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ME 182

EV Economics Assignment

*Gasoline IC engine battery electric-motor hybrid-powered light-duty vehicles are now being sold to customers in significant and growing numbers. Plug-in hybrid vehicles and fully electric vehicles are now being sold as well.*

1. *Hybrid-powered vehicles are estimated to cost several thousand per vehicle more than an equivalent standard gasoline-engined vehicle. List the major additional components that the hybrid propulsion system requires relative to a standard gasoline engine system.*
2. *Also, describe any significant design and operating changes in the IC engine system, between a standard gasoline engine and a hybrid system gasoline engine.*
3. *Estimate the additional cost amongst these additional components and engine changes. Explain your logic and identify any sources of cost information you use.*

-Needed for IC: internal combustion engine, a standard or automatic transmission, an alternator, a carburetor or fuel-injection system, spark plugs, a crankshaft, and a battery.

Additional needed for Hybrid:

-Electric Motor

-Control system (electric motor/battery)

-AC/DC converters (electric motor)

-Expanded Battery

-Cell balancing circuitry (battery)

-Cooling system (battery)

In addition to the parts found in an IC vehicle, hybrids cars need an expanded energy storage, i.e. a battery, and an electric motor, as well as subcomponents for each. For the motor these include a control system and AC/DC converters, to change the DC signal from the battery to an AC signal that an AC induction motor can use. For the battery subcomponents include cell balancing circuitry, to protect against power surges and limit current, and a cooling system to maintain temperature. Both the motor and battery also require additional temperature/voltage/current sensors not required in an IC car.

The transmission of a Hybrid vehicle is also more complex than those in ICs. The outputs of the gas engine and the electric motor will vary in speed/torque outputs, and are also situated in different locations. The transmission must be able to switch quickly between the two, and adjust itself to the appropriate gear ratio for each. Additionally, the transmission needs to be able to go into a dual mover state where it can accept power from both the engine and electric motor simultaneously.

Hybrid vehicles also have energy saving components. They use regenerative braking to recover kinetic energy in the form of electricity. This is done by connecting the wheels to an inductive load. Usually this is simply the motor run in reverse, which will then act as a current source to recharge the battery. They also use start-stop engines which turn off when the car idles or comes to a complete stop. These generally require a separate, smaller battery, so the main battery can continue to power peripheral elements, like the AC, radio, headlights, etc.

The additional components in hybrids increase their retail cost. I will first look at price differences between common hybrid cars and their IC counterparts.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| IC Vehicle | IC Cost | Hybrid Vehicle | Hybrid Cost | Cost Increase | Percent Increase |
| Toyota Camry | $21,497 | Toyota Camry Hybrid | $26,576 | $5,079 | 23% |
| Camry XLE | $24,725 | Camry XLE Hybrid | $27,400 | $2,675 | 11% |
| Honda Civic | $20,655 | Honda Civic Hybrid | $24,200 | $3,545 | 17% |
| Ford SEL | $25,425 | Ford Fusion Hybrid | $28,775 | $3,350 | 13% |

**Table 1:** The retail price of various hybrid cars and their IC counterparts. All prices are for base models.

<http://www.newcars.com/reviews/toyota-camry-vs-toyota-camryhybrid-sedan.html>

<https://www.cnet.com/roadshow/news/the-hybrid-premium-how-much-more-does-a-hybrid-car-cost/>

<https://cars.usnews.com/cars-trucks/toyota/camry>

Table 1 indicates that common hybrids cost $2500-5000 more than equivalent IC cars. A comparison of newer car models (<http://www.vincentric.com/Home/Industry-Reports/Hybrid-Analysis-2016>) reports that the average price premium for 2016 Hybrids is $5,322.

