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The Differences and Similarities between Plug-in Hybrid EVs and Battery EVs

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Abstract

This paper compares and contrasts the characteristics of plug-in hybrid EVs (PHEVs) and Battery EVs. As evident in recent debates, policy papers, and media articles, the differences between PHEVs and BEVs are not well understood. Many of the advantages of PHEVs are being overlooked, and the media focus and policy debates are shifting towards solving the limitations of BEVs.

This paper examines the differences between PHEVs and full-function, full-size BEVs in the areas of chargers and charging infrastructure, costs, benefits, performance, vehicle sizes, features, market niches, customer experience, utility impacts, factors impeding commercialization, and market potential. Many of the differences are from a North American perspective, but most also apply to Europe, Asia and other continents. The 13 similarities between the technologies are also discussed, including those with smaller-size or niche BEVs. The paper details 28 advantages and 12 disadvantages of PHEVs compared to full-function, full-size BEVs and concludes that PHEVs have significant advantages from the consumer, automaker and utility points of view. PHEVs will compete in the same marketplace as BEVs and because of their advantages will present challenges to BEVs. Yet there are many synergies where each technology can help the commercialization of the other or where they have common problems to overcome. Finally, several other commercialization issues are examined including the debate between level 3 charging, level 2 plus charging, level 2 charging and battery exchange infrastructure to serve the BEV market.

Keywords: PHEV (Plug-in Hybrid electric vehicle), BEV (battery electric vehicle), infrastructure, marketing, promotion

1.0 Introduction

The differences in performance and charging between PHEVs and BEVs are often being overlooked in recent debates at conferences and in policy papers and media articles. As a result, much of the focus in the media and policy debates has shifted to solving the limitations of BEVs, which is partially a result of the many recent announcements by automakers to launch BEV product or display their BEV concept cars.

On one hand, PHEVs are much easier to commercialize (gain significant market share) but much more difficult for an automaker to develop and build. On the other hand, BEVs are more difficult to commercialize but much easier for an automaker to develop and build. Yet both PHEVs and BEVs will be competing in the same market.

Much of debate in the press has shifted to the challenges and costs of commercializing BEVs, because of their many limitations. For decades, full-size BEVs have been acknowledged to have historically market limiting features such as a lack of long range per charge, a lack of recharging infrastructure for long trips, a high cost for a large battery, etc. The debates of the 1990s have returned with proposals to assist the commercialization of full-size BEVs with either public-access networks of 1) Level 3 fast charging, 2) battery exchange stations, 3) networks of Level 2 or Level 2 Plus traditional charging, or 4) all of the above. There is a fifth option: PHEVs. Additionally, there are regional variations because the market place is different in North America, Europe, Asia, emerging nations, islands, etc., and consumer choice in these areas could drive regional solutions.

This paper will carefully and methodically examine the many differences of PHEVs and BEVs in the areas of charging infrastructure, cost, benefits, performance, vehicle sizes, features, market/customer niches, customer experience, utility impacts, factors impeding commercialization, and market potential.

For purposes of this paper, PHEVs are defined as the broad family of vehicles that can use two or more types of fuel: electricity from an external source such as the electric grid and at least one liquid or gaseous fuel. This includes PHEVs in all sizes and weight classes that can operate in all-electric mode at freeway speeds (either parallel or series designs), PHEVs that blend their electric and liquid fuel use (even at low speeds), and anything in-between. For purposes of this paper, extended range electric vehicles (EREVs) are considered part of the PHEV family, as both parallel and series designs of PHEVs are capable of high-speed travel in all-electric mode.

Also for purposes of this paper, BEVs are defined broadly as the family of vehicles that use only electricity from an external source to supply a battery and electric motor(s) on the vehicle. This includes BEVs in all sizes and weight classes, from buses to scooters. However, this paper often specifies two types of BEVs 1) full-function, full-size, freeway-capable, crash tested light-duty BEVs in typical car and light truck sales classes and 2) niche BEVs with small battery packs in 2-, 3- and 4-wheel vehicles. Finally, this paper uses the term HEV to mean traditional hybrid electric vehicles that do not plug-in.

