Electric Vehicle Adoption in Illinois

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prepared by
Yan Zhou, Marianne Mintz, Thomas Stephens, and Spencer Aeschliman
Energy Systems, Argonne National Laboratory

Charles Macal
Decision Infrastructure Sciences, Argonne National Laboratory

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SUMMARY

At the request of ComEd, this study analyzed a scenario in which plug-in electric vehicles (PEVs) are adopted at an accelerated rate in Illinois. Postulating a goal that 15% of on-road vehicles would be PEVs by 2032, we examined successful PEV adoption policies implemented elsewhere in the United States and abroad, characterized trajectories of new PEV sales and turnover of the existing vehicle fleet, projected PEV utilization and charging patterns, and computed resulting effects on energy demand, greenhouse gas emissions, and charging load. Based on the scale and scope of the goal, the body of evidence from the academic literature, and the dynamics of vehicle sales and replacement, we conclude that it will take a combination of strong incentives to achieve 15% PEV penetration in Illinois. First, the equivalent monetized value of incentives to vehicle purchasers will need to be a significant fraction of the price of the vehicle in order to induce a large fraction of consumers to purchase a PEV instead of a comparable conventional vehicle. Second, incentives and other policies need to be in place for several years to make a significant impact on the on-road stock. Third, federal, state, and local governments, automakers, dealerships, and non-profit organizations need to take concerted action to promote the adoption of PEVs. No single agent can implement policies that are likely to promote sufficient PEV adoption to accomplish the goal of 15% on-road penetration.

Markets for new vehicles are very heterogeneous. Different types and combinations of incentives are necessary, because different barriers affect different purchasers. In addition to policy, advancements in battery technology, changes in consumer behavior and economic factors play important roles in PEV adoption. Improvements in battery technology that significantly reduce vehicle cost and increase range could make PEVs more competitive within the existing market. The availability of a diverse set of PEVs of different size classes, styles, and capabilities could attract buyers in multiple market segments. Public charging could attract people who cannot charge conveniently at home (e.g., residents of multi-unit dwellings) or during long-distance travel. In addition to changes in the relative affordability of PEVs vis a conventional vehicles, economic signals such as persistently high oil prices could make PEVs more attractive. However, even significant increases in the attractiveness of PEVs can be offset by advances in competing conventional and new powertrain technologies (e.g., improved combustion engines and hydrogen fuel-cell vehicles).

Because there are inherent uncertainties in technology development, market projections, and the potential for implementing incentives, we have examined recent history as a guide to both policy options and realistic outcomes. For the latter, we highlight two cases – California and its Zero-Emission Vehicle (ZEV) mandate, and Norway – to illustrate that it takes significant funding and incentives over a long period of time to substantially increase PEV adoption.

California has been a leader in the adoption of PEVs; it has several financial and non-financial incentives in place at the state level. After aggressively promoting PEVs for over 10 years, EVs now account for almost 8% of new light-duty vehicles (LDVs) sold within the state. California has adopted a broad set of policies, actions, and regulations, including strongly incentivizing installation of residential and public chargers (there are now more than 25,000 ports in over 6,000 locations), and now has more PEV models available to consumers

than any other state. As early as 1990, California implemented a ZEV mandate, which required diverse model availability in the state.

Internationally, Norway is the world leader in per-capita PEV ownership, with about 56 PEVs per 1,000 people in 2018 (IEA 2020; EAFO 2018), and PEVs accounted for over 50% of total new passenger vehicle sales and 10.8% of passenger vehicles on the road in 2019 (Figenbaum 2020). Norway achieved these high penetration levels through a combination of generous financial and non-financial incentives to private consumers and company purchasers, and extensive infrastructure, including nearly 6,000 charging ports in over 2,500 locations. Financial incentives include a value-added tax reduction of 7,500 euros and a registration tax exemption of 10,000 euros, as well as avoidance of high gasoline taxes that result in pump prices equivalent to over 7 USD/gal. The monetary value of these and other incentives can make the cost of owning and operating a battery electric vehicle (BEV) much less than that of a conventional vehicle.