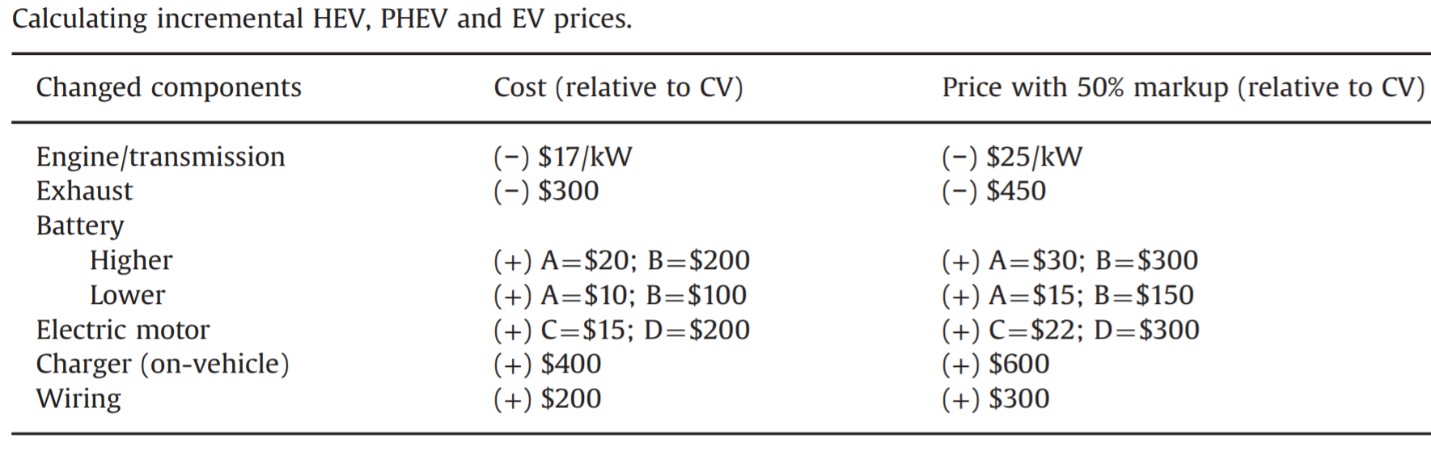


Table 2 summarizes some of the findings from a 2013 paper (Hybrid, plug-in hybrid, or electric—What do car buyers want?) examining the cost-benefit of hybrid and electric vehicles. Manufacturing costs are in the middle column, and retail costs in the right column. They found that reduction in engine and exhaust sizes, and their associated cooling equipment, reduce costs, while adding battery capacity, electric motors, charging systems and wiring/controllers all increase price.

For the batteries and motors, A/C are the cost in crease per kW capacity, and B/D are the base costs. For, a Hybrid Toyota Prius with 130HP/97kW capacity, a high end battery costs 97\*20 + 200 = $2140. This is roughly consistent with the $3000+ (https://www.greencarreports.com/news/1078138\_toyota-hybrid-battery-replacement-cost-guide) cost of the battery replacement service offered by Toyota, accounting for retail mark-up and car model. Summing the retail costs in the table gives an average cost of $4199, which falls in the range of values we found in Table 1.

If we take the values in Table 2 as representative averages, we find that the costs of major Hybrid components are as follows:

Engine/Exhaust reduction: -$2875

Battery: $3210

Motor: $2434

Charger(for PHEVs): $600

Wiring/Controllers: $300

*(b)  The Toyota Prius dominates the hybrid scene to date. Toyota produced about 20,000 hybrid Prius vehicles worldwide in 1997, about 150,000 Prius vehicles in 2004, and sales worldwide passed 17 million in 2017. Identify the major factors involved in sales growth of new technology vehicles, and explain why you think Toyota has not expanded production volumes faster than this, to date.*

Several factors are involved in sales growth of new technology vehicles. To begin with, there must be sufficient demand for the product. The demand curve (i.e. demand vs price) is controlled by the product’s perceived desirability, and the actual demand (i.e. how many will be purchased) is driven by price. The more desirable sustainable vehicles are, the more people will buy them for a certain price. Range anxiety, or the concern that one will get stuck somewhere when the battery runs out, is a reason for reduced desirability. Related to this are concerns over availability of charging stations. Most of the country has few, if any, electric vehicle charging stations, whose presence might alleviate some consumer anxiety about getting stranded. Lastly, marketing plays a big role in consumer interest. Vehicles that are “cool”, or aesthetically and emotionally appealing, will see much higher demand than products that are perceived as uncool, weak, or unreliable will. The cosmetic appeal of Tesla vehicles, coupled with Elon Musk’s successful marketing campaign, has ensured that Teslas are in much higher demand than other EVs like the Toyota Prius.

