Energy and Greenhouse Gas Solutions

Analysis of Introduction of Plug-in Electric Hybrid Vehicles to Honolulu

2009

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Executive Summary

- At currently estimated efficiencies, PHEV's require about half as much energy per mile as today's average gasoline powered vehicle.

- PHEV's appear to have great promise for reducing Hawaii's GHG emissions. Assuming HECO's current emission rate, PHEVs offer about a 40% reduction in GHG emissions. As HECO moves to fueling its units with bio-fuels, this emissions advantage increases. If HECO were to fuel half of its residual fuel oil and diesel Combustion Turbines (CT) with bio-fuels, the emissions reduction would be close to 70% from conventional fueled vehicles. PHEVs also offer emission reductions from criteria pollutants such as CO, NOx, and VOCs.

- In considering the penetration of PHEVs on Oahu it is important to keep in mind that at the end of the study period (2030) plug-in electrical vehicles still constitute less that 25% of the overall light vehicle fleet

- A PHEV vehicle operating under typical Oahu conditions can operate as an 'all electric' vehicle with only marginal needs (under atypical conditions) for power from the on-board gasoline engine.

- Adequate, lower-cost off-peak power for battery recharging, should be available for most of the forecast period (through 2030).

- Meeting PHEV requirements during off peak period will result in better system utilization. Running the existing capacity for more hours will lower the average cost of electricity generation to all ratepayers since the cost of capital and fixed operating cost will be spread across more hours.

- In spite of the considerable GHG reductions PHEV's promise, they cannot (under the penetration assumptions of this study) meet the targets set out in ACT 234 for the ground transport sector. To achieve the targets of 1990 emissions level, consumers will need to choose between hybrid electric vehicles, more efficient ICEVs, and alternate forms of transit (bike, walk, and mass transit) as well as conservation in terms of reducing travel.

- Given the rapidly expanding sales of hybrid electric vehicles (HEV's); the proliferation of models; and the substantial "first-cost" advantage of HEV's over PHEV's it seems likely that both technologies will eventually displace conventional vehicles in the Honolulu market.

- Under current and likely energy price assumptions, PHEV's are not economically competitive with vehicles already on the market. Proponents of PHEV's argue (and we tend to agree) that future technological innovation and/or large scale production will alter this conclusion over time but the necessary changes in basic economics are unlikely to occur before the Act 234 compliance date on 2020.

- Without a change in the economic dynamics of the local market, many of the benefits of the PHEV technology are likely to be slow to emerge. This change could come about as a result of a direct Government subsidy or as a result of aggressive third party financing of incremental costs associated with high tech battery systems.

- Assuming that PHEV purchaser's were willing to pay for improved gasoline mileage and that a public subsidy were equally distributed between the State and Federal Government, the State contribution would be of the same approximate magnitude as the tax credits + rebate currently provided for solar water heaters in Hawaii.

- Introduction of PHEV's into Hawaii would raise a number of economic issues for government, the electric utility and the petroleum refineries/distribution.

- When considering only the direct costs, HEVs are more cost-effective than PHEVs at reducing GHG emissions, especially in the near-term. PHEVs, however, offer several benefits over HEVs and ICEVs:
    - PHEVs provide more potential energy security benefits than HEVs because some bio-fuels could be produced locally;
    - PHEVs offer more diversification in terms of transportation fuels and have a great potential to reduce Hawaii's dependence on oil;
    - PHEVs would likely produce positive benefits to the electricity grid; and
    - PHEVs would produce fewer criteria pollutants.

- PHEV's, however, lack some of the vehicle features of HEVs and ICEVs such as unlimited range, interior space, and rapid acceleration.

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Introduction

Over the past few years, there has been a great deal of concern throughout the US to reduce its dependence on foreign energy sources (particularly oil) and to reduce greenhouse gas emissions associated with the burning of fossil fuels. Plug-In Hybrid Electric Vehicles (PHEV's) are increasingly viewed as a technology that can help in accomplishing both goals.

In 2007, Hawaii enacted Act 234, which calls for Hawaii's greenhouse gas (GHG) emissions to return to 1990 levels by 2020. In parallel with this legislation the Governor, Legislative Leaders and HECO issued calls for a state-wide program to accelerate development of the State's PHEV fleet.

The introduction of PHEV's in Hawaii can be addressed from several energy policy perspectives. First, PHEV's offer a significant fuel diversification for the transportation sector. They can be seen as a conventional fuel substitution policy decision where electricity is substituted for liquid transportation fuels. Second, depending on the source of the electricity generation there may be significant energy security benefits involved in this substitution. Third, PHEV's can be seen as part of an energy efficiency policy. Fourth, the introduction of PHEV's might be approached as a policy for reducing GHG emissions. Fifth, under some considerations, PHEV's might be seen as policy measure for increasing the utilization of renewable energy resources. All of these policy perspectives are directly appropriate for Hawaii. However, the primary perspective taken in this paper will be the impact of PHEV's on GHG emissions in the state.

While substantial public attention has been given to PHEV's as a potential energy strategy for the state[1] very limited quantitative work has been done to estimate the magnitude of benefits or potential costs which might result. The current study was undertaken to develop first order estimates of what PHEV's might mean for Oahu and for the HECO grid[2] in the related areas of vehicle efficiency, fossil fuel reductions, and meeting state GHG targets. In parallel, the study considers the constraints or bottlenecks which will need to be overcome in introducing PHEV's to Hawaii.

The Hawaii energy market has unique characteristics which will strongly influence the impact of PHEV technology. Since there are no transmission links between the various islands there is no ability to transfer electricity between major markets. This is particularly important with wind energy. Without the ability to transfer or access to low cost energy storage, wind generated electricity occurring during minimum load periods may simply be unusable. If load demand for recharging can take place during these low- load periods, PHEV's will boost system utilization, increase cost effectiveness and enable the state to make better use of indigenous wind resources. Another distinguishing characteristic of Hawaii is the States' ambitious bio-fuel plans for fuel substitution in the electricity sector. These plans anticipate large scale substitution of low carbon bio-fuels for high carbon fossil fuels. As a result of bio-fuel substitution, GHG reductions from PHEV's will be enhanced.

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[1] The possible reduction in lifecycle emissions from a PHEV fleet versus a fleet fueled by conventional fuels depends directly on the underlying electricity system that would power the PHEVs.

[2] The same methodology can be replicated for other parts of the state, but the differences between the counties, and their electrical systems, are sufficiently large that useful conclusions cannot be drawn from aggregated State data.