2.0 Differences

Alternative fuel vehicles have been very difficult to commercialize, as evidenced by the last 30 years of effort worldwide where, despite a few successes, no alternative fuel vehicle types have been able to reach even one percent market share. One of the biggest issues is the lack of an existing infrastructure for alternative fuels. Fuels such as methanol, propane, natural gas, ethanol, biodiesel and hydrogen have all struggled with the classic business case problem: which comes first, the chicken or the egg, the vehicles or the infrastructure?

This problem can be solved in geographically-concentrated areas such as an island or city, especially if government is willing to subsidize or jumpstart the installation of alternative fuel infrastructure. PHEVs, however, can bypass the issue altogether because they can use existing electricity infrastructure in a wide variety of cases – at homes, businesses and some multi-family dwellings. In addition, niche market BEVs can also bypass the infrastructure issue in many markets. For example, all-electric scooters, motorcycles, small three-wheel EVs, neighborhood EVs (NEVs), city EVs, and small commuter EVs can be recharged overnight in North America using a 1.4 kW, 120 V electric service, and can find a market without public-access charging.

The expectation a few years ago was that most automakers would start with PHEVs and public charging infrastructure would not be needed, or that public infrastructure would develop slowly as BEVs were produced as a niche product. [1] However that expectation appears to be wrong.

The recent announcements of BEV product launches by large manufacturers such as Nissan, Ford, Mitsubishi, and Chrysler, and by start-ups such as Tesla, Miles, Think and many others are causing a new push for public access charging infrastructure mainly to address BEV's need for charging in order to make long trips. In fact BEVs are coming faster than generally expected. [1]

It is not clear why BEVs are coming faster in the last few years, but likely reasons include the California Air Resources Board's Zero-Emission Vehicle (ZEV) program requirements added in 2007, pressure from other automakers to produce a plug-in vehicle, high gas prices in 2008, and increased awareness of the need to solve climate change and energy security problems. In addition, automakers generally need to have the ability to produce an HEV before they produce a PHEV, but BEVs are simpler for an automaker to produce than either HEVs or PHEVs. For a surprising number of automakers and for all the start-ups, BEVs are the quickest way to get into the plug-in market. And finally consumer interest in BEVs is likely a reason for renewed automaker interest, as automakers clearly do extensive, proprietary market research.

Automakers that do not make BEVs, such as GM, are also advocating for public infrastructure to support PHEVs and EREVs. And PHEVs are coming with much larger battery packs than was expected several years ago. Case in point: the GM Volt and the Fisker Karma. And the perception from some is these vehicles need faster Level 2 charging.

Another lesson learned from the 1990s is that the battery costs – especially in the early years – affect the market potential of PHEVs and BEVs. A major solution to high battery costs is for the vehicle manufacturer to reduce costs to the consumer by making the battery as small as possible (less than 15 kWh is good; less than 10 or 5 kWh is even better). This leads to the PHEV solution or to niche market BEVs such as NEVs and city EVs both of which don't need public access charging infrastructure. The table 1 shows the overnight charging times for PHEVs capable of a 20 mile all-electric range using a 15 amp, 120 volt circuit found in the United States.

Also note (see Table 1) that PHEVs, even when produced in very large platforms, can have small or very small packs, as low as 5 kWh. [2] Full-function BEVs, meanwhile, use battery packs that are 25 – 35 kWh unless they are small BEVs with some limitations on functionality (e.g. city EVs, NEVs, or 2 and 3-wheel EVs). Because of this difference in battery pack size, it is easier for an automaker to place the battery on the car or truck with PHEVs that are mid-size sedans or larger, compared to full-function BEVs as shown by Table 1.

