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Exploring the Paths to One Million Plug-in Electric Vehicles by 2015 Using MA3T Model

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Abstract

The U.S. government's goal, announced in 2011, of putting one million PEVs on the road by 2015 represents a key milestone for the deployment of PEVs in the U.S. However, the forecasts of PEV consumer adoption are not as optimistic as manufacturers' announced production claims. With an overarching objective of exploring alternative paths towards one-million PEVs on the road in the U.S. by 2015, this paper presents a number of possible strategies and evaluates their impacts on PEV market share.

Keywords: plug-in electric vehicle (PEV), market acceptance of advanced automotive technologies (MA3T), transportation energy, policy analysis

1 Introduction

Promoting plug-in electric vehicles (PEVs), including plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV), is considered as an effective measure for reducing oil dependence and vehicle emissions [1][2]. In 2011, the U.S. government called for putting one million PEVs on the road by 2015, which represents a key milestone for the deployment of PEVs in the U.S. [3]. According to the Annual Energy Outlook 2011 the national light-duty vehicle (LDV) sales in the U.S., passenger cars and light-duty trucks combined, are projected to increase from 12.6 million in 2011 to 16.2 million in 2015 (see Table 1) [4]. To reach the one million goal, the average share of PEV sales from 2011 to 2015 needs to be more than 1.3 percent of the LDV market. Based on manufacturers' announced production claims, the cumulative total of U.S. electric vehicles supply is estimated to reach 1.2 million in 2015, presenting a great opportunity for achieving the ambitious goal [3]. This does not include vehicles from at least half a dozen manufacturers who have not announced production capacities. However, the forecasts of PEV consumer adoption, by Zpryme, IHS Global Insight, JD Power & Associates and Center for Automotive Research (CAR), are less optimistic, projecting about a half-million PEVs on the road by 2015 [5][6].

Table1: Market projections of LDV sales and PEV production in the U.S. from 2011 through 2015

Year	LDV sales (million)	PEV production (thousand)
2011	12.6	45.6
2012	14.7	177.6
2013	16	263
2014	15.9	368
2015	16.2	368
Total	75.4	1222.2

Consumer acceptance, existing research and development (R&D) and policy measures are important for achieving the goal. Many strategies have the potential to stimulate PEV deployment and market share, such as extending ARRA

(American Recovery and Reinvestment Act of 2009) incentives that offer subsidies for plug-in vehicles manufacturers [7] and installing significant charging infrastructure in convenient places in urban areas [8]. With an overarching objective of exploring alternative paths towards one-million PEVs on the road in the U.S. by 2015, we proposed a number of possible strategies and evaluated their impacts on PEV market share. In particular, the Market Acceptance of Advanced Automotive Technologies (MA3T) model, developed by Oak Ridge National Laboratory, is used to project annual consumer demand for PEVs, competing against conventional and other advanced automotive powertrain technologies [9] [10]. The MA3T model incorporates relevant attributes of vehicle technologies (e.g. fuel economy, vehicle performance and retail price), consumer behavior (e.g. range anxiety, daily driving patterns and willingness to accept technological innovation), energy prices and a wide range of policies including purchase subsidies, battery warranty extension, feebates, carbon tax, charging infrastructure, parking and driving privileges. For each strategy, the cumulative PEV sales by 2015 are estimated using the MA3T model.

2 Methodology

This section introduces the consumer choice model used in this study, for projecting market adoption of PEVs by 2015 under different technological development and policy assumptions.

2.1 MA3T Model

MA3T is a consumer choice model for projecting U.S. demand for plug-in electric vehicles (PEV) in competition with conventional and other novel light-duty vehicle technologies over the period 2005-2050. New car buyers are disaggregated by region, residential area, attitude toward technology risk, vehicle usage intensity, home parking and work recharging.

What distinguishes MA3T from other vehicle market models are technology richness, detailed consumer segmentation, market dynamics, daily driving distance distributions for households, and range-infrastructure characterization. MA3T includes 40 choices consisting of 20 powertrain technologies for each of two vehicle size classes—passenger cars and light duty trucks. MA3T considers U.S. household users of these vehicles as the consumer market, which is disaggregated into 1,458 segments based on 6 dimensions: census divisions, residential areas, attitudes toward novel technologies, driving patterns, home recharging situations, and work recharging situations. MA3T projections currently cover the period from 2005 to 2050 and capture the temporal interaction between market penetrations and product diversity and risk. MA3T characterizes daily driving distance variation with the Gamma distribution, validated with real-world high-resolution travel data [11]. MA3T explicitly quantifies range anxiety for electric vehicles and reflects the effect of charging and refueling infrastructure on the appeal of plug-in electric vehicles and alternative fuel vehicles.