Objectives of the Study

As suggested above, the primary aim of this study is to understand the benefits and barriers which might be associated with the introduction of PHEV technology to Hawaii. This analysis illustrates that PHEV's represent a much larger and more pervasive strategic opportunity than is generally appreciated in the State. Specific interests that guided our research were:

- To estimate the impacts which relatively modest PHEV penetration rates might have on Hawaii's GHG emission and fuel substitution goals.
- To determine whether PHEV's could be introduced to Hawaii without triggering major generating capacity additions.
- To consider whether PHEV's might play a role in optimizing the use of renewable wind resources that might otherwise be un-usable.
- To assess the role of PHEV's in the Hawaii's attempt to control GHG emissions.

II. Energy Efficiency and Emission Rates: PHEVs vs. ICEVs

A great deal of attention has been given to PHEVs because of their potential to reduce the dependence on foreign oil and their promise of reducing GHG emissions. To see the potential of both of these, we compared the efficiency and the emissions of internal combustion engine gasoline powered vehicles (ICEVs) and plug-in hybrid vehicles (see Figure 1).

The curve shows the efficiency at which PHEVs and gasoline powered vehicles use the same amount of energy per unit of distance traveled assuming an average heat rate of 10.5 MMBtu/MWh on HECO's system. More efficient heat rates would cause the curve to shift to the right and less efficient heat rates would cause the curve to shift to the left. The oval shows where today's technology is for PHEVs and the comparable gasoline powered vehicle. At these efficiencies, PHEVs require about half as much energy per mile as today's average gasoline powered vehicle.

Figure 1
Fuel Efficiency of PHEV's and ICEVs

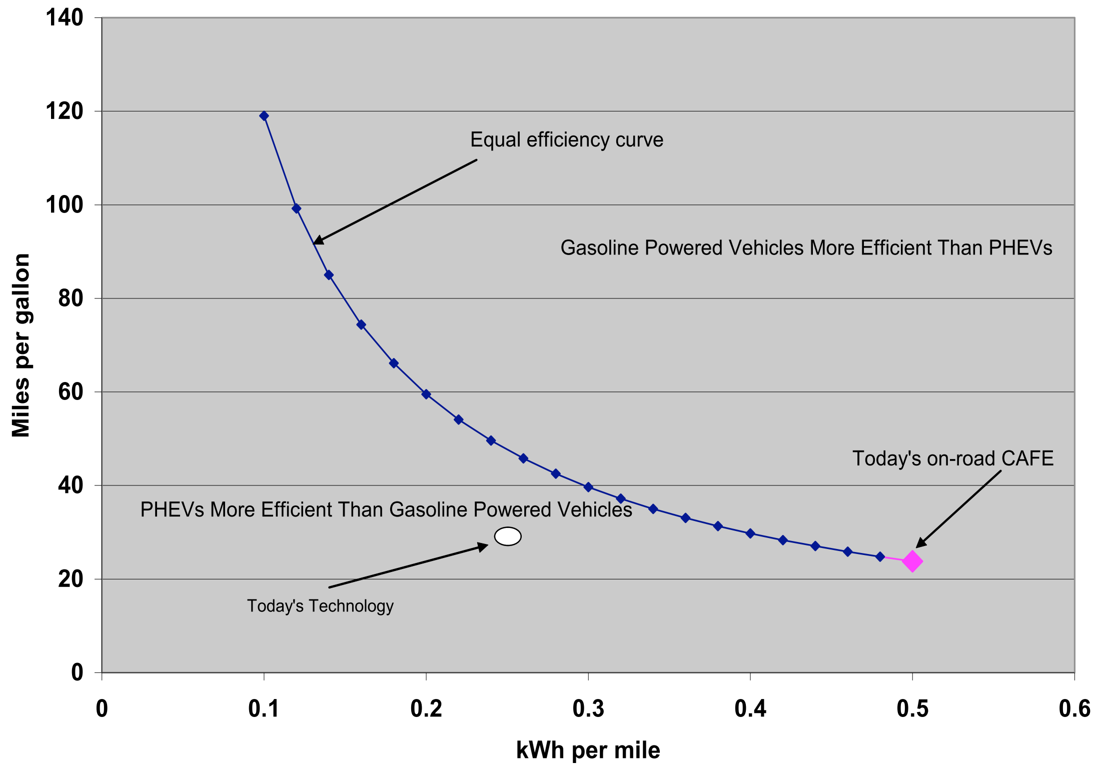
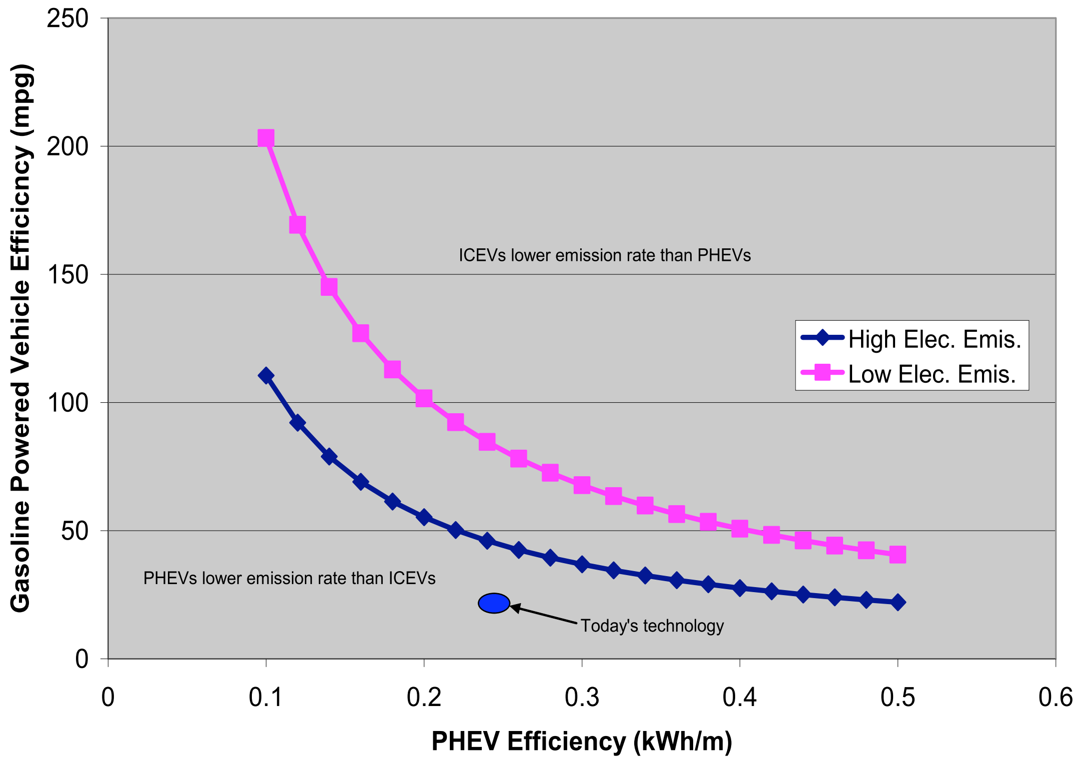