Nonetheless, neither Norway nor California has 15% PEVs on the road. Replacing 15% of the on-road stock of vehicles requires a high sales share for several (more than 10) years. This report summarizes the policies and regulations that have been implemented by ZEV states to promote PEV adoption and charging infrastructure deployment, in comparison with Illinois. It also analyzes possible adoption pathways to reach the PEV target of 15% of on-road vehicles in Illinois, resulting charging demand, and reductions in emissions of greenhouse gases and criteria pollutants.

1 INTRODUCTION

Over 1.3 million plug-in electric vehicles (PEVs) have been sold in the United States since 2010 when the first Chevy Volt and Nissan Leaf vehicles came on the market. Currently, electric vehicles account for about 2% of monthly light-duty vehicle (LDV) sales. More than 40 different electric vehicle models are actively being marketed, and most of these are LDVs. Over the last few years, automakers have brought more models, with varying mileage ranges, to the market, including medium-duty and heavy-duty trucks and buses. Government agencies at the federal, regional, and state levels, as well as utilities across the United States, have provided financial and non-financial incentives to promote electric vehicle adoption and charging infrastructure deployment. Argonne National Laboratory, sponsored by the U.S. Department of Energy, has developed tools and collected data to quantify the energy, economic, and environmental benefits of electric vehicles.

This project has three objectives. First, we summarize the policies and other actions of the federal government, various states/regions, and utilities to promote PEV adoption, and evaluate their relative effectiveness based on a review of the literature. Second, we identify possible PEV adoption paths or scenarios that would result in PEVs making up 15% of all on-road vehicles in Illinois, and we quantify the resulting impacts on petroleum consumption and electricity demand. We also summarize the possible reduction in greenhouse gas (GHG) and criteria pollutant emissions due to PEV adoption. The PEV scenarios include private and public adoption of electric cars, light trucks (e.g., sports utility vehicles [SUVs], vans, pickups), medium-duty vehicles (MDVs), and heavy-duty vehicles (HDVs). Third, we estimate hourly charging loads of light-duty PEVs in 2030 associated with these scenarios, incorporating assumptions about vehicle electric range, efficiency, and travel behavior.

2 PEV MARKET PENETRATION AND POLICIES TO PROMOTE ADOPTION

2.1 VEHICLE SALES AND MARKET SHARES

2.1.1 PEV Sales Trends

In 2019, U.S. sales of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) reached 325,839 units. In total, 1,443,627 PHEVs and BEVs have been sold in the United States since 2010, when the first Nissan Leaf and Chevy Volt models were introduced to the market (Figure 1). Today, about 40 different models are sold in the United States, although model availability varies by state. In Illinois, more than 6,500 PEVs were sold in 2019. About 80% of them were BEVs (EV Hub undated).

FIGURE 1 Annual and Cumulative PEV Sales by Model in the United States, 2013–2019
(Source: Argonne undated)

2.1.2 PEV Market Shares

While PEVs account for 2% of total U.S. LDV sales, they account for less than 1% of Illinois LDV sales. California exceeds the national trend, with PEVs now accounting for almost 8% of LDVs sold within the state (Figure 2).

FIGURE 2 Shares of PHEVs and BEVs as a Percent of Total LDV Sales: in the United States (left), Illinois (middle), and California (right); 2019 numbers in Illinois and California have been updated to June (Source: Argonne undated)

2.2 ACTIONS TO PROMOTE PEV ADOPTION

Several states, regions, and utilities have taken steps to promote PEV adoption. Activities range from outreach to stakeholders and other constituencies, to setting aspirational goals, to developing plans and programs to achieve specific milestones. States with a Zero-Emission Vehicle (ZEV) mandate are particularly active in promoting PEV adoption.

2.2.1 ZEV and Low-Emission Vehicle (LEV) Standards

The ZEV program was established under an October 2013 Memorandum of Understanding (MOU) among California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont. Today, 12 states have committed to the ZEV program.¹ The MOU commits the signatory states to building a robust market for ZEVs (Multi-State ZEV Task Force, 2018) but does not mandate specific policies.

In June 2018, the Task Force published a new ZEV Action Plan for 2018–2021. It set the following priorities for states and other key partners:

- Raising consumer awareness and interest in electric vehicle technology;

¹ New Jersey, Maine, Colorado, and Washington signed onto the MOU after 2013.

