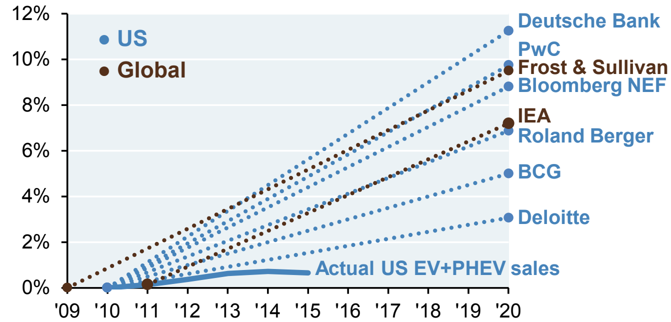
[II] The tortoise, the hare and the electric car: the quiet progress of hybrids over EVs

There's a lot of excitement about Tesla's Model 3, the Chevy Bolt and other electric cars coming to market. However, auto analysts have generally been way too optimistic about adoption of electric vehicles (EVs), as shown in the chart on 2020 projections vs. reality. This isn't the first time; over-optimism on electric cars began in the 1960s with Ford Motor's announcement of an imminent breakthrough on electric car production.

With respect to innovation in the car industry, **the more impactful developments involve the use of electricity in hybrid vehicles (the tortoise), rather than in EVs (the hare).**

Another generation of electric car projections out of sync with reality, EV+PHEV sales as % of total car sales



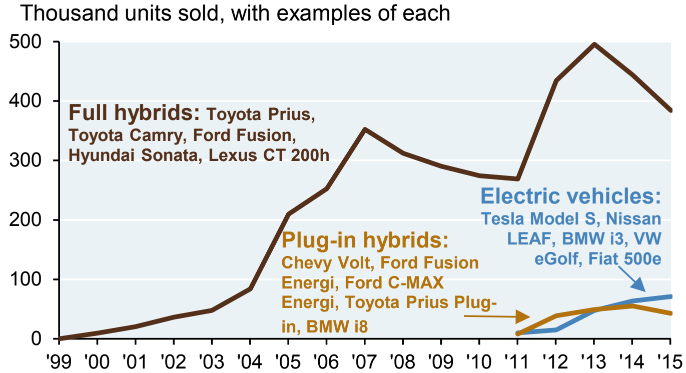
Source: DOE, BEA and listed organizations. 2015. Note: global EV+PHEV sales in 2015 were also around 0.6%.

What's a hybrid vehicle? Well, it depends…

- Micro hybrid: internal combustion engine (ICE) cars with stop-start systems drawing power from regenerative braking; the engine shuts off when drivers idle and restarts when the gas is re-engaged
- Mild hybrid: ICE cars with more powerful batteries (e.g., 48V or 110V instead of 12V), also powered by regenerative braking, which provide engine stop-start functionality while stopping, coasting and decelerating; and which can boost the engine during acceleration
- Full hybrid: ICE cars with larger electric motors that can power the car for short periods; battery packs are charged both by regenerative braking and by the ICE itself
- Plug-in hybrid (PHEV): primary engine is usually the electric motor, recharged with an external electricity supply; ICE mostly used to recharge the electric battery rather than to power the car

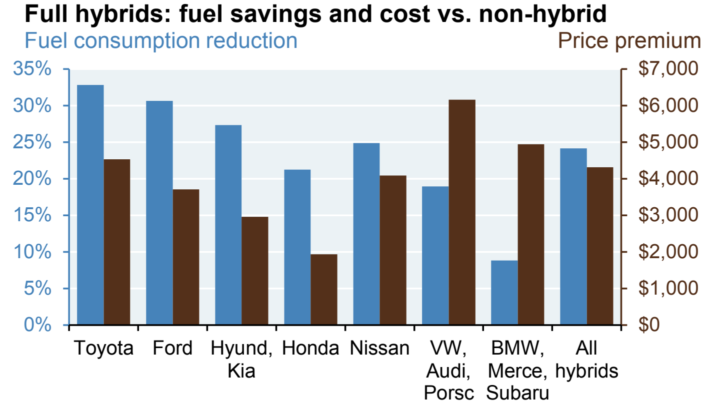
The next chart shows sales for US full hybrids, plug-in hybrids and EVs. Despite the excitement, PHEVs + EVs are still just 0.7% of US light vehicle sales. Full hybrids, on the other hand, have reached 3% of sales. According to the International Council on Clean Transportation (ICCT), full hybrids are an important part of the climate picture since they can reduce fuel consumption and CO_2 emissions by up to 35%[9]. In its analysis, ICCT cites automotive research firm Vincentric which compared 31 full hybrids to the closest non-hybrid vehicle from the same maker. The 2nd chart shows the fuel consumption reduction for some of these vehicles alongside their incremental cost. The tradeoff can be an expensive one: in only ~60% of full hybrids analyzed, the car's extra cost is recouped through lower fuel expense over its life. This suggests that full hybrid costs need to come down further.