Figure 2 displays efficiency rates that produce the same CO2 emissions per mile traveled under two different assumptions about the average emission rate of HECO's electricity system. The top line or low electricity emissions assumes HECO is able to retrofit all its Oahu oil burning units to run on bio-fuels.[3] The lower line (high electricity emissions) assumes HECO's current Oahu system of diesel and low sulfur fuel oil (LSFO) fueled generators. If HECO could retrofit all its units, then the emissions from a PHEV that achieves 0.25 kWh/mile are equivalent to a gasoline powered vehicle that achieves about 80 mpg. Under HECO's current system, a 45 mpg gasoline powered would be equivalent in emissions to the 0.25 kWh/m PHEV. The bubble indicates the efficiency point of gasoline and electric powered vehicles for today's technology as in Figure 1. Since this point is below even the high electric emissions; thus PHEVs appear to have promise for reducing Hawaii's GHG emissions.

[3] IPPs are assumed to continue to burn the same fuel as today. The bio-fuels on a lifecycle basis are assumed to produce 75% fewer CO_2 emissions than the current oil fired units.

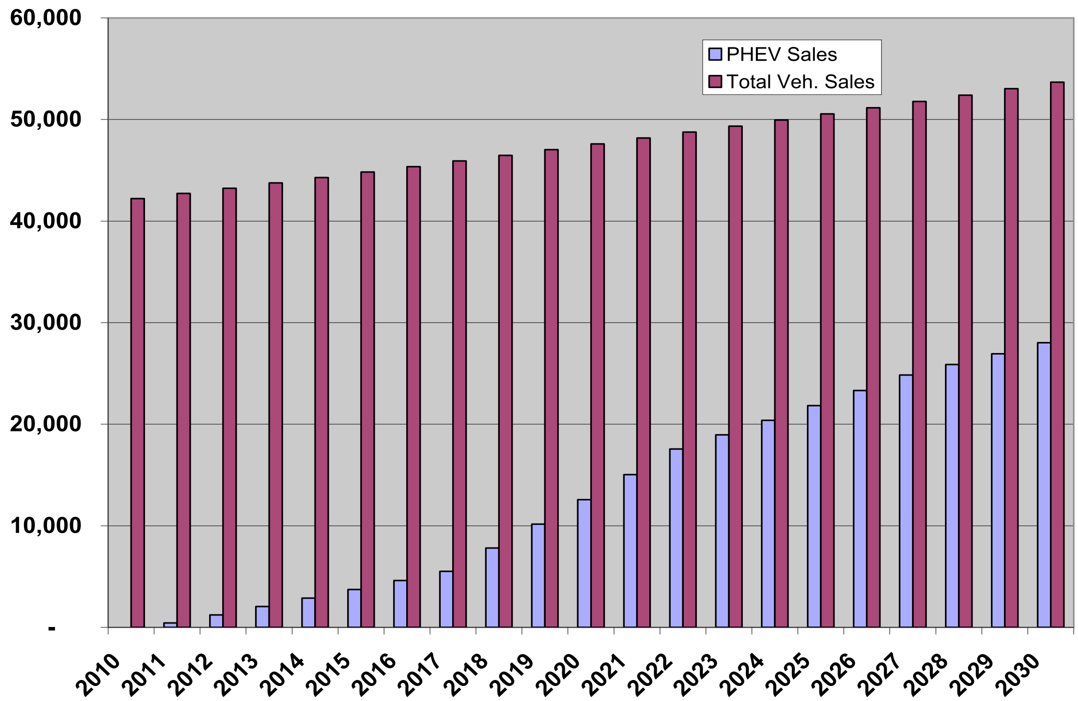
Figure 2
Equal Emission Intensity Lines for PHEVs and ICEVs under different assumptions about the emissions intensity of the Oahu grid



Given the great efficiency and environmental benefits of PHEVs it makes sense to investigate the technological feasibility and financial feasibility of these vehicles. On the technological side, the question arises about HECO's ability to supply power for these vehicles. To understand what the fleet power requirement might be in twenty years, we must make an assumption about the rate of penetration of PHEV's into the Oahu fleet. We assume a technology penetration rate consistent with that from a recent EPRI/NRDC PHEV Study.[4] This is described by EPRI as a "medium" penetration assumption. By combining this basic data with estimates of vehicle scrap rates, key information on annual fleet additions was calculated by the model.

[4] Electric Power Research Institute/ Natural Resources Defense Council; *Environmental Assessment of Plug-in Hybrid Electric Vehicles;* Palo Alto, CA; July 2007.

Figure 3
Annual Additions to Oahu's Vehicle Fleet



In considering the penetration of PHEV on Oahu it is important to keep in mind that *at the end of the study period (2030) plug-in electrical vehicles still constitute less that 25% of the overall light vehicle fleet.*

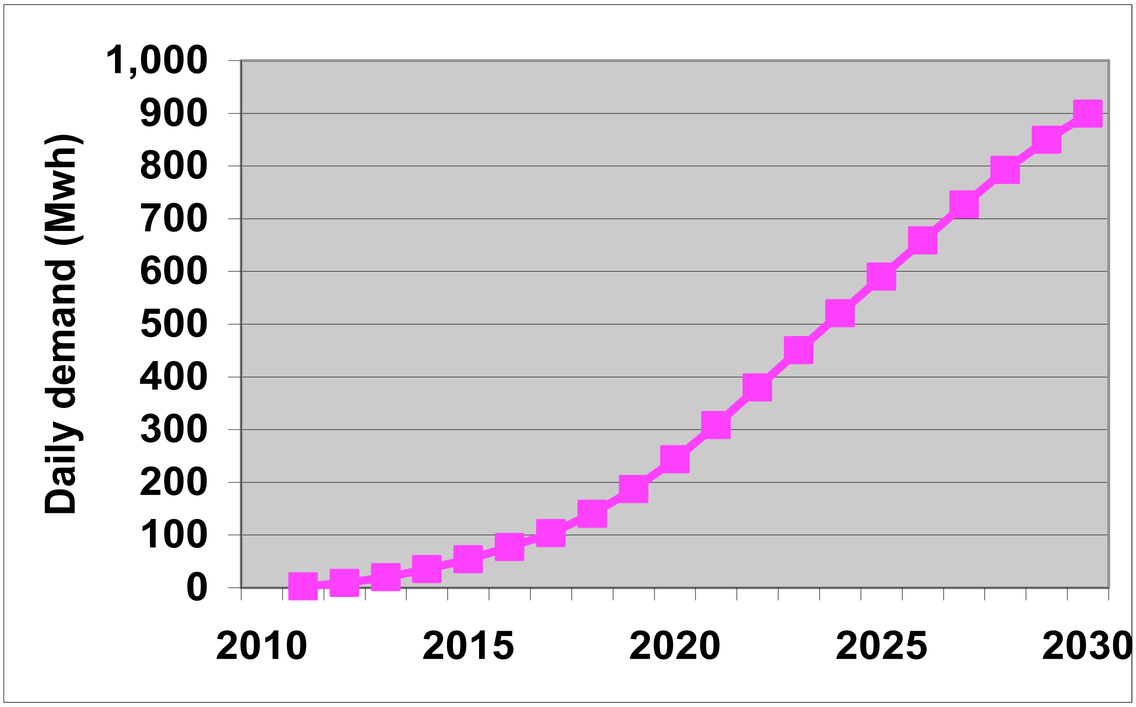
III. Electricity Demand associated with PHEVs

