

Surperiority of plug in hybrid electric vehicle engineering essay

[Engineering](#)



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Prepared for ECE 5462 Team PaperYuan ChiAutomotive System Engineering
ProgramUniversity of Michigan-DearbornDearborn, USAyuanchi@umich.
eduFeng DangAutomotive System Engineering ProgramUniversity of
Michigan-DearbornDearborn, USAfdang@umich. eduZhi LiAutomotive System
Engineering ProgramUniversity of Michigan-DearbornDearborn,
USAzhilii@umich. eduJianan MaMechanical EngineeringUniversity of
Michigan-DearbornDearborn, USAjiananm@umich. eduKeyi XingAutomotive
System Engineering ProgramUniversity of Michigan-DearbornDearborn,
USAkxing@umich. eduAbstract—The goal of this paper is to find the
advantage of Plug-in Hybrid Electric Vehicle compare to conventional Hybrid
Electric Vehicle. Through the analysis of structure differences, the
comparison of emission to environment, the drivability, the convenience and
the life time, the calculation of efficiency and the performance, collection of
the cost data for P-HEV and HEV, to find out the superiority of Plug-in HEV. In
addition with the forecast of the future energy price, the electricity
generation tendency and the development of the battery technology, to
demonstrate why Plug-in HEV will occupy the market share in the coming
decades. Keywords- P-HEV, HEV, Li-ion Battery, Motor, Engine, Efficiency,
Energy, Safety, Cost, Emission

Introduction

As the world wide population and energy consumption increases rapidly
since later 20 century, the energy supply, especially the fossil fuel supply
increasing rate cannot meet the requirement. At the same, the CO2 emission
is also raise to a very high level as the increasing of fossil fuel usage. The
emission of CO2 is the mean factor of Green House Effect. As traveling with

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automotive takes a great share of fossil fuel consumption and CO₂ emission, increasing the fuel efficiency and looking for new energy sources is getting much more necessary than ever before. Hybrid Electric Vehicle (HEV) and Plug-in Hybrid Electric Vehicle (P-HEV) are technologies used to increase the fuel efficiency of the vehicle by applying an electric powertrain together with conventional gasoline or diesel powertrain. The P-HEV has a larger battery and is also able to get charged the grid-provided electricity. Both of the HEV and the P-HEV has the layouts of series HEV, parallel HEV and complex HEV. All of layouts are able to offer the engine working at its most efficient way. The HEV and the P-HEV can be driven by motor only for a certain range, which has higher efficiency and less emission. The P-HEV can get charged from the grid, so that the energy cost and emission would drop. Since the P-HEV has the all the abilities of a HEV but also can charge its batteries by plugging in grid-provided electricity, to improve its primary advantage, a larger battery package is necessary for P-HEV with the additional power electronics. And to provide more power to start the car, the motor of P-HEV will be larger than conventional HEV, and the larger motor will provide a higher efficiency. As a result, the size of engine should be limited to save the total weight of the vehicle. That means, a smaller engine compare to HEV.

EMISSIONS

Study finds that plug-in hybrid electric vehicles (P-HEV) will reduce net emissions of CO₂ and NO_x, but the net effect on CO₂ emissions depends on the carbon intensity of electrical generation. To find out the advantage of P-HEVs over hybrid electric vehicles (HEVs), the following sources and assumptions are used to calculate the emissions of using a HEV and a P-HEV

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vehicle. An all-electric range of 20 to 60 miles [1] is the typical range now assumed for P-HEVs. Assume that the all-electric range of a P-HEV is 35 miles. It is reported that an average one-way commuting distance is 16 miles [2] for Americans. Assume that the round trip length miles are 35 miles and 60 miles. Data needed for calculating emissions are shown in Table 1.