The core of the model is a nested multinomial logit method that predicts purchase probabilities among 40 choices by each of the 1,458 consumer segments based on value components associated with vehicle attributes, user behavior, infrastructure, energy prices, and policies. The segment purchase probabilities are translated into market penetrations, sales, populations, petroleum use, and greenhouse gas emissions. Some of the outputs serve as feedback signals and, together with other exogenous inputs from various sources, affect the purchase probabilities.

MA3T can be used to analyze important issues of vehicle technologies and transportation energy, such as the required government support for promoting vehicle electrification in order to meet certain environmental and energy goals, and the role of infrastructure deployment in the clean energy vehicle market [12].

2.2 Factors Influencing PEV Adoption

Many factors influence PEV consumer adoption, including battery technology development, gasoline prices, federal incentives and charging infrastructure. In the base case scenario, energy prices are assumed to follow the U.S. Energy Information Administration's (EIA) annual energy outlook [13]. The American Recovery and Reinvestment Act that was signed into law on February 17, 2009 provides up to a $7,500 tax credit for each new PEV purchase starting from 2010 [7]. In addition, the coverage of electric vehicle charger infrastructure is assumed to remain unchanged through 2015: (1) about half of the consumers could identify an outlet at home for charging their vehicles [14]; (2) 5% of the workplaces offer charging opportunities for their employees; and (3) hardly any public charging opportunities.

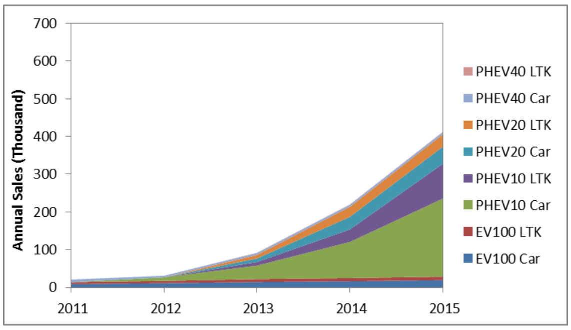

Figure 1: Base Case Projection of Annual PEV Sales from 2011 to 2015

Figure 1 shows the forecast of annual PEV sales from 2011 to 2015 in the base case scenario. The projection of cumulative PEV sales by 2015 reaches 776 thousands. As it is below the one-million goal additional measures are needed to promote consumer adoption of PEV, such as:

Battery cost: The growth of PEV markets is largely driven by the advances in battery technology, in terms of increasing power density and declining cost. Current battery cost is about $700 per kWh, except that the Nissan Leaf EV battery pack costs only $375 per kWh. In the base case scenario the battery cost are assumed to be constant or decline slowly through 2015. However, the goal set by the U.S. Department of Energy's (DOE) vehicle technologies program, is much more aspiring, expecting a battery cost of around $300 per kWh by 2015 [15]. Table 2 lists the battery costs of different PEV technologies, for both the base case and the program goal.

Table2: Battery Cost ($ per kWh)

Year	2011	2012	2013	2014	2015
Base case					
EV100	375	375	375	375	375
PHEV10	725	716	707	697	686
PHEV20	683	677	671	664	657
PHEV40	600	600	600	600	600
Program Goal					
EV100	375	375	347	319	291
PHEV10	725	716	530	348	331
PHEV20	683	677	503	332	317
PHEV40	600	600	450	300	290

Tax credit incentive: The 2009 ARRA offers different amount of tax credit for purchasing PEVs, depending on the battery size. The minimum and maximum subsidies per eligible vehicle are currently $2,500 and $7,500, respectively. Increasing the minimum subsidy will help to promote PHEVs with smaller battery packs. In addition, based on the current ARRA, for PEVs with a battery pack of 16 kWh and more the maximum incentive of $7,500 is applied. For example, purchasing a Chevrolet Volt, a PHEV with a 16 kWh battery pack and a 35-mile CD range according to the U.S. Environmental Protection Agency's (EPA) estimation, or a Nissan Leaf, a BEV equipped with a 24 kWh battery pack to travel 73-mile per full charge according to EPA's estimation, will receive the same amount of federal tax credit (i.e. $7,500). Thus, raising the maximum subsidy to provide more incentives for BEV consumers has the potential to promote the BEV market.