- Building out a reliable and convenient residential, workplace, and public charging/fueling infrastructure network;
- Continuing and improving access to consumer purchase and non-financial incentives;
- Expanding public and private sector fleet adoption; and
- Supporting dealership efforts to increase ZEV sales. (AFDC, undated)

California has unique authority to maintain motor vehicle emission standards that are stricter than federal standards, as long as the EPA has issued a waiver.² California refers to its standards as Low Emission Vehicle (LEV) standards (C2ES 2019). Other states may adopt California's standards, but they may not develop independent standards. Today, two other states (Delaware and Pennsylvania) — as well as the District of Columbia — are following California's LEV standards, but have not adopted the ZEV program.

Figure 3 shows the 12 ZEV and two LEV states, along with the other 36 states that follow federal emissions standards.³ Table 1 shows the PEV-promoting policies that each of them have adopted. Illinois is included as a point of reference. As shown in Table 1, Illinois has few policies promoting PEVs and associated infrastructure.

² In November 2019, the Trump administration revoked this waiver. California, along with other ZEV states, is currently challenging this action in court.

³ Washington became the 12th ZEV state on March 10, 2020. In that state, the ZEV standard went into effect on June 11, 2020.

FIGURE 3 States with ZEV and LEV Standards as of 2019

TABLE 1 Policies Promoting PEV Adoption in Illinois and the 12 ZEV States

State Policies/Programs	CA	CO	CT	IL	ME	MD	MA	NJ	NY	OR	RI	WA
ZEV program	Y	Y	Y		Y	Y	Y	Y	Y	Y		Y
PEV purchase subsidy	Y		Y		Y		Y	Y	Y	Y	Y	
PEV tax credit/sales tax exemption		Y				Y		Y				
Public fleet purchase subsidy	Y						Y		Y			
Truck/bus purchase incentive/tax exemption	Y					Y	Y		Y	Y		
State fee reduction or testing exemption		Y ^a	Y	Y ^a			Y		Y		Y	
Home EVSE incentive	Y	Y	Y			Y	Y	Y	Y	Y		Y
Public EVSE incentive	Y	Y		Y	Y	Y	Y	Y	Y			
Public fleet purchase requirement/guideline				Y								
Manufacturing incentive	Y											
EVSE permitting/building code regulation										Y		Y
HOV lane access	Y					Y		Y	Y			
Utility Programs												
Residential EVSE rebate	Y	Y	Y			Y	Y		Y	Y		
Non-residential EVSE rebate	Y	Y				Y	Y		Y	Y		
MUD and workplace EVSE rebate	Y					Y	Y					
PEV purchase/loan rebate	Y	Y	Y				Y ^b					
Charging rate reduction/incentive	Y					Y	Y		Y			

^a Colorado, Illinois, Oregon, and Washington have an additional annual registration fee for PEVs, as do 24 other non-ZEV states.

^b Massachusetts provides discounts on qualified PEVs purchased or leased from participating dealerships.

^c Tacoma Public Utility provides an incentive for customers to report charging patterns.

Source: Adapted from AFDC (undated).

Collectively, ZEV states currently account for nearly 30% of PEV sales and are committed to having at least 3.3 million ZEVs operating on their roadways by 2025. However, each state has adopted a somewhat different path toward that collective goal. As shown in Table 1, most (though not all) ZEV states have PEV purchase subsidies, incentives for deploying publicly available electric vehicle supply equipment (EVSE), and purchase incentives for home EVSE. Some of those purchase incentives are in the form of tax credits or waivers of sales taxes; others are rebates either at the point of sale or shortly thereafter.

2.2.2 Other State Actions

Both ZEV and non-ZEV states have enacted various policies to promote PEV adoption. In addition to purchase incentives, they include support for electrifying state- and other public-owned fleets, rebates or other financial incentives to promote investments in public charging infrastructure and/or to reduce the cost of public charging, state and regional planning and coordination, and consumer education and outreach.

Many states have adopted policies to promote electrification within their own fleets. “Leading by example,” these policies seek to both demonstrate the state’s commitment to

electrification and make PEVs more ubiquitous, thereby increasing consumer awareness. Unfortunately, however, the relatively higher cost of PEVs (as compared with their internal combustion [IC] counterparts) can strain limited state resources and violate procurement rules that often require contracting with the lowest bidder regardless of future operational and maintenance savings. In the future, with anticipated declines in battery costs, PEVs should approach IC cost parity and this issue should become less burdensome.