Table 1 Vehicle Parameters	Parameter	Value	Source
Gasoline	24 GHG/gal	Derived using GREET model version 1. 8d available at [4]	National Average
Electricity	1. 58 GHG/kWh	Derived using GREET model version 1. 8d available at [4]	Conventional Vehicle
HEV	42 mpg	SAFÉ standard	HEV
P-HEV	37 mpg	Based on Chevy Volt specification	P-HEV
P-HEV All-Electric Range	35 mile	Based on Chevy Volt specification	P-HEV
EV	0. 34 kWh/mi	Based on Nissan Leaf specification	EV

weighted average: 2010 sales from spreadsheet " HEV Sales by Model" [5];
MPGs from 2010 Fuel Economy Guide [6]

Hybrid Electric Vehicle Emissions

The average fuel consumption of an HEV is 42 miles per gallon. For a 35-mile trip, it uses about 0. 83 gallon of gasoline and 1. 43 gallons of gasoline for a 60-mile trip. Gasoline contains about 24 pounds of CO₂ equivalent per gallon, resulting in 20 pounds of CO₂ emissions for a 35-mile trip and 34. 29 pounds of CO₂ emissions for a 60-mile trip. HEV results in an average of 0. 5714 pounds of CO₂ emissions per mile.

Plug-In Hybrid Electric Vehicle Emissions

For a 35-mile trip, the vehicle is driven in all-electric range. The electricity used by the vehicle in electric mode is 0. 36 kilowatt-hours per mile. Thus,

12. 6 kilowatt-hours (kWh) will be used for the 35-mile trip. The amount of emissions caused by generating electricity depends on how the electricity was generated. The U. S. national average grid mix is 1. 58 pounds of greenhouse gas per kilowatt-hour of electricity. Thus, a 35-mile trip results in 19. 91 pounds of CO₂ emissions. P-HEV results in an average of 0. 5688 pounds of CO₂ emissions per mile in electric mode. For a 60-mile trip, first 35 miles results in 19. 91 pounds of CO₂ emissions in electric mode. A P-HEV averages 37 miles per gallon and uses about 0. 68 gallon of gasoline for the remaining 25 miles. Gasoline contains about 24 pounds of CO₂ equivalent per gallon, resulting in about 16. 21 pounds of CO₂ emissions. Totally, about 36. 13 pounds of CO₂ emissions of a P-HEV for a 60-mile trip. P-HEV results in an average of 0. 6486 pounds of CO₂ emissions per mile in this portion.

Table 2 Average CO₂ emissions of HEV and P-HEV

	Average CO ₂ emissions □pounds per mile□	Within all-electric range	Beyond all-electric range
HEV	0. 5714	0. 5714	0. 5714
P-HEV	0. 5688	0. 5688	0. 6486

The average CO₂ emissions of HEV and P-HEV for within all-electric range trip and beyond all-electric range trip are shown in Table 2. It is easy to see that when the trip distance is within P-HEVs' all-electric range, P-HEV results in less CO₂ emissions. Based on Chevy Volt specification, the P-HEV all-electric range is 35 miles. In the situation of U. S., the average one-way commuting distance is 16 miles for Americans which means most of Americans drive within the P-HEV all-electric range every weekday. Thus, P-HEV is a better choice to reduce the CO₂ emissions. As mentioned previously, the all-electric range of P-HEVs can reach up to 60 miles which means P-HEV can result less CO₂ emissions than HEV even in longer trip. What's more important is that the emissions of P-HEV for its all-

