agree in most cases it's just a AC that was converted but not always. as i said Solar PV is DC.

Thank you for your time!

Adam - March 17, 2017
I'm really not sure about the Well to tank in the article.
I mean no info or calculation. I'm certain that transporting electricity is far more efficient than fuel.

13. **Arron@oz - March 21, 2017**
Maury,

Good article, at last some real world figures.

I am about to change my rooftop solar from panels w mini inverters (i.e. AC) to a DC optimiser sytem (with a 27.6Kw 3 phase Solaredge inverter). That means I can charge an EV directly from a string of my panels by simply matching the car's required voltage – no conversion loss. Given an inverter with the capacity for multiple strings (becoming more common each year) I suspect that may be a good way to avoid extra losses. Mind you, the alternative is just to stick more panels on the roof…

Reply
14. **Peter Chase - May 2, 2017**
Maury,
Thank you for a very good explanation of EV vs ICE efficiency. I just found this site while looking for data on a cursory EV/ICE weight comparison and voila! You've answered my questions and then some. I will certainly explore Energy Matters further.

I do have one comment on EV vs ICE economics and that is that EVs have other economic benefits than just ultimately a much cheaper transport than ICEs. They are also less polluting which translates to health benefits and they also represent synergy with grid storage in that EV batteries will be viewed, at least, as an emergency source of grid backup or a civil defense asset.

Reply
15. **William Griffith - June 2, 2017**
What about expanding the electric grid capacity and all it entails? Energy, mpney, materials, etc.

Reply
Maury Markowitz - June 4, 2017
Actually, there have been many, *many* studies on this topic. All the recent ones say the same thing: there are some areas that need new transformers, but that's about it.

This should not be surprising. The average North American driver goes about 25 km a day. In a typical EV that would require 5 kWh. That's about the same as 1 to 1.5 hours of central air. The typical EV charger is 240/15 or 240/30, while a typical aircon unit is 240/50. So basically anywhere there is widespread aircon you already have the needed capacity.

That said, the power companies are actually much more at risk due to added aircon than they are EVs. And that's a serious concern, because the climate warms people are adding a lot more aircon:

https://arstechnica.com/science/2017/02/us-electric-grid-isnt-ready-to-handle-our-future-climate/

Fast chargers, 60A and up, are a different kettle of fish, and those might require transformer upgrades. The "good news" is that these are limited by local code, so they can be rolled out as the grid can handle it.

Reply

16. **Damien - July 10, 2017**

Thank you for this in depth write up about EV vs Fossil efficiency. It fits very well with my own comparison of GHG emissions after driving a Nissan LEAF for almost 2 years in the Netherlands.

I took my own real world usage in kWh, multiplied it with the average CO2/kWh in the Netherlands grid and compared that with a low emission diesel from about the same class (Citroën C4 Cactus Blue HDi). I corrected the fossil energy label for real world performance (typically, the European NEDC efficiency test is off by between 25 – 40%!), and found a 'well to tank' study that adds another 20% efficiency hit. My conclusion is that the EV saves between 40-50% GHG emissions on the Dutch grid that relies quite heavily on coal. So, I guess that correlates well with your double efficiency.

What you could add is that fossil fuel exploration is getting harder and less efficient as the easy resources are drying up. The 'Energy Return on Energy Invested' is a useful concept in that regard. It measures how many barrels of oil (or equivalent energy) you need to extract a number of consumable barrels. It used to be 1 barrel to produce 25 or more (Middle East, or Texas), but now we're relying more on sources like tar sands which get as low as 2.9 barrels produced for 1 barrel invested.

https://insideclimatenews.org/news/20130219/oil-sands-mining-tar-sands-alberta-canada-energy-return-on-investment-eroi-natural-gas-in-situ-dilbit-bitumen

Then there's the matter of methane emissions from natural gas extraction from shale. Methane is a much more potent GHG than CO2, and it is released in such quantities at shale sites that it actually nullifies the gains in CO2 emissions of natural gas vs coal. So, the only way forward is full EV with 100% renewable energy.

Finally, I see some people asking about battery production. This has been studied of course, and while producing an EV does cause more emissions (15-70% more depending on model and range), that is made up for in 6-18 months of driving.

http://www.ucsusa.org/clean-vehicles/electric-vehicles/life-cycle-ev-emissions#.WWOWN2jRY0M

Reply

Maury Markowitz - July 11, 2017

"fossil fuel exploration is getting harder and less efficient" – indeed, the numbers on fracked oil in the US are truly abysmal, I've seen numbers that suggest some wells take almost a barrel of energy for every two they produce. It used to be 100 to 1.