Today, most states are using Volkswagen (VW) settlement funds to deploy charging infrastructure at government- and non-government-owned facilities including workplaces, multi-unit dwellings, and along major travel corridors. According to the National Governor's Association (NGA), 35 states are utilizing the full share (i.e., 15%) of their VW mitigation trust funds for PEV charging installations (Rogotzke et al. 2019). States are also supporting PEVs on the regulatory front, approving utility "make-ready" investments up to the charger and, in some cases, permitting utilities to spread those costs over their rate base (see Section 2.2.3).

States are also collaborating in regional partnerships to develop charging infrastructure on major travel corridors. These efforts include the West Coast Electric Highway (spanning California, Oregon, Washington, and British Columbia), REV West (encompassing Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming), the Northeast Electric Vehicle Network (including all 12 east coast states from New England to Virginia), and the Mid-America Alternative Fuel Corridor (on I-80, from New Jersey to Pennsylvania, Ohio, Indiana, Illinois, and Iowa).

Despite these policies, PEV adoption continues to lag in many parts of the country. As stated above, PEVs comprised 2% of U.S. LDV sales in 2019; this is a rising share, but still far short of ZEV and other goals. Even in California, a majority of consumers are unaware of policies supporting PEV adoption (Kurani and Hardman undated; Turrentine et al. 2018).⁴ According to the NGA, "States need to overcome large gaps in consumer awareness about EV availability and incentives [...] if EVs are to make up a significant market share of vehicles sold" (Rogotzke et al. 2019). States are grappling with how best to engage car dealers, original equipment manufacturers (OEMs), private fleets, and consumers. Messaging focuses on how PEVs can save drivers money, potentially reduce electricity rates, improve public health, and reduce greenhouse-gas emissions from the transportation sector, as well as on providing information addressing common myths surrounding PEVs.

2.2.3 Utility Actions

While only two utility filings (totaling \$4.5 million) were related to transportation electrification investments in 2013, there were 159 such filings (representing nearly \$3.3 billion) by the end of 2019 (EV Hub undated, Lepre and Smith 2019). Of the 159 filings, commissions approved 112 (either with or without modification), while 47 were denied or withdrawn.

⁴ Between 2014 and 2017, Kurani and Hardman found no increase in the shares of California car-owning households who (a) considered purchasing a PEV, (b) were able to name a PEV model for sale, (c) were aware of PEV incentives, or (d) acknowledged having seen an away-from-home charger (despite the number of such chargers more than doubling in those three years).

Approved filings represent a potential utility investment of \$1.4 billion, nearly 75% of which is associated with three major California utilities⁵ (Figure 4). SCE, with over \$435 million in total approved investment, is particularly active. In May 2019, SCE launched the \$356 million “Charge Ready” program to enable charging at 870 sites for 8,490 PEVs (Arellanes 2020).

FIGURE 4 Approved Investments in Transportation Electrification by Regulated Utilities
(Source: adapted from EV Hub [undated])

As shown in Figure 5, approved investments could potentially support 51,114 charging stations (EV Hub undated).

FIGURE 5 Potential Charging Stations in Approved Programs by Utility (Source: adapted from EV Hub [undated])

⁵ Southern California Edison (SCE), Pacific Gas & Electric (PG&E), and San Diego Gas & Electric (SDG&E).

In addition to capital investment, many utilities (e.g., National Grid, Eversource, Portland General) promote electrification through outreach and education (Jones et al. 2017).

2.2.4 Actions to Promote PEVs in Underserved Communities

Programs like California’s Clean Vehicle Rebate Project (CVRP) have been found to aid “EV Anyway” purchases because, given the relatively higher price of PEVs, purchase incentives have tended to benefit wealthier buyers (Santulli and Williams 2015; Johnson and Williams 2016). Moreover, vehicles replaced by CVRP-incentivized PEVs tend to be more fuel efficient than those replaced by conventional vehicles (Xing et al. 2019). In response to these findings, California updated requirements for the rebate. Since March 2016, when those new requirements went into effect, the CVRP has seen a marked increase in participation by low-income households (Figure 6).