electric portion are zero if the electricity is generated from a non-polluting, renewable source, such as wind or solar. Emissions of P-HEV will be reduced greater than HEV if biofuels are used to displace fossil fuels to generate electricity. Figure 1 Carbon monoxide emissions (grams/mile) vehicle-to-vehicle comparison [1]Figure 2 Volatile organic compound emissions (grams/mile) vehicle-to-vehicle comparison [1]To find out other advantages of P-HEVs, the carbon monoxide emissions, volatile organic compound emissions and nitrogen oxides emissions of different vehicle technology types are listed in Figure 1, Figure 2 and Figure 3. P-HEV 20 stands for P-HEVs whose all-electric range is 20 miles, while P-HEV 60 stands for P-HEVs whose all-electric range is 60 miles. Both vehicle operation emissions and fuel production emissions are shown in these figures. It can be found in Figure 1 and Figure 2 that P-HEV has much less carbon monoxide emissions and volatile organic compound emissions than HEV no matter how the electricity was generated. Also, the longer the all-electric range is, the less carbon monoxide emissions and volatile organic compound emissions P-HEV has. Figure 3 Nitrogen oxides emissions (grams/mile) vehicle-to-vehicle comparison [1]Different from carbon monoxide emissions and volatile organic compound emissions, nitrogen oxides emissions of P-HEV are affected badly by how electricity was generated. Figure 4 shows that national average amount of electricity generated by coal is 49. 61%. From the data in Figure 3, it can be calculated that P-HEV can reduce the nitrogen oxides emissions by about 26. 5% to 47. 1%, comparing with HEV, depending on the all-electric range of the P-HEV. Figure 4 National averages of electricity sources [7]

efficiency

Hybrid Electric Vehicle Efficiency

The efficiency of pure HEV can be generally defined as the efficiency from the maximum energy of the fuel to the energy of the wheel consumed . It can be presented by the equation For very short period of time, the Power can be considered as constant. Because the HEV power flow is shown in Figure 5. Figure 5 Power flow of HEV The energy firstly flow from the gas tank to the engine with the fuel, then the fuel is combusted in the engine and turned into mechanical power. Then the mechanical power distributed by the Plenty Gear or Coupling mechanism, into the generator and the transmission separately. The generator transfers part of the mechanical power into electric power and stored in the battery or directly used by the motor. The motor output the mechanical power with the electric power. The mechanical power from the engine is also transferred by the transmission. Finally, the mechanical power from the motor and transmission would be get together by the final drive, and then drive the wheels. Because the power flow is distributed into two branches, the efficiency should also include two parts. One part comes from the electronic powertrain and another comes from the mechanical powertrain. And the weight of each part is the weight of the power from the engine. The equation can be presented as, Table 3 Factors in equations

Symbol	Value	Symbol	Value
HEV eff		Generator	
Engine	eff	Motor	Final
drive	Battery	Powertrain	Mech
wt	Transmission	Electric	

Plug-In Hybrid Electric Vehicle Efficiency

Generally speaking, the P-HEV efficiency is defined as the efficiency from energy of the fuel and power plant to the energy of the wheel, and the

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efficiency of power plant should also be considered. It can be presented by the equation
 The power flow of P-HEV is shown in Figure 6. Figure 6 Power flow of P-HEV
 The only difference between the HEV power flow and P-HEV power flow is the battery can also get energy from the power plant. The efficiency should be presented as:

Efficiency Comparing between P-HEV and HEV

Because the P-HEV has a bigger battery, a larger motor can be applied and the motor efficiency is usually higher than engine. In addition, because of equipped with a bigger motor, the engine size can be reduced and the smaller engines are always more efficient than larger engine. At the same time, the motor is much more efficient than engine. The more motor being used the higher efficiency the vehicle would get when the power source of the battery is not engine. On the other hand, as lager motor is able to offer larger regenerative braking force to collect more braking energy, the overall vehicle efficiency would be improved by higher regenerative efficiency.

Based on the equation (1) of HEV efficiency:(1)And the equation (2) of P-HEV efficiency:(2)It can be found that the only difference between HEV and P-HEV is if the efficiency of the power plant needs to be considered. If the efficiency of the power flow, " power plant- battery- final drive" is larger than the efficiency of the power flow " engine- final drive",, it can be concluded that, the P-HEV is more efficient than HEV. Based on common sense, the efficiency of the power plant is always higher than the efficiency of engine. It can also be calculated by the following data shown in Table 4: Table 4 Efficiency Data0. 220. 950. 90. 90. 950. 99The efficiencies of the generator, motor and powertrain is from ECE 5462 homework. The efficiency of engine for a

conventional vehicle is usually around 18%. For a HEV, because it has a CVT mode, the engine efficiency can be assumed as 22%. The overall power plant efficiency is based on the distribution of different types of power plant.