With projections of the annual PHEV fleet additions and a simple vehicle turnover model, we estimated the cumulative number of PHEV vehicles that would be operating on Oahu for any year. Combining the computation of the number of PHEV vehicles with data on PHEV electricity requirements developed by EPRI, an electricity consumption (demand) curve was calculated for the fleet.[5] [6] This daily electricity demand curve is presented in Figure 4.

[5] EPRI estimated that 0.262 KWh of electricity would be required per mile of driving. For the 40 mile range assumed in this study each vehicle would consume ~10.48 kWh per operating day. While this efficiency might reasonably be expected to improve over time no additional improvements were assumed in the Study.

[6] For the purposes of this study all PHEV power demand was presumed to be supplied during the 10pm-4am "minimum load" conditions on the HECO system.

Figure 4
Daily Electricity Requirement for PHEV fleet (MWh)



The 8593 annual mileage[7] assumed in Figure 4 is less than 60% of the annual range that a fully utilized PHEV40 vehicle might be capable of traveling over the course of a year.[8] *Therefore, we assume that a PHEV vehicle operating under typical Oahu conditions can operate as an 'all electric' vehicle with only marginal needs (under atypical conditions) for power from the on-board gasoline engine.*

As PHEV penetration increases over time, the PHEV fleet demands a significant amount of electricity. The lowest cost and greatest environmental benefits would arise if this generation could be supplied by off-peak power. The following assesses the feasibility of charging the fleet of PHEVs during off-peak hours (e.g. during the 6 hour period between 10:00 pm and 4 am). At the forecasted recharging levels the PHEV fleet would draw on underutilized base load capacity that already exists on the HECO grid. Essentially, the PHEV would play a load filling role in the HECO grid and could be expected to have a significant impact on overall system utilization. Clearly, the feasibility and economics of this issue require detailed study but early indications are that adequate, low-cost off-peak power should be available for most of the forecast period. Table 1 summarizes current data on the HECO grid during the off-peak hours.

[7] Average annual mileage for Oahu vehicles in 2005 was 8,593 miles.

[8] (8593/ (40*360)) < 60%

Table 1
Capacity of HECO Grid to Support PHEV Demand During Off-Peak Period (MW)*

Time	11pm	12pm	1am	2am	3am	4am	Total
Load	*870*	*780*	*720*	*680*	*660*	*670*	
Capacity of base load generators*	1230	1230	1230	1230	1230	1230	
Difference between load & Capacity	360	450	510	550	570	560	
Available for PHEV*	180	270	330	370	390	380	1,920

* Less 180 MW for Spinning Reserve

Based on these gross capacity estimates there is enough apparent capacity on the current HECO system to support the level of demand predicted by the model for PHEV recharging. In 2030, PHEV electricity demand is forecasted to be about 900 MWh, and today's available power from 10 PM – 4 AM on the HECO system is around 1,900 MWh.

Beyond HECO's <u>current</u> capacity, HECO's latest Integrated Resource Plan (IRP4) anticipates that further capacity additions will be required during the next two decades. This need for additional capacity does not account for demand by PHEVs. But given the load shape on Oahu and available supply in off-peak hours, it appears that capacity built to meet rising peak demand would result in enough capacity to satisfy the PHEV for quite some time. A substantial fraction of this new capacity will be available to the grid on an "as-available" basis from wind resources. A considerable fraction of these wind resources are likely to be available during off-peak periods. In the absence of new (PHEV) demand, or the availability of large energy storage, this as-available resource might be wasted through curtailed wind production.

In summary, there appears to be ample power for PHEVs if they are charged during off-peak hours. Meeting PHEV requirements during off peak period will result in better system utilization. Running the existing capacity for more hours will lower the average cost of electricity generation to all ratepayers since the cost of capital and fixed operating cost will be spread across more hours. The economic benefits from this improved system utilization will accrue to either utility customers or to vehicle owners depending on the relationship between the tariff rate for off-peak charging and the marginal cost of off-peak power production. Finally, off-peak charging of PHEV's will make it possible to make better utilization of nighttime wind resources.

IV. Role of Alternative Fuel Vehicles on Reducing Greenhouse Gas (GHG) Emissions

To this point, this paper has concentrated on the potential emissions benefits of PHEVs and energy side of PHEVs – a comparison of the energy required to power PHEVs vs. the energy required to power internal combustion engine vehicles (ICEVs) and ability of the existing electricity system to meet these energy needs. This section analyzes two issues: (1) the potential that PHEVs offer to reduce emissions; and (2) the cost-effectiveness of PHEVs vs. HEV's at reducing greenhouse gas emissions.

Emissions from PHEV's versus Conventional Vehicles

In estimating the difference in GHG emissions from PHEVs and ICEVs, we need to compare the emissions associated with each vehicle type for a given level of travel. In doing this, we must compare vehicles of comparable attributes and make allowances for any differences in attributes. For Oahu where vehicle range is not a critical attribute (unlike on the Big Island or the US Mainland), we choose to compare a PHEV and gasoline-powered mid-size vehicle. Table 2 reports the assumed efficiency of these vehicles over time.

Table 2
Assumed efficiency of Gasoline Powered and Plug-In Hybrid vehicles

	Vehicle Efficiency			
	Gasoline		PHEV	
	(mpg)	(MBtu/m)	(kWh/m)	(MBtu/m)
2010	25	5.0	0.24	2.5
2015	29	4.3	0.22	2.3
2020	32	3.9	0.20	2.1
2025	35	3.6	0.18	1.9
2030	38	3.3	0.16	1.7

For the PHEV, GHG emissions per mile depend on the vehicle efficiency and the energy grid. We consider two cases – current electricity generating profile and a full conversion of all fossil fuel fired units to low-emitting bio-fuels.