Aside from competition with other EV producers, Toyota also may have limited Prius production because the Prius is a Hybrid Electric Vehicle (HEV), as a opposed to fully Electric Vehicle (EV). Rather than investing further in the Prius, Toyota may be pursuing the market trend for EV demand replacing Hybrid demand. Toyota should try to keep apace of the changing demand for hybrids, avoiding a situation where the Prius is overproduced and Toyota loses money by selling them at a loss, or worse, not selling them at all.

*(c) There is substantial debate over how rapidly sales of hybrid and electric vehicles will expand, industry wide, and what the eventual longer-term market-share in 2030 might be, in various world regions. Discuss the critical factors that you judge will affect the rate of growth in sales—auto industry and society wide—considering both the U.S. and other major markets. Also discuss the factors that are likely to be important in determining the longer-term market share that hybrid and electric propulsion systems (HEVs, PHEVs and BEVs) could attain. Include in your assessment a discussion of hybrid propulsion system evolutions or changes that are plausible and could have a significant impact on the rate of expansion and long term market share of this technology.*

Increased consumption of electric vehicles worldwide will largely depend on how EVs compete with ICE vehicles in terms of cost. This includes manufacturing costs, which will directly affect consumer prices, and electricity costs, which may factor into consumer considerations to a lesser degree. As seen in part a), cost of the battery is a significant portion of EV manufacturing costs as compared to ICE vehicles. If technological advances allow for cheaper battery production, EV prices would be predicted to fall, allowing more people to afford EVs. Aside from reducing the upfront cost of a car purchase, lower electricity costs relative to gas prices could also make EV ownership more economical.

Current oil prices are relatively low, but as more countries attempt to tackle climate change, we will likely see more regulations to reduce the use of fossil fuels. This may take the form of a tax on polluting sources of fuel, like gasoline, which would lower the relative day-to-day cost of running an EV as compared to an ICE vehicle. Policies to counteract climate change could also take the form of incentives for using clean energy vehicles. California currently offers tax credits to owners of electric vehicles to decrease upfront costs and make EVs more economically competitive with ICE vehicles. National governments could also reduce the tariffs on imported EVs, which would encourage EV development in other countries. Governmental policies could significantly increase demand for EVs by incentivizing consumers to reduce their contributions to global climate change.

Convenience-related factors may also influence the market-share of EVs in 2030. As discussed in part b), “Range Anxiety” can limit the penetration of EVs, although expanding the network of charging stations would likely alleviate some of these concerns. Tesla has already taken steps in the right direction with their Supercharger network, but the expansion of EVs will be limited until charging stations are ubiquitous. Even if charging stations do exist in all locations, EVs should either charge quickly or have very long battery lives in order to be convenient to consumers, especially to those driving long distances. Gas-powered cars remain attractive partly because fully refueling takes only minutes. Hybrid electric vehicles are a good option for those concerned with slow recharging or inaccessibility of charging stations. HEVs or PHEVs could thus see their market shares grow in regions where charging stations are less accessible or where people may have to drive longer distances.

Technological innovations that reduce the dependence of EVs on charging stations could reduce the importance these considerations. Cars that have solar panels that charge the battery while you drive would reduce the need for charging stations, particularly in sunny regions, although improving solar technologies may make solar cars feasible even at higher latitudes. Similarly, some experiments have tested solar roadways, whereby solar panels in the road collect energy and wirelessly charge EV cars as they drive. While these technologies may not be widespread by 2030, they may contribute to making EVs ubiquitous in the future.

Finally, the composition of consumers in the market itself could change. With the rise of ridesharing companies like Uber and Lyft, and with the advent of self-driving technology, some predict that the future of driving is in fleets of self-driving vehicles. In place of buying personal cars, consumers could simply hail self-driving cars as needed, and ridesharing companies would comprise a rapidly growing segment of car consumers. Investment in electric fleets by ridesharing companies could significantly increase US and even global demand for EVs.