Based on the data of 2012 from Figure 4, Table 5 can be obtained. Table 5

Efficiency	Weight	Data	Coal	N-gas	Rennu	cothert	total
0.350	0.350	0.010					

3200. 3w0. 420. 260. 120. 190. 011 Plug all these data into equations (1) and (2), and assume the weight of the power took by generator and motor are the same. It can be found that , . In conclusion, the P-HEV is more efficient.

Control Strategy

An HEV usually has several different control modes such as, Full EV, Engine Only, Standing Charge, combine mode and regenerative braking. There are many papers and engineers working on the control strategy of HEV, and many control strategy has been worked out for how to choose these control modes in different driving conditions. But the control strategy of HEV can be briefly explained as keeping the battery around a certain target SOC (State Of Charge), and made the engine, electric machine and battery working with their best efficiency and performance. Different control strategy of HEV is just different ways to choose HEV mode to get this target. The P-HEV also has the same control modes as the HEV. But in most of cases, P-HEV often uses more Motor Only mode and less Standing Charge mode. The biggest difference between HEV control strategy and P-HEV control strategy is the target battery SOC is much lower than the HEV and before getting the target SOC, the P-HEV would have a relatively long range of Full EV mode or Blending modes which means blending the motor and engine usage to make both of them working efficiently. For example, here is the control strategy of

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Toyota Prius and Prius Plug-in: Figure 7 SOC control strategy of Toyota Prius and Prius Plug-in [8]The P-HEV battery capacity is always measured by the full-EV model driving range. Assuming the range of real full-EV mode and Blending mode, which means the driving range before the battery get to the target SOC, is 2 times of the maximum full-EV model driving range. The full-EV mode driving range of some P-HEV is 35 mile [3]. The daily use of average driving range of 32 miles/day [2] the P-HEV would be mostly driven in Full EV mode and Blending mode. In fact, the manufacturers should design the P-HEV mostly drive in Full-EV mode or Blending mode. In these modes, vehicle can have better overall fuel efficiency, fuel economy, vehicle performance, and emissions. An all of these benefits can still be developed by optimizing the control strategy. DRIVABILITYFigure 8 shows an ideal propulsion system which has constant torque at low speeds to provide high tractive effort to accelerate vehicle or climb a slope. Also, an ideal propulsion system should have constant power over most speed ranges to avoid jerks as speed increases. Figure 8 Ideal Propulsion SystemHowever, an actual internal combustion engine, as shown in Figure 9, is far from ideal propulsion system. Constant torque and power cannot be obtained in an engine. Thus, the acceleration feel and noise, vibration and harshness (NVH) will be affected by the feature of engine. Figure 9 Typical Internal Combustion Engine MapComparing with internal combustion engine, electric motor, as shown in Figure 10, is much closer to an ideal propulsion system. That is why the drive ability of electric vehicle (EV) is better than internal combustion engine vehicle (ICE). Figure 10 Electric Motor MapP-HEV can be seen as an intermediate technology between EV and HEV. The difference is that electric

motor in P-HEV is been used more frequently which means the effect of P-HEV's propulsion system is closer to the ideal propulsion system than HEV's. Thus, P-HEV has better drive ability than HEV. Since the internal combustion engine is been less used, P-HEV has less noise and vibration than HEV. Besides, P-HEV has smaller engine than HEV, meaning P-HEV has better NVH than HEV. performanceThe main difference between HEV and P-HEV comes from who is in charge. In HEVs, the electric motor assists the internal combustion engine, while in the P-HEVs is the other way around. P-HEV has a larger motor which will provide more power when starting the car which has been shown in the table below, and definitely save more gasoline than conventional HEV and also save more energy in total. And also, needless to say, the latter is more environmentally friendly and one step closer the full-electric vehicle. Table 6 0 to 60 mph acceleration timeFord C-MaxFord FusionSEL HEV9. 4 s8. 5 sEnergi P-HEV8. 4 sLess than 8. 0 sFrom the comparisons of two types of ford vehicles which have both P-HEV and HEV, better performance is demonstrated in P-HEV than that in HEVsafety [9]P/HEVs and EVs are equipped with safety systems that are designed to immediately shut down the high voltage system in the event of a crash impact, airbag deployment, damage to the high voltage cabling, or short circuit. Still, always treat the HV systems as energized for maximum safety. How to manage the dramatically increasing Plug-in Hybrid Electric Vehicles (P-HEVs) and Electric Vehicles (EVs) for the safety of distribution networks is still a vital challenge. Here are some available solutions to solve the P-HEV battery issues: Isolated bidirectional architecture, Charge balance, Dynamic