Table 1

PHEV 20 Vehicle	Pack Size	Charger Circuit	Charging Time 20% SOC
Compact Sedan	5.1 kWh	120 VAC / 15 A	3.9 – 5.4 hrs
Mid-size Sedan	5.9 kWh	120 VAC / 15 A	4.4 – 5.9 hrs
Mid-size SUV	7.7 kWh	120 VAC / 15 A	5.4 – 7.1 hrs
Full-size SUV	9.3 kWh	120 VAC / 15 A	6.3 – 8.2 hrs

Another side to the debate is not PHEV versus BEV but rather which infrastructure is needed. One of the big advantages of PHEVs is the existing Level 1 infrastructure at home. Most continents already have Level 2 infrastructure at home, and in North America most of the single family and some of the condominiums do. This is a large advantage for BEV commercialization and a "nice-to-have" for PHEVs.

Level 2 infrastructure at homes with some public level 2 charging seemed to be working in the 1990s market launch of BEVs by providing a psychological solution to range anxiety and for the occasional medium-distance trip (e.g. Los Angeles to San Francisco). Today, many are calling for new infrastructure solutions – battery exchange, Level 3 fast charging, and Level 2 plus fast charging. Each of these adds significant cost to a basic Level 1/2 infrastructure plan. But because data shows that 80 percent of people drive less than 40 miles a day and experience shows that range anxiety is a psychological concern that generally fades within a few weeks of actual use of a BEV, the incremental benefit for this extra cost is questionable.

These new three infrastructure solutions will have to compete with the level 2 solution and with each other. This will be a challenge, and it is unlikely all will succeed in the marketplace. Plug-in hybrids also will compete with these three new solutions as PHEVs are very good at long distance trips.

Table 2 explains the 28 advantages of PHEVs compared to full-function BEVs. And the advantages that require more explanation are detailed in the next few paragraphs. There are some caveats to Table 2. As the battery pack on a PHEV gets larger (e.g. a PHEV with 60 mile all-electric range) some of the advantages and disadvantages change.

Because of its greater functionality, the market potential for the PHEV is larger. For example, the Green Car Institute study found the BEV market potential to be about 12 – 18 percent. [3] Other studies have found similar results. [4] [5] While the consensus HEV Working Group study that involved EPRI, automakers, agencies, utilities, national labs and leading consultants found the market potential for PHEVs to be over 50% and potentially close to 70% depending on gas prices and number of models offered in the mid-size sedan market segments. [6] This market potential was slightly less for other market segments. [7] In addition more recent simple surveys have found that PHEV benefits are highly compelling. [8] This same study by Synovate Motorreseach for US Department of Energy found that after the consumer was educated the interest in PHEVs jumped from 33 percent to 64 percent, by far the most of any fuel in the survey. On the other hand, after the consumer was educated the interest in BEVs jumped only from 33 percent to 35 percent. [8]

All-electric vehicles can have a dramatic impact on the summer and winter peak electricity generation loads and the distribution system of utilities if charging is occurs without any utility influence. This is because charging during weekdays has been shown in the 1990s to occur after work and because the charging rate at 6.6 kW per hour (or more) is a very large residential load. However, PHEVs and small BEVs charge at 1.4 kW per hour (in North America) and thus have about one fifth the impact during the early evening hours when both winter and summer peaks occur for many utilities (except those in far northern climates). Utilities through rates, incentives or other load control programs are expecting to be able to shift the both the PHEV and BEV loads to non-peak periods as was done successfully in the 1990s. This will exert a downward pressure on rates by using the existing generating and distribution facilities more hours per year.