Energy prices: Gasoline and electricity prices largely determine vehicle's operating cost and thus affect consumers' vehicle choices. If the fuel expense is expected to be greatly reduced, consumers will be willing to choose a relatively more expensive alternative such as a PEV, instead of a conventional gasoline vehicle. Therefore, high gasoline prices tend to motivate consumers to purchase an alternative fuel vehicle. Alternatively, reduced electricity cost will further cut the operating cost of PEV and make it a more attractive option. This can be achieved by proving free charging at workplaces and public charging stations.

3 Result and Discussion

3.1 Battery Cost

The battery costs of the base case and the program goal (see Table 2) are used to update battery production and maintenance costs, as well as the resultant vehicle costs, for the corresponding PEVs. The "Battery Success" scenario assumes the reduced battery costs defined in the program goal.

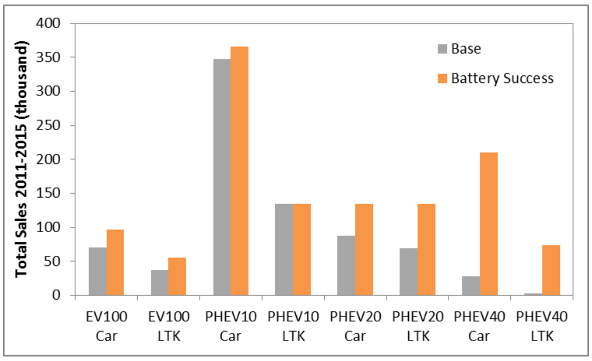

Figure 2: Total Sales Comparison: Base vs. Battery cost reaches DOE's program goal

Figure 2 compares the total sales from 2011 to 2015 for different types of PEV technologies. Declining battery costs results in a significant increase in PHEV20 and PHEV40 sales, as the vehicle cost reduction is more significant for PHEVs with a large battery pack, compared to the ones with a small battery pack (e.g. PHEV10). However, the current battery cost of BEVs is close to the DOE's program goal. As a result, the increase in sales of EV100 is marginal, compared to the base case.

3.2 Charging Infrastructure

As explained earlier, current PEV consumers mainly rely on home charging. Home charger coverage is assumed to be 52% in the base case scenario [14]. Some workplaces have also installed charging stations allowing employees to charge their vehicles at work. As the baseline, 5% workplace charger coverage is assumed. Availability of public charging services, including chargers installed at grocery stores, restaurants, fitness centers, and highway rest stops, is very limited at the current stage and assumed to be zero.

Different charging infrastructure deployment strategies are evaluated: (1) Scenario "65% Home Charger" assumes that home charger coverage will gradually reach 65% by 2015. Bureau of the Census's American housing survey reported that about 65 percent of housing units have a carport or garage [16]. However, some are not currently equipped with a proper outlet for charging electric vehicles. Upgrading is needed to allow home charging at these places. (2) Scenario "20% Work Charger" assumes that the coverage of workplace chargers linearly increases from current 5% to 20% by 2015. (3) Scenario "20% Public Charger" assumes that the coverage of chargers at convenient public locations linearly increases to reach 20% by 2015.

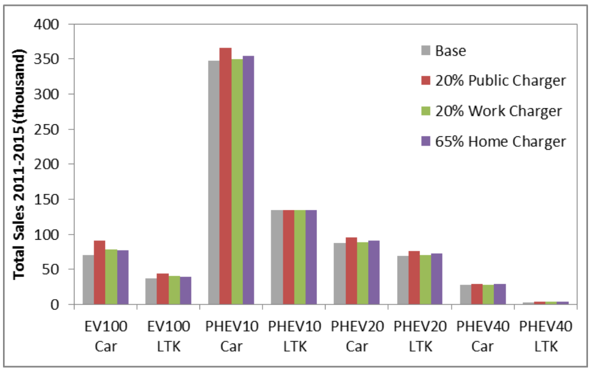

Figure 3: Total Sales Comparison: Home, Work and Public Charger Deployment

As shown in Figure 3, providing more charging opportunities helps to increase PEV sales, especially for EV100 and PHEV10 cars. The latter is consistent with the observation in [12], which concludes that public charging offers greater benefits for PHEVs with a smaller battery pack, by encouraging within-day recharge to compensate battery capacity.