To estimate the impact of PHEV's on GHG emissions in the transportation sector requires comparing the emissions from HECO generation with GHG emissions from fossil fuels. The most current and comprehensive estimate of GHG emissions from the electrical sector is from a study undertaken by the University of Hawaii Economic Research Organization for the year 2005. For surface vehicles, an Environmental Protection Agency (EPA) estimate of the GHG emissions from gasoline and diesel was used for this study.[9]

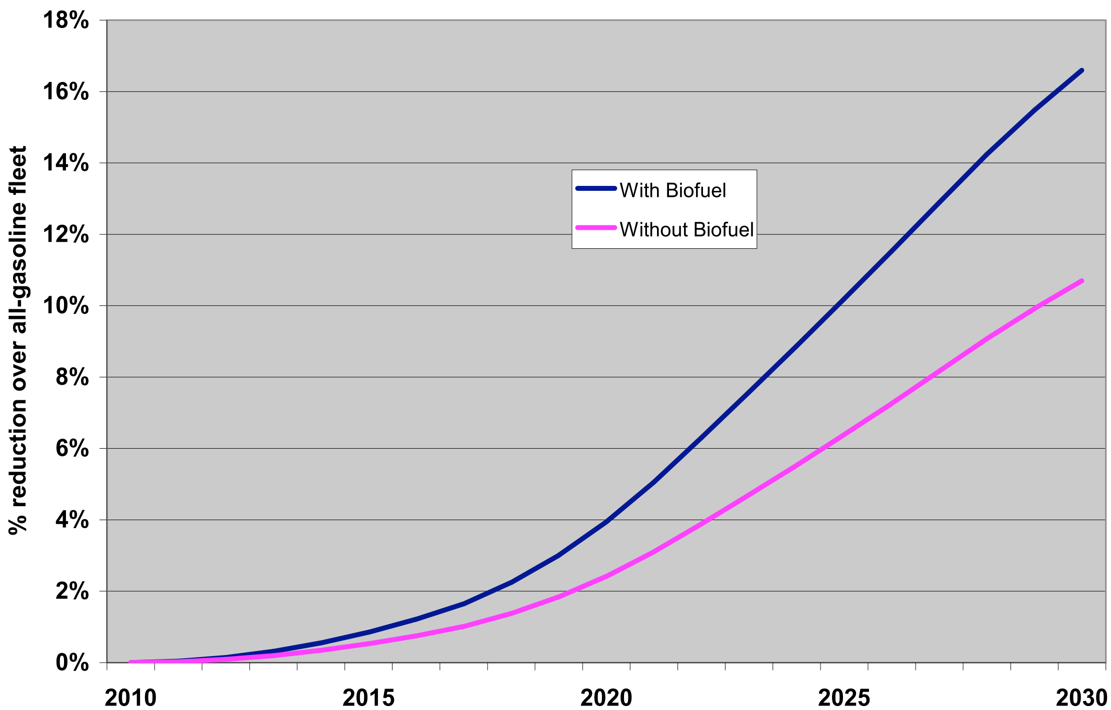
The UHERO emission inventory for 2005 does not include any bio-fueled generating units. HECO, however, has ambitious plans for bio-fueling its Oahu generating plants. These plans involve substituting low-carbon-content bio-fuels for high-carbon-content fossil fuels. Since this conversion involves a lengthy testing and retrofitting program it is not possible to predict a precise schedule. However, it is possible to estimate the impact of a 'before' and 'after' scenario that compares an all-fossil (conventional vehicle) system with an all-bio-fueled generation system.

Table 2 displays the efficiency benefit of PHEVs relative to a comparable ICEV. These efficiency benefits translate directly into emission reductions. Using the same penetration profile as for the analysis of energy requirements, we show in Figure 5

[9] *Emission Facts: Average Carbon Dioxide Emissions resulting from Gasoline and Diesel Fuel*; EPA 420-F-05-001; February 2005. (Updated December 2007)

the total reduction in emissions from personal transportation under the two alternative assumptions about HECO generators fuel source – refined petroleum products and bio-fuels.

Figure 5
Effect of biodiesel generation on PHEV GHG reductions



It is clear from Figure 5 that through bio-fueling its generating units, HECO substantially enhances the emissions savings resulting from introduction of PHEV's. By 2030 this additional bio-fueling benefit results in an incremental reduction of GHG emissions of 16% vis a vis BAU light vehicle consumption of gasoline. In 2020, emissions are 4% below 2020 baseline levels. Emissions from light-duty are projected to be 10% below 2005 levels and about 35% above 1990 levels.[10] Therefore, if the transportation sector were to return emissions to 1990 levels, the penetration rate would need to be about five times as great. In spite of the great reductions PHEV's offer, (under the penetration assumptions of this study) they cannot meet the targets set out in ACT 234 for the ground transport sector. To meet these goals, Hawaii drivers will need to purchase more fuel efficient vehicles or drive fewer miles or both.

V. Role of Current Hybrid Vehicles (HEV)

Although most of the current analysis of PHEV's revolves around comparisons with conventionally powered vehicles, this comparison may be overly simplistic and even misleading. Given the rapidly expanding sales of hybrid electric vehicles (HEV's); the

[10] Forthcoming UHERO study on GHG emissions in Hawaii (2008).

proliferation of models; and the substantial first-cost advantage of HEV's over PHEV's it seems likely that both technologies will displace conventional vehicles in the Honolulu market.

Continued and growing HEV market penetration is important to achieving ACT 234 targets. Today's HEV's are among the most fuel efficient vehicles in their classes. As HEV numbers increase, overall fleet gasoline consumption and, more importantly for the successful implementation of ACT 234, GHG emissions will decline. HEV's are likely to benefit from battery research and innovation associated with the emerging PHEV's technology. It is quite plausible to assume that the performance and efficiency of future HEV's will be substantially greater than today's HEV's. In short, HEV's and PHEV's are likely to be both substitutes and complimentary transportation technologies in the future.

According to a recent Consumer Reports (CR) survey 32% of active car shoppers are considering hybrid vehicles. Table 3 summarizes CR's estimated savings in gasoline mileage between comparable hybrid and conventional vehicles which are typical of the Honolulu vehicle fleet.