The slower 1.4 kW per hour charging rate in North America also means less impact on utility distribution systems (e.g. less need for transformer upgrades). Tens of millions of customers already have an existing electric panel that can handle the PHEV, and this means less hassle to the consumer (no electricians, building inspectors, and utility service planners). The extent of this benefit is not clear. Studies show that 40 to 85% have relatively each access to a plug for a PHEV in

the U.S. [6] Detailed analysis has not been published.
From an automotive perspective, PHEVs in some cases do not add the mass penalty that is found with BEVs. [6] Also, the so-called "blended mode" design can allow the automaker to rely more on the engine as the vehicle ages. This allows the battery to be more fully used. Perhaps the battery end-of-life can be as low as 50 percent of original energy using the "blended" strategy instead of the standard estimate of 80 percent of original energy. This also has not yet been studied.

As the lifetime of batteries continues to improve (cycles increase), a peculiar problem emerges: too much battery life for longer-range BEVs, but not for PHEVs. In other words, in many climates, the vehicle will rust before the battery dies. Testing is showing that 4000 deep discharge cycles (100% to 20% state-of- charge) in today's lithium ion technology is not unreasonable. [9] If a BEV were designed with a 300 mile range (almost every automaker said this was needed in the 1990s), then at 4000 deep discharge battery cycles, this EV has a 1,200,000 mile lifetime range (based on miles, not calendar life). Some types of lithium ion that are underdevelopment appear to be candidates for even longer cycle life in deep discharge. [10] Imagine 10,000 cycles in a 200 or 300 mile per charge EV. This issue is more pronounced in the many countries where average annual miles is typically half that of the U.S. Clearly, the consumer is paying for range that they will likely not need with a BEV.

However, for a PHEV the battery pack lifetime is much less because the pack is much smaller, and this is true of niche application BEVs with small packs too. For example, a PHEV with 10 mile or 40 mile all electric range and 4000 deep discharge cycles can go 40,000 and 160,000 lifetime miles from grid electricity, as well as additional miles in HEV mode powered by the spark-ignited engine. Because of the recent improvements in cycle life of batteries, PHEVs and small-size or lower-range BEVs should have an advantage over full-size, full-function BEVs by having a less expensive, more appropriately-sized battery that will last the typical design life of a car or truck. This is particularly true of PHEVs with 30 to 40 mile ranges in blended or all electric mode. But for PHEVs with less all electric range, designing the vehicle to last 150,000 miles or more on a single battery pack will be an engineering challenge. It will likely require a strategy that extracts from the battery most of the miles from the gasoline-powered hybrid engine system rather than the battery.

This expected greater lifetime of the battery for BEVs while adding to the up-front cost also offers financial advantages during operation or at the end of life. The battery can be used in a secondary life (after the end of the life of the car) or used for either vehicle to home, vehicle to commercial building, or vehicle to grid. In addition, BEVs are more likely to have faster charging levels than PHEVs (e.g. 6.6 or 10 or even 15 kW) because 6.6 kW charging (level 2) is a necessity for full-size BEVs to charge overnight but not for PHEVs (e.g. North America). In addition, these higher levels are needed for vehicle-to-grid because it depends on contracts with grid operators (called Independent System Operators in the United States), and a typical minimum contract is for 1 MW which requires aggregating many BEVs or PHEVs. For example, at 10 kW charge rate, 100 vehicles are required to be aggregated into a contract, at 6.6 kW about 150 vehicles are required, and at 1.4 kW about 700 vehicles are required.

Table 3 shows the 12 disadvantages of PHEVs compared to full-function BEVs. The disadvantages that require more explanation are detailed in the next few paragraphs.

There is no universally-agreed upon way to explain the fuel economy of PHEVs, and as a result, this challenge becomes a barrier. [6] Because PHEVs are dual fuel vehicles they have two very different metrics for the miles traveled on gasoline and grid electricity. There are various ways to combine these metrics into a single metric, which adds another challenge. In addition, PHEV fuel economy is very sensitive to trip length and for blended mode hybrids, vehicle speed. The same driver in the same mid-size car can have fuel economy (gasoline use only) of anywhere between 50 miles per gallon (mpg) and 120 mpg. The fuel economy is also influenced by how often the driver plugs in, and whether the fuel economy is measured over a day, a month or a year. While some of these issues are true of BEVs and conventional vehicles, it is definitely more pronounced with PHEVs. [6]