balance, Advanced control algorithm, Thermal management, Safety monitoring.

Isolated bidirectional architecture

Figure 11 Isolated bidirectional architecture [9] Isolation is added between battery and grid that makes them not influence the other when the battery or the grid has some issues, and it is also capable to feed power back to the grid which will be introduced latter in this paper.

Charge Balance

Figure 12 Charge Balance configuration [9] This architecture starts to bypass when one cell is full and also automatically reduced the charging current when the voltage in the one cell reaches the demand.

Dynamic Balance

Figure 13 Dynamic Balance configuration [9] The lowest row/cell is charged by the DC-DC converter using the pack voltage and the highest cell is discharged to the whole pack so that it can keep each cell's voltage not too high or too low.

Advanced control algorithm

Different advanced control algorithm has been used in the battery control system. Here is an example of model based technology: A distribute network modeled by a Finite State Machine with Variables (FSMwV) method and then controlled by a corresponding safety controller. A supervisory control approach cooperates with smart distribution network technologies to

adaptively change the protection settings to manage the entire distribute network [10].

Thermal Management

Temperature of the pack is monitored during charge, charge balancing, and discharge. Cooling system is enabled when temperature exceeds a preset range. Design the thermal management system to minimize temp gradient coupled electromagnetic, electro-chemical and electro-thermal modeling.

Figure 14 Thermal management architecture [9]

Safety and Health monitoring

Discharge limit is determined by the lowest cell and charge limit is determined by the highest cell. Temperature is another factor in the decision process. SOC, voltage, and temperature, determines available capacity. LIFE CYCLE

Battery life cycle

In some cases, the battery lifetime are determined mainly by temperature, vibration condition, discharge intensity, and depth of discharge. Since the former three will different depends on different region and drive hobbies. Here the influence from depth of charge is discussed. The lifetime of Li-ion batteries decreases as depth-of-discharge (DOD) of each cycle increases. In addition, the storage life of secondary batteries is also limited by chemical reactions that occur between the battery parts and the electrolyte. With deep discharge rate, internal parts may corrode and fail, or the active materials may be slowly converted to inactive forms. It is assumed that the batteries in HEVs and P-HEV last the lifetime of the vehicle and will be

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discharged to a maximum of 80% DOD [11]. As shown in Table 1. Lower discharge rate will have longer discharge cycle for battery. Table 7 Cycle life as a function of depth of discharge [11] For both HEV and PHEV, care should be taken to avoid deep discharging. Since each charge and discharge cycle causes active material to be shed from the plates. Figure 15 Battery performance requirement vs. vehicle application [12] From Figure 15, compare to HEV, compare to HEV, although the deep discharge for PHEV battery is much higher than HEV, which considered as one of the most influence point for battery. But with suitable battery management strategy, it could reduce the deep discharge condition for PHEV so that the battery life will increase. After the battery management is applied, the total battery service life could reach almost the same amount. In addition, although the deep discharge requirement will have a negative influence for the battery life, the usage of the PHEV battery is not always keep at the peak power range to exhaust the battery.