FIGURE 6 Recipients of Rebates from California’s CVRP by Household Income (Source: Williams and Bodanyi 2018)

Utilities have also responded to the criticism. As part of the transportation electrification filings discussed above, a number of utilities have initiated programs to promote electric mobility in less advantaged communities. Figure 7 contrasts the approximately \$345 million in approved electrification investments through September 2019 that include a transportation equity element (orange bars) with the approximately \$1 billion in total approved electrification investments through that date (blue bars).⁶ Four entities — SCE, PG&E, SDG&E, and Eversource — account for virtually all such equity investments.

⁶ Potential investment in transportation electrification through September 2019 (as shown in Figure 7) and approved investment through December 2019 (as shown in Figure 4) are nearly identical.

FIGURE 7 Utility Transportation Electrification Investments Dedicated to Underserved Communities (Source: Winjobi and Kelly 2020)

Another way of expanding electric mobility to lower income buyers is through incentives for the purchase or lease of used PEVs. Under a policy of “electrification for all,” some states and utilities offer rebates or other incentives for the purchase of used PEVs. As shown in Figure 8, California, Oregon, and Pennsylvania offer such incentives, as do several utilities.

FIGURE 8 States and Utilities Providing Incentives for Purchasing Used PEVs (as of March 2020) (Source: Winjobi and Kelly 2020)

Incentives for installing home EVSE may also promote “electrification for all” if eligibility includes purchasers of used PEVs. As shown in Figure 9, Hawaii, Maryland, and California incentivize home EVSE, as do a number of utilities.

FIGURE 9 States and Utilities Providing Incentives for Purchasing EVSE (Source: Winjobi and Kelly 2020)

2.3 RESEARCH ON PEV ADOPTION POLICIES

A number of researchers have examined policies to encourage PEV adoption. Zhou et al. (2014, 2016), Stephens et al. (2018), Collantes and Eggert (2014), DeShazo (2016), Liao et al. (2016), Jin et al. (2014) and Anable et al. (2014) summarize many of these efforts. Since 2016, another 33 studies have been published, most of which are reviewed and summarized in Hardman et al. (2017), Hardman (2019), Coffman et al. (2017), Jones et al. (2017), Cattaneo (2018) and Morrison et al. (2018). Although these studies differ in scope, timeframe, geography and methodology, most of them rely on surveys, workshops, interviews, and case studies, especially initially. More recently, with additional data availability, statistical analysis and modeling have become more common.

Most studies focus on financial incentives for PEV purchase or use. Supply-side effects, such as PEV model availability and the role of ZEV mandates and/or Low-Carbon Fuel Standards, have also been studied. However, metrics and paradigms are challenging for analyses of non-financial incentives like public information and outreach, and interactions between different incentives.

Table 2 shows the variation in scope of PEV adoption policies examined in 33 studies published since 2016.

TABLE 2 Scope of PEV Adoption Policies Examined in 33 Recent Studies

Scope	Policy Type
National	PEV purchase subsidy/tax credit
	EVSE purchase subsidy/credit
	Emission/fuel standards/taxes
State	PEV purchase subsidy/credit
	Licensing fee reduction
	Emission test exemption
	EVSE purchase
	EVSE purchase subsidy/credit
	Preferential parking/tolls
	Public charging provision/support
	Fleet purchasing
	PEV/EVSE manufacturing support
	Low carbon/zero emission policies
	Outreach/education
City/ Metropolitan Region	PEV purchase subsidy
	Preferential/reduced parking/tolls
	Access to high-occupancy vehicle (HOV) lanes or restricted zones
	EVSE purchase subsidy/financing
	Public charging provision/support
	Fleet purchasing
	Streamlined EVSE permitting /building codes
	Outreach /education
Utility Service Territory	Public EVSE provision/support
	Preferential PEV charging rates
	Home/work EVSE provision/financing
	Outreach/education

Table 3 summarizes the policies reviewed in these studies by geographic region. Some studies examined multiple regions; others examined multiple policies; still others examined multiple policies across regions. Although most North American studies investigate the United States, Melton et al. (2017 and 2020) and Wollinetz and Axsen (2017) focus on Canada.