Reply

17. **Steve Emsley - August 5, 2017**

Thanks, a very informative article. An observation I reacently discovered was in comparing household energy emissions with car emissions. Our reductions in household energy , fossil fuels equates to around 85, 000 miles of driving an electric car. Our car use is only 6000 miles a year. So we were right to prioritise reducing household energy by insulation, efficient products, wood use , and solar electricity. However , changing to an electric car may now be further up the list of priorities. Night time charging in the UK uses a good portion of wind power. Night time cost of electricity is half the daytime standard rate. However using trains and buses increasingly makes me wonder whether to give up cars and just rely on public transport and a very occasional car hire. Decision time.

Reply

Maury Markowitz - August 5, 2017

Well it's difficult to beat the utility of a car. The only time I didn't need one was when I lived in downtown Toronto, but now that I moved there's no escaping it. My new(er) home doesn't need the level of work my former 1917 one did, but I replaced all the lighting and the furnace and aircon are next on the list. In the meantime my Civic Hybrid simply won't die (did the first brakes at 210000!) so every year it lasts makes it that much easier to choose an EV when it finally does.

Reply

18. **Arron@oz - August 5, 2017**

There seems to be two competing factors in getting renewable energy into an electric vehicle (whether hybrid or pure).
1) In Oz more and more people are putting solar on their own roofs and lately matching batteries to offset power usage over time are also becoming a lot more common. Power grid usage remains unchanged or even diminishing.
2) It seems that the USA is installing huge solar farms and wind farms so the major utilities are retaining their control & revenue models. That relies on the grid having ever increasing capacity. That also implies transmission losses will continue to be a factor.
In the case of OZ, one of the "3rd year uni student projects" I set was to calculate the transmission losses if the whole country was powered by a 50 * 50km solar array in the centre of the country (yep, that is all it needed, USA would be a lot bigger but a decent sized desert would hold it) whilst the location of electricity consumption remained unchanged. Surprising answer 17% +/- 2% using the normal high voltage AC lines commonly found here and the USA.
Maury, I suspect if you recalculated / updated the figures to compare local battery charging the EV would start to approach the real world figures for Oz in 2025 (if not earlier).

Reply

19. **David D. Hebb - September 9, 2017**

Thanks for the clear analysis. Like all such estimates, there are assumptions which may be optimal rather than realistic, e.g., your assumption regarding electrical generator plant efficiency, i.e., 50% or .5 in your calculations. It is true that a combined cycle gas turbine plant can achieve such figures but not all fossil fuel generating plants in the USA achieve this level of efficiency and and even the combined cycle, like all generating plants do not operate at peak efficiency all the time, needing start-up and shut-down periods where they are at much less than peak efficiency; Secondly, in order to meet anticipated demand, generating plants produce more electricity than needed. With this in mind, might not a factor of .4 or .45 might be more realistic. Also, as well as considering in your equation electrical transmission losses, one would need to include a factor that recognizes battery electricity draining that occurs over time and not assume that all electricity that reaches the battery from a generating plant is consumed in the electric motor and propelling the automobile. Finally, there is the assumption relating to the efficiency of ICE automobiles. ICE engines are capable of far greater efficiency than the low figure you use in a comparison. In the last month or so, Mazda has indicated it has an ICE engine ready for production that is superior on a wellhead-to-whell basis.

Reply

Maury Markowitz - September 9, 2017

> your assumption regarding electrical generator plant efficiency, i.e., 50% or .5 in your calculations

I think you missed the point here: that number is an average mix of all sources. When you consider things like wind and hydro as part of the mix, when you add up all the kWh produced and divide by all the fuel burned, it's as if it was created in a plant with 50% efficiency. Actually, it's higher than that.

> battery electricity draining that occurs over time

This is *tiny* for modern batteries. Less than 1% for the average car cycle.

> ICE engines are capable of far greater efficiency than the low figure you use in a comparison

The problem is that when you are at a stop light the efficiency of the engine is exactly zero. The Mazda engine you refer to improves top-end performance by a percent or two, but it's still zero at the stoplight. This is why all cars should have had auto-stop as a mandated feature a decade ago (I REALLY don't understand that one).

Reply

20. **| Hinduja Tech - October 15, 2019**

[…] protocols are built. It is essential that the aforementioned costs are taken into consideration for forthcoming studies. An organic growth rather than rapid commercialization of electric mobility is essential for a […]

Reply