Engine lifetime

Large portion of energy offered by battery means, less fuel burned in the engine for P-HEV. The energy source for P-HEV is based on the electricity charged from home or public charge station. However, for HEV, the mean energy source is from the gas burned in the engine. Under this circumstance, as a final energy supplier, engine in HEV will definitely has less service time. In addition, as for HEV, the engine not only requires driving the vehicle when battery runs out of charge, but also keeps charging the battery at the same time. All driving mode in HEV requires engine to participate into offering power, direct-drive or both conditions for the vehicle. While for P-HEV, engine

only working when battery run out of charge condition, or high performance condition. The working load for HEV engine is much higher than P-HEV. Thus, longer engine service life in P-HEV than HEV.

Drivetrain components life time

Compare to HEV, P-HEV has less coupling between engine and battery or engine with vehicle final drive. Since most electricity is from home charging or charge station, the engine charge mode is less happen in P-HEV than HEV. Therefore less coupling process will happened between the engine and battery, which will reduce the wearing of the coupling component such as clutch or plenary gears. Besides that, with larger battery capacity, P-HEV motor could run for longer time by using the battery energy source so that engine has less chance to kick in to drive the vehicle directly. The clutch and plenary gear system in P-HEV transmission will have longer serving lifetime than HEV. In addition, during the regeneration breaking process, because of the higher power generator capacity for the P-HEV, it could offer higher power breaking torque during breaking process. In this case, less breaking torque is required from the breaking disk. Thus, there will be less tearing on the break disk and pad to increase the lifetime of the physical breaking components. CONVENIENCE

Charging method to improve P-HEV—charging station

Although, compare to the HEV charging takes longer time than refuel the vehicle. But most of the charge time is happened at night, which is a great way to make full use of the time in our daily life. Since driver do not need to take the time, which they should work or rest at their day time, to drive all

the way to the gas station and refill the gas, it is much easier and convenience to charge their vehicle at home. What they really need to do is spend 30 seconds every day when they arrive home to plug in charge their vehicles. And go to sleep, the next the vehicle is full of charge and ready to go. Furthermore, for some special situation, if the vehicle requires charge at the nearest place and the home is far away. There are quick public charge station offer, which will charge the battery to 80% within 30 min. Quick chargingFigure 16 Quick charge stations [13]Public quick charge station using Direct Current fast charging, which as 600 V, enables charging along heavy traffic corridors and public charge station. It only takes about 30 minutes to charge the battery to 80% SOC. This fast charge cycle could provide enough energy for P-HEV drive at least 100 miles. Convenience charge at homeDue to low cost and convince, usually the home used charge station is a 240 V AC plug and takes about 3 to 8 hours to fully charge the vehicle depend on different battery capacity. The plugin station set up cost less time than gas station. What's more, night time is fully used and day time is saved for the driver.

Less chance to go to gas station compare to HEV

Compare to HEV, mostly P-HEV is charging at home, there is less chance to go to gas station to refill the gas when using the vehicle. Home is like a gas station and the vehicle could refill the " gas" every day at home. C

Manufacturing cost

The extra manufacturing cost of P-HEV cost to conventional HEV can be divided into three parts, the cost on vehicle, the assembly cost, the cost of

electric system upgrade at home. For extra assembly cost, it is generated by importing new assemble tools and redesigning new assembly line. The initial cost will be very high but it will decrease to a very low level with the production volume increase. So it can be ignored in comparison. Since the electricity used to power P-HEV will be supplied from the nation's power grid, the load of the grid is varied with the time, to satisfy the requirement of the P-HEV, the electric system is necessary to charge the vehicle at home. The update price will be about \$1, 000 [14]. The cost of battery package is the key issue compared with motor and engine cost for P-HEV. Quote cost for the battery pack with battery nameplate capacity. Use Toyota Prius-HEV as an example, the battery used for Prius is Ni-MH, which has a price of \$1200/kWh [15], and the battery capacity is about 2kWh. But since Ni-MH battery cannot be used for P-HEV because of the limit of capacity, P-HEV use Li-ion battery with has required performance for P-HEV. Paradoxically, the Li-ion battery is still under development, even though the price is equal to Ni-MH battery at the present, about \$1200/kWh [16], after times the required capacity, for example, the P-HEV-40 need the capacity of 8kWh [17], the final price for the battery would be \$10000, that is not an acceptable price for ordinary families while compare to HEV: Prius, has a much affordable price of whole battery package, \$2500. But with the battery technology developing, the price for Li-ion battery will fall down, as the National Academies report projected, the future cost will reduce to \$400-560/kWh in 2020, and \$360-500/kWh in 2030. Some other laboratories even expect the lower price, \$420/kWh in 2015 (McKinsey Report), \$168-280/kWh in 2014(Department of Energy) [16]. With the expect cost of NA report, the battery cost of P-HEV-40