Table 2

Summary of the advantages of PHEVs (compared to full-function BEVs) from the viewpoint of consumers, automakers and utilities	
PHEVs	
1	Can use battery packs that are 2 to 5 times smaller than full function BEVs [6] [7]
2	As result of the smaller packs, have a much lower cost premium than full-function BEVs even though they have an engine that BEVs do not. [6] [7]
3	Can be driven home from the car dealership. In other words they don't have to wait for an electrical upgrade at the house, apartment, condo or business fleet
4	Are not impacted by power outages
5	Are not impacted by the driver forgetting to plug in or by vandalism of the cord, etc.
6	Address range anxiety issues (The biggest limiting factor for BEVs is human psychology as BEVs can be very capable vehicles).
7	Serve well as large vehicles (vans, pick-ups, sport utility vehicles) in addition to mid-size and small vehicles. (BEVs are most functional and cost-effective as small cars such as neighborhood EVs, city EVs, and compact commuter electric cars) [7] [11]
8	Are wide-application consumer vehicles. (BEVs often are placed in niches such as islands, low-range fleets, etc.) [4]
9	Don't need to wait for or require a public infrastructure to be built (chicken and egg business case problem)
10	In North America, typically don't need to pay for the expense of installing a 3.3, 6.6 or 10 kW charging infrastructure at home). This is an optional for homes but not fleets.
11	In North America, reduce impact on utility systems because they charge slowly (while BEVs charging at 6.6 kW which will impact utility peak load more and cause more utility transformer upgrades than PHEVs using 1.4 kW charging infrastructure). Slow charging at 1.4 kW per hour is also true of NEVs and city EVs. [2]
12	Owners typically don't need to deal with city building inspectors and utility planners (i.e., don't need an electric panel upgrade because they can charge at 1.4 kW – similar to a hair dryer or portable electric heater) This process can take months.
13	Can weigh the same as their gasoline car counterparts (e.g. this is possible with some well-designed PHEVs with 10-20 mile range in all-electric mode) [6]
14	Can use their battery down to low energy levels at end of life – perhaps as low as 50%. Blended mode operation opens new possibilities because the vehicle relies more on the engine as it ages, but the driver can't tell if it is engineered well.
15	Are not only for low mileage drivers (per day) or in-town driving
16	Are not only for multi-car households (where BEVs typically need a back-up 2nd car powered by a liquid fuel to provide mobility for long trips)
17	Have small packs that are relatively easy to package or place inside the vehicle. (E.g. a small 5 kWh pack is relatively easy to package in various sizes of vehicles). However, packaging can be an issue for smaller PHEVs with larger packs. [6] [7]
18	Carry the appropriate amount of battery, while a BEV with 100 or 150 mile range has too much battery from a lifetime perspective. (E.g. a BEV with 150 mile range and Li-ion with 4000 deep discharge cycles over its battery life will last about 600,000 miles not counting calendar life.)
19	Are not impacted at all by aggressive and high speed driving (and associated loss of range) because much of the acceleration power is provided by the engine in most designs. [6] [12]
20	Can more easily have the same sustained performance (acceleration, passing, and grade climbing) as its gasoline vehicle counterpart. (BEVs – except sports cars – typically are either thermally limited or limited by battery energy.) [6] [12]