(d) Make rough quantitative estimates, using your answers to part (c) above, as to the relative impact in 2030 of hybrids (both HEVs and PHEVs) on the 2030 new light-duty vehicle sales mix average vehicle fuel consumption, and on the 2030 average vehicle in the in-use LDV fleet fuel consumption. You do not need to write a computer program to do this: use appropriate rough numbers for all the various factors that come into these calculations. Explain your logic clearly.

Based on factors discussed in part c), it is likely that although HEVs may not continue to grow significantly in terms of market share, the market share for PHEVs may grow significantly by 2030. Their ability to use fuel will alleviate concerns about EV range, particularly since it may take many years to expand the network of charging stations, but their increased reliance on electricity will allow consumers to save money on gas. While BEVs will likely increase their market share, they will probably comprise such a small portion of total cars in the LDV fleet by 2030 that we can exclude them from estimates. Therefore, we can roughly predict the relative impact of HEVs and PHEVs on average fuel consumption of new and in-use vehicles by adding the effects of an increased share of PHEVs to current observed trends in fuel efficiency.

Using data from the Bureau of Transportation Statistics, I extrapolated data for passenger car fuel efficiency 2000-2014, since Priuses were introduced to the US in 2000. It showed that fuel efficiency has thus far obeyed a roughly linear trend, with average fuel efficiency of new cars increasing by roughly .6 MPG per year, and fuel efficiency of in-use cars increasing by .15 MPG per year. Fuel efficiency of in-use cars did not fit the linear model as well.

By 2030, new passenger car fuel efficiency (without more PHEVs) would be 45 MPG, and in-use LDV fleet fuel efficiency would be approximately 24 MPG.

According to predictions by BCG consulting (<https://www.bcg.com/d/press/2november2017-electrified-vehicles-take-half-of-global-auto-market-175464)>, EVs will take ~50% of the market share by 2030. To simplify calculations, we predict that the number of hybrids will counterbalance the number of electric vehicles in this new fleet, and we can estimate as if the large majority of this growth is driven by an increase in PHEVs.

PHEV is estimated at 100 MPG based on a survey of current PHEV MPG for cars on the market in the US, although this will likely increase with new technologies.

**New passenger car fuel efficiency in 2030 = 45 MPG \*50% + 100 MPG \*50 % = 72.5 MPG**

In 2015, there were 263 million vehicles in the US, and 17 million new cars were sold, meaning new cars comprised 6.5% of the total in use fleet.

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%Find rough estimates for the proportion of total cars that are electric in  
%2030. We make the simplifying assumptions that we start in year 2015 (the  
%year we have data for) and that we start with 0 EVs. We start with 260  
%million cars in the US, and an EV market share of 1%. By 2030 EV market  
%share will be 50%. We use a car sales rate of 6.5% of the total number of  
%cars for a given year.  
%We do not account for cars removed from circulation.  
  
totalCars = 260000000;  
totalElectricCars = 0;  
  
for t = 1:15  
 percentElectricCarYear = t\*(0.5-0.01)/15;  
 % CarsSoldYear = CarsSoldYear + 0.002\*CarsSoldYear;  
 CarsSoldYear = 0.065\*totalCars;  
 ElectricCarsSoldYear = percentElectricCarYear\*CarsSoldYear;  
 totalCars = totalCars + CarsSoldYear;  
 totalElectricCars = totalElectricCars + ElectricCarsSoldYear;  
end  
  
ElectricRatio = totalElectricCars/totalCars

ElectricRatio =  
  
 0.1828

[Published with MATLAB® R2017b](http://www.mathworks.com/products/matlab)

24 MPG represents the predicted average fuel efficiency for all vehicles in use by 2030, based on extrapolating yearly average fuel efficiency for all vehicles in use 2000-2015. We would expect that in 2030, the remaining 81.7% of the total fleet that are not EVs would obey this prediction for fuel efficiency, while the 18.3% of all vehicles in use by 2030 will be EVs. We estimate that most of these will be PHEVs, with a fuel efficiency of 100 MPG.

**In use vehicle fuel efficiency in 2030 = 100 MPG \* 18.3% + 24 MPG \*81.7% = 37.9 MPG**