3.3 Federal Incentive

The ARRA federal tax credit incentive started in 2010. The maximum cumulative number of subsidized vehicles per OEM is 200,000. The number of OEMs producing eligible PEVs is assumed to be 6. The minimum battery size of eligible vehicles is 2kWh, the battery size beyond which each additional battery capacity earns the incremental incentive. Table 3 lists the current ARRA specifications and a new scheme with larger minimum and maximum incentives, as well as an adjusted increment.

Table3: ARRA and New Tax Credit Incentive

	ARRA	New
Starting Year	2010	2010
Vehicles per OEM (1000)	200	200
Number of OEM	6	6
Minimum Battery Size (kWh)	2	2
Minimum Incentive ($)	2,500	**3,000**
Maximum Incentive ($)	7,500	**10,000**
Increment ($/kWh)	417	**375**
Size Threshold (kWh)	4	4

Different from the current ARRA, the new incentive scheme offers a larger tax credit for EV100 purchases than for PHEV40, and thus significantly promotes the BEV market, as shown in Figure 4.

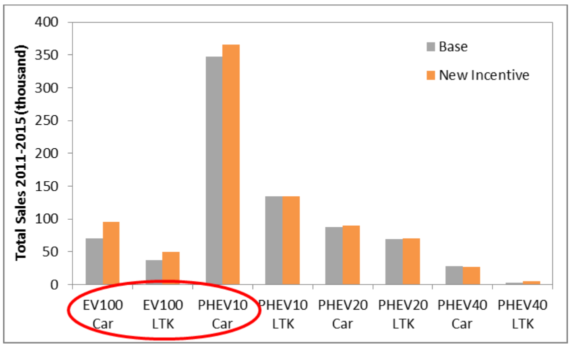

Figure 4: Total Sales Comparison: Base (ARRA) vs. New Incentive Scheme

3.4 Energy Price

The gasoline and electricity prices in the base case are obtained from the U.S. Energy Information Administration's annual energy outlook (AEO) [13]. Two scenarios evaluating the impact of higher gasoline prices are created, assuming gasoline prices gradually reach $4 and $4.5 per gallon by 2015, respectively. In addition, a scenario with a reduced electricity price of 5 cents per kWh is considered to represent the reduced electricity cost by using the free charging services offered at work, restaurants, and retail stores etc.

Table1: Energy Prices ($)

	Base		Gas	Gas	Elec.
	Gas	Elec.	$4/gal	$4.5/gal	¢5/kWh
2011	2.62	0.10	2.62	2.62	0.05
2012	2.65	0.10	2.97	3.09	0.05
2013	2.80	0.10	3.31	3.56	0.05
2014	2.88	0.10	3.66	4.03	0.05
2015	2.95	0.10	4.00	4.50	0.05

The resulting total sales of different types of PEV are compared in Figure 5. Though both gasoline and electricity prices affect PEV sales, gasoline prices have a greater impact.

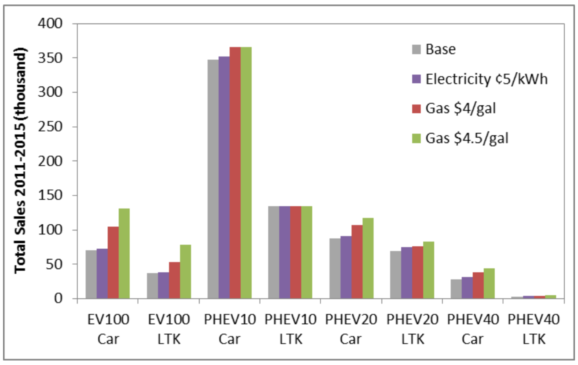

Figure 5: Total Sales Comparison: Higher Gasoline Prices and Lower Electricity Prices

3.5 Scenario Comparison

The cumulative PEV sales by 2015 are computed and compared for above mentioned scenarios, see Figure 6. When battery cost is reduced to meet the program goal or gasoline price surges beyond $4.5 per gallon, the combined BEV and PHEV sales reach one million by 2015. Though they all promote the PEV market by a certain degree, other strategies do not achieve the one-million goal by itself.

Figure 6: Total PEV Sales Comparison

4 Policy Implications

This section explores some alternative paths towards achieving the goal of putting one million PEVs on the road by 2015, including advances in battery technology, a possible surge in oil price, and government support in terms of deploying charging infrastructure and increasing tax credit incentives.

Path 1: Battery Technology Success

As mentioned in the previous section, reducing the battery cost to around $300 per kWh by 2015 alone will make PEV a competitive vehicle technology for over one million consumer adoption. The annual sales of different types of PEV are shown in Figure 7. Significant growth in PHEV20 and PHEV40 is observed, compared with the base case scenario (i.e. Figure 1).