US full hybrid, plug-in hybrid & electric vehicle sales
Thousand units sold, with examples of each



Source: US Department of Energy. December 2015.

Full hybrids: fuel savings and cost vs. non-hybrid



Source: ICCT, Vincentric Hybrid Analysis. July 2015.

[9] The 2014 EIA fuel economy report reached a similar conclusion in terms of potential hybrid fuel and GHG savings.

The potential for lower hybrid costs and greater market share

"High-power electronics" is a relatively new field, and costs are coming down rapidly. ICCT expects hybrid system component costs to fall in half by 2025. Manufacturers and suppliers are sorting out advantages and costs of the different configurations, such as voltage level (from 12V all the way up to 330V), power density, energy storage (lead-acid, NiMH, Li-ion) and drive type. New 48V mild hybrid systems may turn out to be the most promising, achieving 1/2 to 2/3 of the benefits of a full hybrid at less than half the cost. Barclays projects greater acceptance and penetration of mild and full hybrids; the table below shows actual 2015 data and their projections for 2020 and 2025.

The big picture:

- Port fuel injection technology is expected to give way to gasoline direct injection in many ICE cars.
- 48V mild hybrid and full hybrid cars are projected to increase market share. The EPA has a similar outlook, expecting mild and full hybrids to capture 31% market share in the US by 2025 (mostly through mild hybrids).
- Combined plug-in hybrid and EV shares are projected to hit just 5% in 2025, way below most of the 2020 forecasts shown on the prior page.
- What about Tesla? In 2015, Tesla delivered 50k units and is projected to deliver 75k in 2016. The company mentioned 500k as annual capacity for its new US gigafactory by 2020, and mentioned one million units as its global target by 2020. This seems ambitious, but even if these levels are reached, Tesla's EVs would still represent just 1.2% of global vehicle production.

Bottom line: compared to EVs, hybrids are making more impactful but less glamorous use of electricity, and can be similar to EVs in terms of GHG emissions as well (see next page).

A 2015 projection of future global light vehicle production by powertrain type

Powertrain	2015	2020	2025
ICE port fuel injection	50.9%	36.8%	20.8%
ICE gasoline direct injection	24.0%	31.2%	29.4%
ICE diesel	19.7%	19.9%	17.0%
Compressed natural gas	1.9%	1.9%	1.8%
48 Volt (mild) hybrid	0.0%	3.6%	15.5%
Full hybrid	2.8%	4.4%	10.4%
Plug-in hybrid (PHEV)	0.4%	1.5%	2.0%
Electric vehicle (EV)	0.2%	0.7%	3.0%

Source: Barclays, IHS. August 2015.

Where does hybrid car energy conservation come from? As per the ICCT:

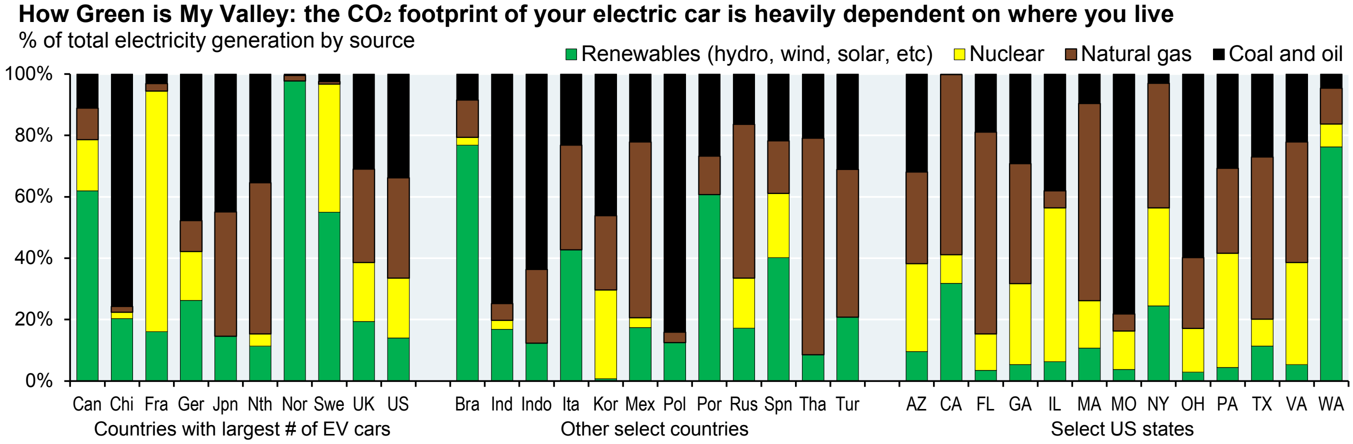
- Using energy normally lost during braking
- Maintaining performance while using a smaller, more efficient engine
- Shutting the engine off at idle and at low load conditions
- Enabling the engine to be run at lower speeds, where it is more efficient
- Replacing the alternator as a means of generating power with more efficient motor/generator systems
- Replacing less-efficient mechanical water and oil pumps with electrical pumps that only operate when needed
- Supplying power required by safety features, heated seats, dynamic chassis control and other power-hungry components

Sparse penetration aside, how "green" are EVs compared to hybrids?

Energy use and GHG comparisons of hybrids with EVs are very complex. A comprehensive "well-to-wheels" analysis has to factor in the current electricity mix and how it's changing over time, energy used and lost in transmission of electricity and gasoline, energy used on oil extraction and refining, energy used in the manufacturing of EVs vs. hybrids, battery disposal and other subtleties such as driver habits.

Based on data from the ICCT and a November 2015 paper from the Union of Concerned Scientists, our sense is that the GHG footprint of a full hybrid like the Prius is roughly the same as an EV in a state with the ***average*** US electricity mix. The chart below shows the electricity mix by country and by US state. Where coal usage is high, hybrid cars can produce better GHG results than an EV. As penetration of renewable energy increases, the EV becomes the greener choice.

How Green is My Valley: the CO_2 footprint of your electric car is heavily dependent on where you live



Source: World Bank (2014) for countries, EIA (2015) for US states, JPMAM.

A few things to keep in mind when looking at this chart:

- ***Coal vs. natural gas***. An EV charged by a grid powered 100% by natural gas has ~50% of the GHG footprint of an EV charged by a grid powered 100% by coal. Of the countries shown, only the US experienced a double-digit decline in coal's share of generation from 2006 to 2014, mostly due to expansion of natural gas. From 2006-2014, coal's share of *global* electricity generation was unchanged.
- ***Renewable energy mostly hydro***. As per the chart on page 1, green renewable energy segments are mostly made up of hydroelectric power, whose global share of electricity generation was 3.6x higher than wind and solar power combined in 2015.
- ***How green is nuclear*?** Difficult question. The Clean Air Task Force, climatologist James Hansen of Columbia University, David Mackay of Cambridge, Robert Hargraves from Dartmouth and 65 biologists who signed an open pro-nuclear letter in 2015 support it. On the other hand, there are disturbing reports of Fukushima's aftermath: rain and other sources of water flowing through the site and becoming radioactive, some of which seeps into the ground or the ocean; signs that cesium and strontium were still leaking into the ocean as of 2013; and the lack of knowledge as to exactly where the molten cores from the reactors are located. I don't know what color to make the nuclear bars in the chart: green when it works and vantablack (the darkest color in the universe) when it doesn't?