Continued - Summary of the advantages of PHEVs (compared to full-function BEVs) from the viewpoint of consumers, automakers and utilities	
PHEVs	
21	Are easier and faster to sell for sales staff, dealerships, and automakers because of the lack of range limitations and because they typically don't have to wait for infrastructure to be built or for electrical panels to be upgraded.
22	Are a good option for condo and apartment dwellers that do not have a regular parking spot for recharging (e.g. won't be stranded if a public charging spot is not available).
23	Have a substantially larger market potential than BEVs. [6] [7] [13]
24	Should be a challenge for BEVs because BEVs will have to be marketed in the same market with PHEVs (unless the range anxiety and cost issues with BEVs are addressed in other ways).
25	Offer automakers many niches to exploit because there are so many types of PHEVs. (E.g. different ranges, vehicle platforms, engine turn-on speeds, control systems, etc.). This should enable many competitors and marketing strategies.
26	Offer greater fuel diversity (while electricity for BEVs can be made from over 10 different sources, PHEVs can be dual fuel or tri-fuel vehicles using several types of liquid fuels.
27	Can offer more consumer features (e.g. ability to run "appliances" with the engine off for use with a mobile office, camping, vending, or tailgate parties, or a more useful emergency back-up system with engine off capabilities). [6]
28	Offer automakers more options to solve design issues because of the engine (e.g. trailer towing, cabin heating, battery heating and cooling, battery reserve, etc.) [6]

Table 3

Summary of the Disadvantages of PHEVs (compared to full-function BEVs)	
PHEVs:	
1	Are technologically complex [12]
2	Difficult for many automakers (especially if they don't have an HEV in their product mix)
3	Are difficult for start-ups or new market entrants
4	Are arguably higher emitting in terms of greenhouse gases and air pollutants (but this assumes BEV owners will drive as far as PHEV owners per year)
5	Are a wide family of vehicles, which makes them challenging to explain compared to the simplicity of a BEV (e.g. series versus parallel designs, various modes of operation, various control strategies, various possible engine turn-on speeds, EREVs vs other designs etc.) [6] [12]
6	Use a battery with a higher power to energy ratio which generally costs more ($/kWh) than a BEV battery but less than an HEV battery. [6]
7	Are difficult to explain in terms of fuel economy (e.g. many ways to explain the fuel economy of PHEVs). PHEVs can have many different fuel economy measurements on the same car and same driver (E.g daily, monthy, or yearly). While this is true of BEVs and conventional vehicles it is more pronounced with PHEVs. [6] [11]
8	Have the added costs of the engine and related components (e.g. for an incremental cost similar to a PHEV's, a BEV can have a larger battery pack because of this). [6] [12] [14]
9	Need to overcome current market confusion (PHEVs have a similar public awareness currently to BEVs, but consumer interest level in PHEVs is much higher than BEVs once they are educated.) Other terms such as plug-in vehicle and EREV are also adding to the confusion [8]
10	Potentially need more maintenance than a BEV. [11]
11	Could be unnecessary on small islands where the annual or daily miles are not great. Why pay more for the long range from the engine, when it is not needed?
12	Should have less financial value for recycling or re-use of the battery (See text and PHEV advantage 18 for more detail.)

Table 4

Summary of the Similarities of PHEVs and BEVs	
	Both PHEV and BEVs
1	Share a common problem – high up-front costs but low fuel and maintenance costs
2	Share many common parts (motors, controllers, etc, and, depending on design, the battery)
3	Potentially have lower life cycle costs than conventional counterparts depending on gasoline prices, the vehicle design, the vehicle platform and assuming mass production [11] [12] [14]
4	Can take advantage of the mass production of components that are shared with HEVs or are shared with each other
5	Can share a public charging infrastructure (PHEVs drivers can use Level 2 public infrastructure, but they don't *need* it except for those PHEV drivers without garages).
6	Share a common problem – their environmental benefit changes as the vehicle moves to different areas with different electricity mixes.
7	Can use the same utility / source of electricity
8	Can complement each other in a multi-car household (providing both long-range and short-range travel without need for a large public charging infrastructure)
9	Can assist in the commercialization and development of each other. For example, they share many common benefits, consumer features, research needs, and supply / disposal chain issues.
10	Don't have to use Level 3 fast charging or Level 2 plus charging infrastructure (but a case can be made for BEVs to use them)
11	Don't have to use battery exchange systems (but a case can be made for BEVs to use them)
12	Can use the same battery (although this is not an optimized design) [6]
13	Can have excellent torque (depending on the design) and make good sports cars

Another advantage of BEVs compared to PHEVs include engine/component simplicity, which will potentially result in less maintenance. BEVs (compared to PHEVs) also work very well in space constrained applications such as bicycles, scooters, motorcycles, and similar vehicles.