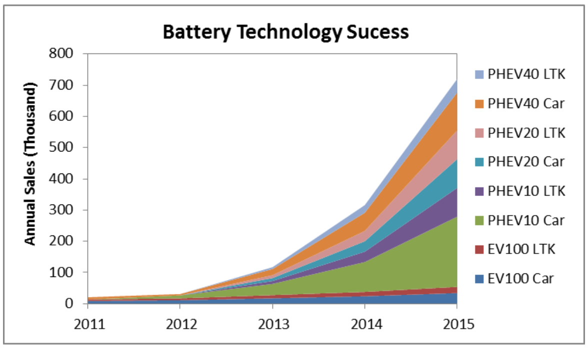

Figure 7: Impact of Battery Cost Reduction on Annual Sales of PEV

Path 2&3: Combining New Tax Credit with Charger Deployment or Higher Gasoline Price

Though implementing the new tax credit policy as specified in Table 2 will considerably promote the sales of BEVs, as well as increase PHEV sales, the total consumer adoption of PEVs by 2015 is still below one million. Therefore, the new tax credit scheme is evaluated in combination with the assumptions of gasoline prices rising higher than the AEO forecast and improvement in charging infrastructure deployment. In particular, scenario "New Incentive+$4 Gas" assumes that the new federal incentives providing more tax credit for PEV purchases is implemented and that the gasoline price reaches $4 per gallon by 2015. Scenario "New Incentive + Charger" considers applying new incentives and expending the charger coverage to achieve 65%, 20% and 20% for home, workplace and public charging, respectively. Both scenarios project a total PEV sale close to one million (about 950 thousands). As illustrated in Figure 8, implementing new incentives in tandem with deploying charging infrastructure has a greater impact on increasing EV100 car sales; while implementing new incentives with a higher gasoline price assumption offers more benefit for promoting PHEV20 and PHEV40 car sales.

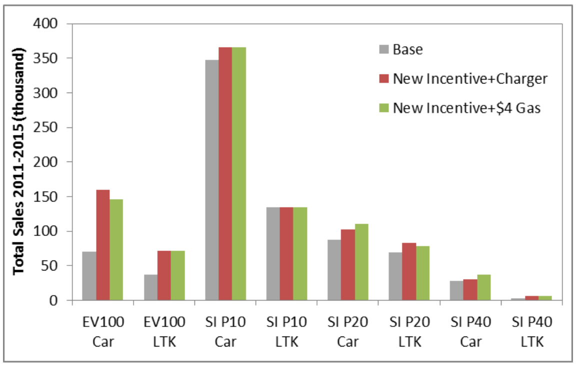

Figure 8: The Combination of New Tax Credit and Higher Gas Price or Charger Deployment

Path 4: Gasoline Price Reaches $4 per gallon and Charger Deployment

Finally, a scenario combing higher gasoline prices and broader charging infrastructure coverage is considered. Figure 9 compares the sales of different types of PEVs under such assumptions, against the base case. As a result, the total PEV sales by 2015 reach over one million.

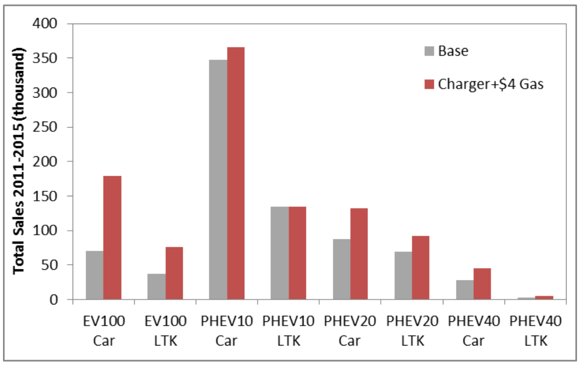

Figure 9: The Combination of Higher Gas Price and Charger Deployment

5 Conclusions

This paper evaluates the effect of different strategies on promoting PEV consumer market, and proposes some alternative paths towards one-million PEVs on the road in the U.S. by 2015. Declining battery costs and surging gasoline prices play an important role in achieving the ambitious goal, as well as the combination of federal incentives, charging infrastructure deployment and so on. In addition, some policy strategies benefit one PEV technology more than others. The costs associated with the alternatives paths to meet the one-million PEVs goal are not considered in the present paper and need to be quantified in the future study.

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