TABLE 3 Geographic Regions of PEV Adoption Policies Examined in 33 Recent Studies

Policy Type	Total 2016–2019 ^a	North America ^b (California)	Europe ^c (Norway)	China ^d
Purchase incentive:	12	6	6	0
- PEV rebates/tax credits	12	(2)	(3)	0
Preferential access/use:	21	9 (3)	8 (5)	4
- Parking	8	4 (1)	3 (1)	3
- HOV lanes/restricted zones	18	9 (4)	7 (5)	4
Operating cost savings:	13	4 (4)	7 (4)	5
- Licensing fees	8	3 (2)	0	5
- Charging costs	1	0	0	1
- Higher gas prices	3	2 (1)	2 (0)	0
- Tolls	6	0	5 (5)	1
Infrastructure	22	12 (3)	8 (3)	6
- Public charging	21	11 (3)	7 (2)	6
- Workplace charging	4	3 (1)	1 (1)	0
- Building codes/PEV readiness	0	0	0	0

^a Row and column sums do not add due to multiple regions and/or policies included in individual studies.

^b Bonges and Lusk (2016); Kurani et al. (2016); Lutsey et al. (2016); Sheldon et al. (2016); Silvia and Krause (2016); Tal and Nicholas (2016); Levinson and West (2017); Jenn et al. (2018); Narassimhan and Johnson (2018); Wolbertus et al. (2018); Zhou et al. (2017); Zambrano-Gutierrez et al. (2018); Gorzelany (2019); Hardman and Tal (2016); Javid and Nejat (2017); Sheldon and DeShazo (2017); Tal and Xing (2017); Wolinetz and Axsen (2017); Melton et al. (2017, 2020).

^c Ajanovic and Haas (2016); Bjerkan et al. (2016); Figenbaum and Kolbenstvedt (2016); Langbroek et al. (2016); Mersky et al. (2016); Nilsson and Nykvist (2016); Plotz et al. (2016); Tietge et al. (2016); Zhang et al. (2016); Figenbaum (2017); Slowik and Lutsey (2016); Tal (2016); Kangur et al. (2017); Egner and Trosvik (2018); Adeptu et al. (2016).

^d Wang et al. (2017a–c); Wee et al. (2018); Huang and Qian (2018).

Figure 10 shows the results of these studies are consistent across different technologies. As shown in Figure 10, increasing the number of PEV models available to buyers and expanding charging opportunities are most effective, followed by providing purchase incentives and preferential access to transportation facilities.

FIGURE 10 Number of Studies by Type of Policy Incentive and Methodology Used to Examine Effectiveness of PEV Adoption Incentives

2.4 CONCLUSIONS ON THE EFFECTIVENESS OF PEV ADOPTION POLICIES

Based on our examination of the PEV market and its development over time, our review of the literature, and our understanding of both consumer behavior in general and PEV adoption more specifically, we conclude:

- Although all types of PEV purchase incentives can increase adoption, some features are especially effective:
 - Incentives at the point of sale.
 - Incentives for PEVs at lower price points and/or with lower incremental cost.
 - Long-term incentives, especially if coupled with consumer outreach.
 - Incentives that contribute to “electrification for all” goals.
- Improved access to infrastructure is very effective at increasing adoption:
 - Especially when focused on home and workplace charging.
 - When other conditions are also favorable (in other words, infrastructure is a necessary, but not exclusive, precondition for increasing adoption).
- Public education and outreach is effective:
 - When combined with other PEV incentives (increasing their effectiveness).
 - When other conditions are also favorable (again, public education is a necessary, but not exclusive, precondition for increasing adoption).
- Preferential access and pricing is effective:
 - Where conditions increase incentives’ perceived value (e.g., preferential access for PEVs to carpool lanes on congested roadways).

- Until that perceived value diminishes (e.g., carpool lanes become as congested as other lanes) and/or preferential access becomes financially or operationally burdensome to the agency providing it.
- PEVs in public fleets demonstrate commitment to electrification (i.e., “leading by doing”) and increase community awareness, which can further increase adoption.
- Effects of EVSE purchase incentives are difficult to assess:
 - Home EVSE purchases typically occur *after* the decision to adopt; thus, it is unclear whether the decision to purchase EVSE (and the availability of incentives for their purchase) affects the PEV adoption decision.
 - Incentives for workplace and public EVSE charging indirectly influence PEV purchases by improving charging infrastructure.
- Utility efforts (e.g., vehicle or infrastructure purchase incentives and “make-ready” investments):
 - Are becoming more widespread, beyond ZEV and LEV states.
 - Unfortunately, however, there is relatively less documentation and analysis of these efforts in the peer-reviewed literature.