Table 3
Fuel Efficiency of Hybrid versus Conventional Vehicles
Typical of Hawaii Vehicle Fleet

Vehicle	MPG	% MPG Reduction
Honda Civic Hybrid	37	30%
Honda Civic LX	26	---
Toyota Prius (Hybrid)	44	48%
Toyota Corolla	32	---
Ford Escape Hybrid	27	33%
Ford Escape XLT	21	---
Saturn Vue Greenline	28	22%
Saturn Vue	22	---

Source: Consumer Reports; October 2008; Page 41

VI. Comparative Economics of PHEV's and other vehicles

The Economic Trade-Offs of PHEV and Conventional Vehicles (ICEV's)

Figure 6 displays breakeven lifecycle cost curves between PHEVs and gasoline powered vehicles under alternative assumptions about PHEV efficiency and electricity prices. For example, the middle line shows that if PHEVs had an efficiency of 0.26 kWh/mile and electricity cost $0.25/kWh, then if the purchase price of a PHEV was about $8000 more than a gasoline powered vehicle and the average price of gasoline over the life of the vehicle in real dollars were $5.00/gallon, then the lifecycle cost of the two vehicles would be the same.

Figure 6

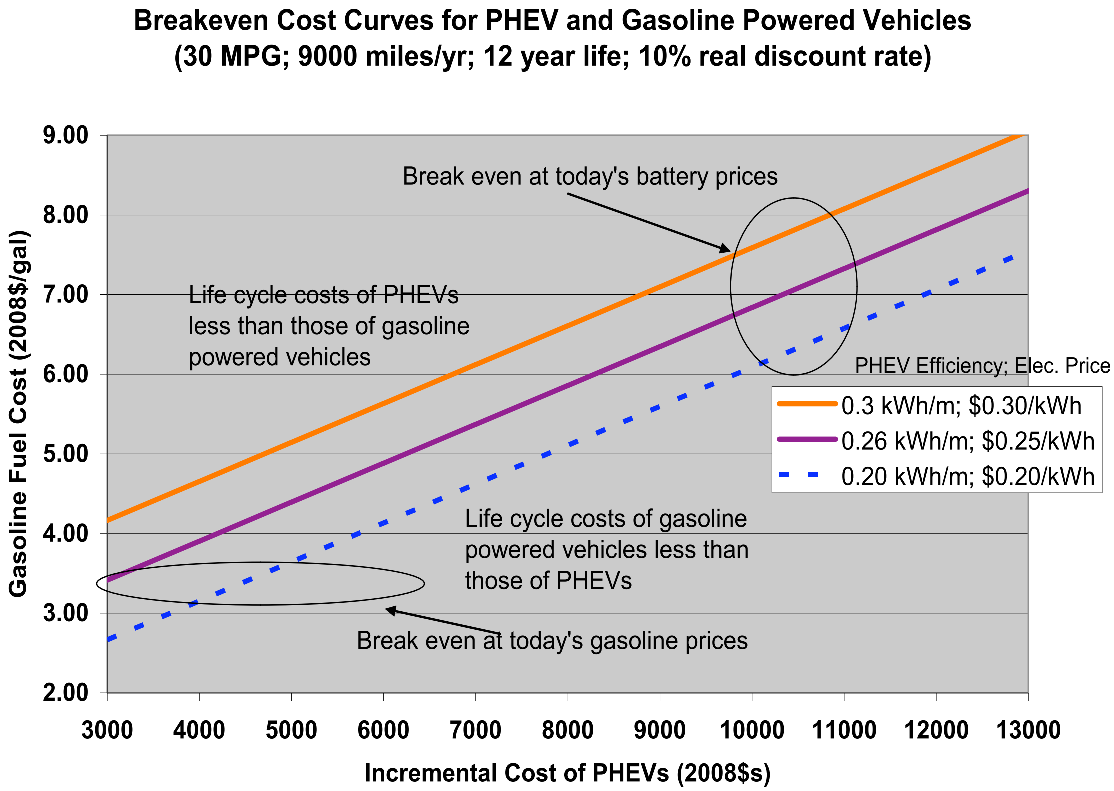
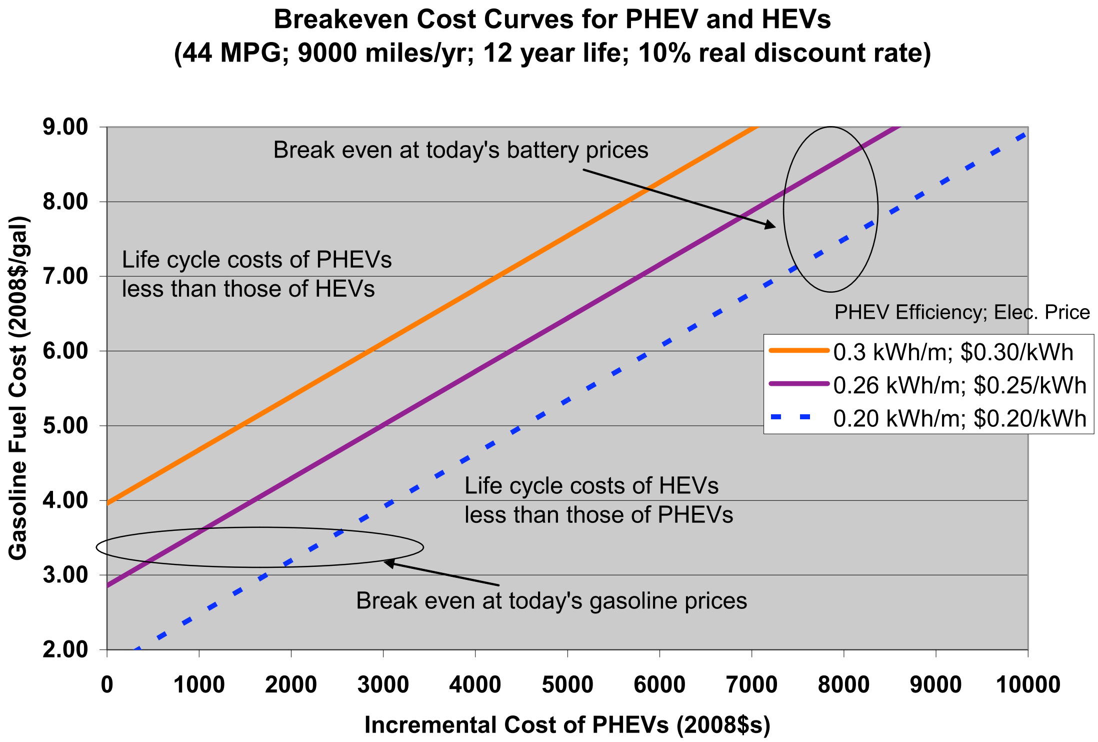


Figure 6 shows that PHEVs are more costly than ICEVs at today's fuel and battery prices. Presumably, battery technology will improve over time, which will close the gap in cost advantage for ICEVs. Under a GHG abatement policy like Act 234, the gap will close further. For example, a $100/ton permit price or tax for CO2 would lead to an increase in gasoline prices of one dollar per gallon. Therefore, if battery costs dropped to about $7,000, Phi's would have a lower life cycle cost than Ice's assuming PHEV efficiency of 0.26 kWh/mile and electricity price of $0.25/kWh.