PHEVs could be unnecessary on small islands where the annual or daily miles traveled are not great. Why pay more for the long range from the engine, when it is not needed? BEVs have an advantage of never having to go to a gas station, and this is important to a few consumers who strongly dislike the fumes and the security issues with gasoline stations in some areas. [6]

4.0 Similarities

Table 4 shows the 13 similarities or synergies between PHEVs and BEVs. These generally are obvious and don't require additional explanation.

5.0 Other issues

Several issues are not so clear cut. They are explored in this section.

Securing reductions in global warming gases, air pollutants, energy use, and petroleum use is directly proportional to vehicle miles traveled using an off-board source of electricity. It is possible for a PHEV to have more annual miles from off-board electricity than a BEV, because there is less "range-anxiety." More evidence is needed on this issue, but drivers have reported this before. [15] Thus is it not clear that BEVs have larger environmental benefits than PHEVs.

Even if a BEV is driven more miles using off-board electricity than a PHEV, it is possible for the PHEV to have equal reductions to a BEV in greenhouse gases and petroleum. This is possible due to advanced biofuels. Several environmental groups are touting this option. [16] The combination of PHEV technology and biofuels are an attractive combination. Biofuels , due to lack of arable land, water supply and other constraints, can't provide a full solution to transportation issues such as energy security and climate change.

One irony is that of all the alternative fuels, only electricity is faced with the expectation of free fuel. Perhaps this is because the cost is low or because of the experience in the 1990s where malls, restaurants, and other stores offered free charging as a way to bring customers. The analogy today is similar to the difference between free wi-fi and internet cafes that charge for internet access. It is not clear how the market will evolve, but it is an issue for charging infrastructure development.

Another issue is how to integrate PHEV and BEV charging with renewables such as wind and solar. Development work has begun with the goal of allowing the battery in the plug-in vehicle to be a storage device for the grid. For example, intermittent wind-generated electricity could in theory be timed with intermittent charging of PHEVs and BEVs. PHEVs seem particularly suited to this type of intermittent charging because they do not need a full charge every morning, and there may be an attractive incentive from the utility. But there should be enough time for most BEV designs to have some intermittent charging linked with wind. This smart grid system, while challenging, is less complex than vehicle-to-grid because it is the opposite: grid to vehicle. In addition, it could provide competition to the vehicle-to-grid concept, vehicle-to-home concept, and stationary energy storage systems by providing many of the same benefits at a much lower cost.

6.0 Conclusions

PHEVs have significant advantages from the consumer, automaker and utility points of view compared to BEVs. PHEVs will out-compete BEVs in most markets. Other solutions to the historically market limiting features of BEVs such as battery exchange, level 3 fast charging networks, and level 2 charging networks appear to be emerging. But these solutions will face the difficult challenge of building a new infrastructure for BEVs. Building a new infrastructure has been the major obstacle for every other alternative fuel and none have succeeded on large scale after thirty years of alternative fuel vehicle commercialization.

PHEVs will compete in the same marketplace as BEVs and because of their advantages will present challenges to BEVs. Yet there are many synergies where each technology can help the other become successes, or where they have common problems to overcome.

Plug-in hybrids will be benefited by the development of a level 2 charging infrastructure that will likely be built for BEVs. For example, apartment and condo dwellers with PHEVs will benefit. But PHEVs do not need – nor do they benefit from - level 2 plus, battery exchange and level 3 charging infrastructure. As a result the business case for these three solutions will face strong competition from PHEVs, and PHEVs appear to have more advantages at the start.

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