3 SCENARIOS OF PEV ADOPTION PATHWAYS

3.1 PEV SALES SHARES NEEDED TO REACH 15% OF ON-ROAD STOCK BY 2032

Hypothetical scenarios of accelerated adoption of light-duty PEVs in Illinois were modeled assuming that PEV market shares increase at given annual growth rates starting in different years. An additional scenario, derived from the Energy Information Administration's 2019 Annual Energy Outlook (AEO) Reference case (EIA 2019) was developed by scaling the vehicle stock by 3.9% (the percentage of LDVs in the United States that are registered in Illinois) and the vehicle miles traveled, energy use and emissions by 3.2% (the percentage of U.S. VMT in Illinois). The growth rate in PEV sales shares required to reach 15% of the LDV stock was determined, and the sales, electricity use, petroleum use, and GHG emissions by LDVs in Illinois were estimated using the Argonne VISION model (Argonne 2019a,b) for the years 2020 through 2032. The question we intended to address is how fast do PEV sales shares need to grow to get 15% of the on-road stock to be PEVs in 2032?

Because a modest growth rate was assumed for PEV shares prior to the first year of accelerated growth, starting the accelerated growth later requires a faster growth rate to meet the 15% stock target. That is, in order to have 15% PEVs on the road in 2032, PEV sales shares must increase more rapidly than they have in recent years; if this increase in sales shares starts later, the growth rate must be even higher. As shown in Figure 11, PEV shares of LDV sales must rapidly grow to very high levels, in excess of 30% by 2030. This market penetration is much more rapid than most PEV market projections, and aggressive adoption policies would likely be required to achieve it. The annual growth rates required for different start years (year of initial accelerated growth rate) are given in Table 4. Starting in 2026 would require a growth rate that is more than double that required if starting in 2022. The sooner PEV sales are accelerated, the easier it will be to reach 15% PEVs on-road by 2032.

FIGURE 11 PEV Sales Shares Needed for PEVs to Reach 15% of LDV Stock with Different Start Years

**TABLE 4 Annual Growth Rate in PEV Sales
Shares for PEVs to Reach 15% of LDV Stock by
2032**

Start Year	Required Annual Growth Rate
2022	26.5%
2023	30.7%
2024	36.8%
2025	47.8%
2026	66.5%

The aggressiveness of these projections can be appreciated by comparing the projected PEV sales in Illinois for these scenarios, shown in Figure 12 with actual PEV sales in Illinois of 7,357 vehicles in 2018 (Auto Alliance 2020). In the accelerated growth scenarios, PEV sales grow by a factor of 50 or more within a few years.

FIGURE 12 Illinois LDV EV Sales

3.2 ACCELERATED LDV SCRAPPAGE AND REPLACEMENT SCENARIO

An alternative scenario for rapidly increasing the PEV share of on-road LDVs was analyzed. In this scenario, we assumed that light-duty gasoline-powered vehicles more than 10 years old would be scrapped at an increased rate in year 2030, and that scrapped vehicles would be replaced by new BEVs. We assumed that for these older vehicles the scrap rate would be about 5% higher than typical, resulting in about 130,000 gasoline cars and light trucks being taken off the road and replaced by new BEVs. This number of vehicle is about 1.4% of the on-road stock of LDVs. These BEVs were assumed to be purchased in addition to the base-case sales projected for future years. This was modeled in the Argonne VISION model, and national-level results were scaled by the Illinois fraction of on-road LDVs, as was done with the scenarios described in Section 3.1. Figure 13 shows the resulting on-road share of PEVs for the base case and for the accelerated scrappage case.