The Economic Trade-Offs of PHEV and Current Hybrids (HEV's)

Figure 7 displays five lines which depict breakeven lifecycle cost curves between PHEVs and a Toyota Pries under alternative assumptions about PHEV efficiency and electricity prices. For example, the middle line shows that if PHEVs had an efficiency of 0.26 kWh/mile and electricity cost $0.25/kWh, then if the purchase price of a PHEV was about $4000 more than a Toyota Pries and the average price of gasoline over the life of the vehicle in real dollars were $5.50/gallon, then the lifecycle cost of the two vehicles would be the same.

Figure 7



This figure shows that gasoline prices need to rise or technology costs of PHEVs need to fall for PHEVs to look cost competitive to HEV's if only the direct costs of the two vehicles is considered.

The clear suggestion from Figures 6 and 7 is that under current and likely energy price assumptions, PHEV's are not economically competitive with vehicles already on the market. Comparing a typical ICEV to today's HEV (e.g., Toyota Prius), it would cost over $60 to remove one metric ton of CO2.[11] Comparing a PHEV to the same ICEV, results in a cost of over $600 per metric ton of CO2.[12] Proponents of PHEV's argue (and we tend to agree) that future technological innovation and/or large scale

[11] This comparison assumes an ICEV with a fuel efficiency of 27 mpg, an HEV efficiency of 44 mpg, and gasoline prices of $3.00/gallon. The HEV is assumed to cost $3,000 more than the ICEV.

[12] This comparison assumes an ICEV with a fuel efficiency of 27 mpg, PHEV efficiency of 0.24 kWh/m, electricity prices of $250/MWh, and gasoline prices of $3.00/gallon. The PHEV is assumed to cost $12,000 more than the ICEV.

production will probably alter this conclusion over time. If one assumes that the cost premium to an ICEV is reduced in half for both the HEV and PHEV and gasoline prices rise from $3/gallon to $4/gallon, then the cost to reduce a tonne of CO2 relative to an ICEV is $17 and $25 for an HEV and PHEV, respectively.[13] However, it seems unlikely that the needed improvement will come early enough to achieve the sort of penetration rates and GHG emissions reductions necessary to comply with ACT 234's implementation date of 2020. In short, without a change in the economic dynamics of the local market, many of the benefits of the PHEV technology are likely to be slow to emerge. There are two commonly accepted approaches to changing the economic climate for PHEV's: public subsidy and third party financing.

When considering only the direct costs, HEVs are more cost-effective than PHEVs at reducing GHG emissions, especially in the near-term. PHEVs, however, offer several ancillary benefits over HEVs:

- PHEVs provide more potential energy security benefits than HEVs;
- PHEVs offer more diversification in terms of transportation fuels and have a great potential to reduce Hawaii's dependence on oil;
- PHEVs would likely produce positive benefits to the electricity grid; and
- PHEVs would produce fewer criteria pollutants than either ICEVs or HEVs.

VII. Barriers to PHEV Introduction

The Public Subsidy Approach

It is widely recognized that the major barrier to PHEV introduction is its significant cost premium over gasoline powered vehicles.

Today's PHEV's high tech battery systems cause this vehicle to cost at least $10,000 more than an ICEV. It is commonly accepted that without direct government subsidization or some sort of innovative funding, PHEVs will be very slow to be adopted. Because PHEVs offer the ability to greatly reduce demand for foreign oil and emissions, people have argued that there is a role for government to help promote these vehicles. In considering this capital cost problem a convenient starting point is to compare the difference in price between a PHEV and the (now well established) hybrid vehicles that are currently available.

Price estimates for PHEV's vary considerably but most commentators believe that they will be at least $10,000 more expensive that current hybrids. Since part of this cost will be recouped by PHEV owners through operating cost savings there is an argument that some significant fraction of the cost differential should be directly borne by owners. To induce customers to purchase these vehicles, government would need to lower the costs consumers perceive. One obvious method is to offer a direct subsidy or credit for the remainder of the differential (at least during an initial introductory period). This policy strategy mirrors the one adopted to encourage the introduction of current hybrid vehicles like the Toyota Prius where federal vehicle subsidies of $2500-$3100 /vehicle were available to car purchasers. There is

[13] As this is assumed to be an analysis based on future technologies, we assume the efficiency of ICEVs, HEVs, and PHEVs, is 35 mpg, 48 mpg, and 0.2 kWh/m, respectively.

widespread political agreement with the idea of helping vehicle buyers meet at least part of the incremental costs of PHEV's.[14]

By examining different combinations of gasoline prices and electricity charges it was determined that annual owner operating savings of $667-$755 could be expected on Oahu from owning a PHEV. If owners were willing to allocate 75% of this saving over a 5 year period toward the battery capital differential, the residual subsidy required from government would be ~$5500-6000 /vehicle. If this sum were equally distributed between the State and Federal Government the PHEV subsidy portion to the State would be of the same approximate magnitude as the tax credits + rebate currently provided for solar water heaters in the state.

Third Party Financing Proposals

Another way to lower costs to consumers is to convert the upfront battery cost into a long-term loan payment or leasing arrangement. Third party financing schemes have been advanced by at least two groups. The first proposal by the Israeli group 'Better Place' involves third party electric car ownership using a cell phone payment model (e.g. vehicle owners buy "electrical miles" as cell phone users buy connection minutes). *Better Place* describes their system as follows; [15]

> • Drivers pay to access a network of charging spots and conveniently located battery exchange stations powered by renewable energy.
> • Drivers pay for the miles they drive.
> • Cars are made much more affordable—even free in some markets—by the business model's financial and environmental incentives to add drivers into the network.
> • *Better Place* operates the electric recharge grid that brings it all together. "

A second proposal would involve utility ownership of PHEV batteries. Cost recoupment would be through special utility tariff rates. This approach was proposed in a recent paper from the Brattle Group and is described as follows,

> "To accelerate widespread introduction, in addition to the efforts already underway it may be useful to create a program to directly offset the added costs and risks of the battery portion of PHEVs. A rate base approach by electric utilities could be the answer. The core idea is that the utilities would own the batteries within PHEVs sold in their area and treat them as their own asset. They would lease the battery free to the car owner (offsetting the incremental battery cost to the car owner) and utilities would recover this added cost through utility rates."[16]

The Brattle approach has been endorsed by the Democratic Party of Hawaii.