in 2020 will be become \$4000, this price would be affordable for ordinary families. In addition, compare to HEV, the other extra cost would be \$663 for charging plug, \$150 on smaller engine, \$250 on larger motor [18]. So in current technical condition, the manufacturing cost of P-HEV will be \$8500 higher than HEV in total without considering other features like interior trim.

Gasoline and residential electricity price

The purchase of P-HEV will get a long term benefit on oil since the P-HEV will mainly drive on motor-only mode for everyday use. For instance, P-HEV-40, means has an all-electric range of 40mile, which is the average distance from home to work for Americans. That means, they can drive the P-HEV on daytime and charge at night to pay for the gasoline of 40miles only. So to compare the cost of P-HEV and HEV, the price of gasoline and electricity should be considered. Figure 17 Regular gas price of last two years [19]From Figure 17, the regular gas price was about 1. 5\$/Gallon on April 8 2003, and finally it increased to about 3. 7\$/Gallon, According to the trend of the price, the future price can be forecast that it will keep increasing, and increase to about 5\$/Gallon by 2020. Figure 18 Electricity price and the tendency [20]The residential electricity price in 2013 is 11. 79 ¢/kWh, and the forecast of electricity price is 12. 3 ¢/kWh because of the more application of nuclear, solar and wind energy.

Money saved after purchase

From the statistical data of National Academies, the annual petroleum and electricity consumption are shown in Table 20 below. Table 8 Energy use [21]Petroleum(gals)Electricity(kWh)HEV4000P-HEV10340800P-

HEV402102300 With the data below, compute the annual cost on oil and electricity, With the price of 2013, the annual cost of P-HEV-40 will be \$1048.17 while the annual cost of HEV is \$1480. By using the P-HEV, \$431.83 will be saved every year. Consider the extra manufacturing cost \$8500 for P-HEV, 20 years after purchase, these money will be returned. But after considering the change of price from year to year according to the prediction, as the Figure 19 shown, only 12 years is needed, after 12 years, P-HEV will save more money in totally. The price increase of energy is conducive to P-HEV. Figure 19 Annual operating cost for HEV and P-HEV-40 Moreover, as mentioned before, after the Li-ion battery price go down to 500\$/kWh, the extra manufacturing cost will reduce to \$2900, it is evident that 5 years is enough for saving \$2900.

Charging time

The definition of off-peak is typically evening and night hours - after the business day - and on weekends, when wireless networks experience less demand. Service providers often offer lower rates to calls placed and received during off-peak hours. The figure above shows the on-peak hour and off-peak hour. Figure 20 On Peak and off peak Hours Distribution Also the P-HEV electricity usage plot is shown in Figure 21. Table 9 Electricity Price From the Figure 21, it is clearly to see that nearly all the P-HEVs are charged from 8: 00pm to 6: 00am, which is in the off peak range. The approximate price of the electricity in different places and different times is shown in Table 9. Figure 21 P-HEV Using Off-peak Hour's Electricity [23] From Table 9, it can be found that the P-HEV are using the cheapest electricity.