VIII. Summary of Benefits from PHEV's to Hawaii

The benefits from accelerated introduction of PHEV's are not unique to Hawaii. However, they are accentuated by the unique character of the local energy economy. PHEVs offer potential benefits in terms of reducing the States' almost total

[14] During the recent election campaign President-elect Obama has proposed a $7000/vehicle rebate and his opponent John McCain suggested a federal rebate which could reach $5000/vehicle.

[15] See http://www.betterplace.com/our-bold-plan/business-model

[16] See http://brattle.net/_documents/UploadLibrary/Upload653.pdf

dependence on foreign energy while simultaneously reducing GHG emissions. For Hawaii, PHEV's mean both reduced gasoline consumption and emissions for light vehicles and-through locally sourced bio-fueling of HECO's generation- reduced emissions from diesel and fuel oil. Similarly, since it is clearly feasible to power PHEVs with the existing electricity infrastructure, and PHEVs could increase overall system utilization. Finally, the PHEV technology has the additional benefit of potentially increasing the utilization of the State's considerable wind potential.

PHEV's are ideally suited to urban areas in Hawaii for several reasons. First, with relatively short driving and commuting distances, the operating and economic advantages of electric vehicle technology can be maximized. Secondly, the relatively compact nature of the Oahu population centers suggest that PHEV supporting infrastructure (e.g. distribution and grid connections) investments will be more manageable than in areas of low population density. Third, Act 234 has created a legislative mandate which will place a direct economic penalty on emitting GHG.

IX. Wider Public Policy Implications

The introduction of PHEV's will have a ripple effect on Hawaii's energy economy. There will be economic winners and losers.

1. At the center of these changes will be the electric utilities,

- Through the use of 'smart' metering and time-of-use pricing the electric utilities could capture the economic and environmental benefits of PHEV's and pass these benefits to ratepayers through lower electricity rates. This may require significant near term investments in the distribution system.

- So long as PHEV charging occurs during off peak hours, one of the potential financial winners will be the electric sector. In contrast, if battery charging takes place during peak demand periods there will be pressures for new generating capacity which might- at the discounted electricity rates necessary to make PHEV's financially attractive- have an adverse effect on utility economics.

- The additional sales from PHEV charging will likely coincide with a period of reduced overall electricity system demand resulting from GHG regulation. If GHG allowances and targets are allocated on a sector by sector target basis, there would be a disincentive toward using PHEVs. This distortion would lead to less cost-effective solutions being developed to reduce Hawaii's GHG emissions. Therefore, implementation of ACT 234 needs to adopt a policy objective to reduce GHG in the most cost effective manner possible - irrespective of sector targets.

2. There will be significant changes in the Public Sector,

- If PHEVs were to significantly penetrate the vehicle market, gasoline and fossil diesel sales would decline leading to a significant reduction in state, federal and county liquid fuel tax receipts. Since most of these funds go toward road maintenance and construction, the budget for these programs would decline even though the total vehicle miles being travelled might be increasing. Presumably a smart metering system could determine when electricity was being consumed by a PHEV battery, and then could assess a fuel tax that would go toward the general road maintenance and construction fund.

- In the event that the State decides to accelerate PHEV introduction through a price subsidy or 'buy-down' scheme, there would be substantial outlays of public funds.

- A market-oriented GHG regulatory scheme would raise revenues that could be used for both road maintenance and PHEV subsidies. As PHEVs become more prevalent, the reduction in GHG emissions brought about by these vehicles should translate directly into reduced emission compliance costs through lower overall auction prices or carbon tax rates.

- There will be increased revenue to the Public Utility Commissions'' Public Benefit Fund.

3. At the county level, the introduction of PHEVs may not have an equal impact among the islands. As demonstrated by this Study, plug-ins make considerable sense on Oahu and the same is probably true (but yet to be demonstrated) on Maui. Beyond these islands, the benefits from PHEVs may be marginal. The major mitigating factors against PHEV's on the other neighbor islands is the low population density and transit conditions which may exceed the PHEVs assumed 40 mile electricity operating range.[17] Further study is needed to examine the costs/benefits on the neighbor islands.

4. Possible changes in the oil refining industry might include,

- Reduced demand for high-profit-margin gasoline sales will directly impact the bottom line (and tax payments) of the Hawaii's oil refiners.

- Over time it may also affect product yields from the oil refineries. This could necessitate new or abandoned investments and the State's Import/Export balance of individual petroleum products.

- Of particular interest is the consequence of declining gasoline sales occurring in parallel with HECO's bio-fuel initiative. The combination of bio-fuel substitution (for refined diesel and LSFO) with declining gasoline sales (resulting from PHEV introduction) might lead to the restructuring of the local oil refinery industry.

- It seems likely that the number of retail gasoline outlets on Oahu will decline as a result of PHEV penetration. Conceivably, new PHEV charging stations might take their place or could have mixed fueling stations. This could have direct implications for the electrical distribution system on Oahu.

5. Potential impact on vehicle purchasing and resale patterns,

- Early buyers are likely to pay a substantial premium price for the initial PHEV models. As demonstrated by the history of conventional hybrids, purchasing decisions are likely to be heavily influenced by anticipated gasoline savings.

[17] Low population density could increase utility distribution expenditures and line loses significantly. Transit distances beyond the assumed operating range would necessitate either a non-home recharge network (such as proposed by *Better Place*) or creation of publically accessible distribution facilities.

However, it is not obvious whether the new CAFE standards that mandate higher fuel mileage standards will make traditional vehicles and conventional hybrids more or less attractive than PHEV's.[18]

- In the final analysis, the 'first costs' of all new cars are likely to increase but life-cycle costs, inclusive of GHG emissions costs, may well decline more for PHEVs than for other types of vehicles.

- For Hawaii the important rental car resale market needs to be carefully considered in any PHEV policy package. Rental cars have an exaggerated importance in Hawaii since they represent a disproportionately large share of annual fleet additions…but are often not resold in the State.[19] An important policy issue is whether Hawaii should subsidize the purchase price of rental PHEVs that will ultimately be resold and end-up in the vehicle fleets of other states.

[18] PHEVs like other alternative vehicles (i.e. flex fuel vehicles) might receive special treatment under CAFÉ. It is entirely possible that legislation could be written to favor these vehicles over ICEVs or HEVs. The electric utility, oil and automobile industries have vital interests in how any revisions to the CAFÉ are might deal with PHEV's.

[19] The value of rental cars is heavily dependent on the regulations prevailing in West Coast markets where the vehicles are ultimately re-sold. For example, a booming California market for used PHEV's may mean higher resale value.

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