Future of P- HEV Nowadays, the main obstacle of Plug-in HEV is soaring price,

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made it hard to popularize and replace the conventional vehicles, despite the money saved after purchase can counteract the selling price with the long term use. But because P-HEV can achieve almost 100 mpg and emit almost no greenhouse gases on tailpipe, the purchasing of P-HEV is greatly encouraged by government, the tax incentives and installment plan with low interest rates will be provide to the customer who intent to buy P-HEV. And with the promotion of P-HEV, the electric grid will be updated by government, it will be unnecessary for customers to update their electric system by themselves, the money will be saved. With the development of battery technology, the large capacity Li-ion will become much cheaper with less weight. It will allow the vehicle to have larger all-electric range. And the lower price will solve the main problem of P-HEV to compete with HEV. The major CO₂ emission caused P-HEV is the electrical generation, at the grid-average carbon intensity, emission reductions of P-HEV compare to HEV are very small [16], but with the more efficient utilization of solar and wind energy, wider use of nuclear energy, the large scale mining of natural gas, reductions will grow. The use of natural gas and renewable sources will reduce 15. 3% carbon emission and 47% oil consumption for P-HEV relative to HEV [22]. And carbon emission will increase to 20% when using nuclear. In additional, near zero marginal emissions in electric mode of P-HEV will beat HEV in point source emissions (e. g. electricity sector). Next, the exhaustion of nonrenewable resources will happen after several decades, the electricity generation will major rely on nuclear energy. And the pure EV will replace the conventional vehicle for the lack of petroleum. The technology developed for P-HEV will benefit EV a lot, especially the large capacity battery and

quick-charge technology. And the P-HEV can be easily remade to EV by utilizing a larger battery. Due to all these factors, the Plug-in HEV has a better future compare to HEV. And the sales volume of P-HEV will increase to several times than today. P-HEVs and fully electric cars may allow for more efficient use of existing electric production capacity, much of which sits idle as operating reserve most of the time. This assumes that vehicles are charged primarily during off peak periods (i. e., at night), or equipped with technology to shut off charging during periods of peak demand. Another advantage of a plug-in vehicle is their potential ability to load balance or help the grid during peak loads. This is accomplished with vehicle-to-grid technology. By using excess battery capacity to send power back into the grid and then recharge during off peak times using cheaper power, such vehicles are actually advantageous to utilities as well as their owners. Even if such vehicles just led to an increase in the use of night time electricity they would even out electricity demand which is typically higher in the day time, and provide a greater return on capital for electricity infrastructure [23].

CONCLUSIONAs it is mentioned above, the comparison and result between PHEV and HEV are listed below: Emission—PHEV has lower CO₂ emission when all-electric drive range is lower than 35 miles, which fit for most cases in U. S. driving condition. And PHEV has less carbon monoxide and volatile organic compound emissions compare to HEV. Efficiency—PHEV equipped with larger size and higher power electric motor which has higher efficiency than engine. Besides that, smaller engine in the PHEV will have a better efficiency than the large size engine installed in HEV. Both the motor and engine efficiency in PHEV are higher than HEV. Control Strategy—in most

cases, PHEV maintains motor only mode and less chance for standing charge mode compare to HEV. Because it is easier to control motor only mode rather than standing charge mode, which require more complex control input and data processing, it is easier and less cost for PHEV to design and implement the control board on the vehicle. Cost—although PHEV has a little higher cost in battery package and require extra cost for electric system installed at home, it is estimated that, with the battery development in the future 10 to 20 year, the battery price will low down to an lower price for both PHEV and HEV, larger size battery will cost less or keep even price with HEV small battery. Furthermore, considered the gasoline cost versus the electric cost, the gasoline cost will definitely higher from now to the future. Therefore, the cost for PHEV will less than HEV from a future point of view. Performance—PHEV has better acceleration at 0~60 mph compare to HEV. Lifetime—it is no doubt that PHEV has longer engine and drivetrain component lifetime compare to HEV. As for battery, although except for temperature vibration condition for battery, it is the depth of discharge influence the battery lifetime a lot, but with right battery management and PHEV battery usage character the battery lifetime will not quite different with HEV. Convenience—Less chance to visit gas station is time saving. And convenience home charge station and public quick charge station will satisfy most customer needs.