FIGURE 13 LDV PEV Stock Share in Illinois under the Accelerated Scrappage/Replacement Scenario

To put this in context, this fraction of vehicle stock can be compared to the 2009 federal Car Allowance Rebate System (CARS) or “Cash for Clunkers” program, which provided rebates for vehicle owners to scrap cars and light trucks that had low fuel economy. About 700,000 vehicles were scrapped, and nearly \$3 billion was spent on rebates (Huang 2010). This number of vehicles can be compared to the 10.2 million new LDV sales and the 135 million LDVs registered in the United States in 2009. Therefore, the Cash for Clunkers program induced vehicle owners to scrap about 0.5% of the existing LDV stock. The scenario analyzed here would assume more than twice that scrappage and replacement rate. Even so, the PEV stock share increases by just 1.4%, so achieving 15% PEVs by 2032 would likely require significantly more PEV adoption. In all likelihood, an even more aggressive accelerated scrappage program would be required, in combination with other incentives. Analysis of such a combination of incentives and aggressive scrappage was beyond the scope of this effort.

3.3 ACCELERATED MEDIUM- AND HEAVY-DUTY PEV ADOPTION SCENARIO

A scenario of accelerated adoption of BEVs in MDVs and HDVs was modeled, in which the annual growth rate increases by 26.5% per year, starting in 2022, as in one of the accelerated growth rate scenarios for LDVs. This may be more optimistic than the corresponding LDV scenario, since the PEV market is less mature than the LDV market, fewer medium- and heavy-duty PEVs are being offered by vehicle manufacturers, and other barriers remain significant (Satterfield and Nigro 2020; Smith 2019). Assuming this BEV sales share growth rate in Class 3–6 trucks and in Class 7 and 8 combination (tractor trailer) trucks produces the projections in Figure 14, which shows Class 3–6 BEV sales and stock, and Figure 15, which shows Class 7 and 8 BEV shares.

FIGURE 14 MDV PEV Sales Shares in Illinois under the Accelerated Growth Rate Scenario

FIGURE 15 HDV EV Sales Shares in Illinois under the Accelerated Growth Rate Scenario

Although BEV sales shares grow quickly in these accelerated growth rate scenarios, they start at a fraction of a percent. Thus, the stock fraction of BEVs, which starts close to zero, grows only slowly. Scaling the national-level results from the VISION model by 3.8% (the fraction of trucks in the United States that are registered in Illinois), BEV stock projected for Illinois in 2032 is 13,000 medium-duty (Class 3–6) BEVs, out of 332,000 total medium-duty trucks, or 3.8% of on-road medium-duty trucks, and 1,650 heavy-duty (Class 7 and 8) BEVs out of 200,000 Class 7 and 8 trucks.

4 ENERGY AND EMISSION IMPACTS

4.1 ENERGY USE

The energy used by PEVs and by all LDVs, as well as the GHG tailpipe (or tank-to-wheels, TTW) emissions, were calculated for the scenarios described in Section 3. Default assumptions were used in the Argonne VISION model about annual distance driven as a function of vehicle age and fuel or energy cost per mile. The VISION model gives U.S. national-level estimates which were scaled down to represent vehicle sales, energy use, and emissions in Illinois. Vehicle sales and stocks were scaled by 3.9% (the percentage of LDVs in the United States that are registered in Illinois) and the vehicle miles traveled, energy use, and emissions were scaled by 3.2% (the percentage of VMTs in the United States that LDVs travel in Illinois).

Figure 16 shows the projected electricity demand from PEVs in Illinois for the five accelerated growth rate scenarios described in Section 3.1. They each reach 15% of PEVs in on-road stock by 2032, but start in different years.

FIGURE 16 Illinois LDV PEV Electricity Use in the Accelerated Growth Scenarios and Base Case

Electricity demand projected for the accelerated scrappage/replacement scenario was estimated and is shown in Figure 17. The electricity demand mirrors the growth in stock share of PEVs, as expected. Electricity demand projected for the accelerated medium- and heavy-duty PEV growth rate scenario was estimated and is shown in Figure 18. Electricity demand for medium- and heavy-duty PEVs is lower than that for light-duty PEVs, since the number of PEVs is much lower.

FIGURE 17 Illinois LDV PEV Electricity Use in the Accelerated Scrappage/Replacement Scenario

FIGURE 18 Illinois Medium- and Heavy-duty PEV Electricity Use in the Accelerated Growth Rate Scenario

4.2 PROJECTED GREENHOUSE GAS EMISSIONS

The total TTW (tailpipe) emissions of GHGs by LDVs in Illinois were estimated for the five accelerated PEV adoption scenarios and the base case. As shown in Figure 19, replacing 15% of LDVs with PEVs decreases GHG emissions; however, the decrease in 2032 is about 8%, which is less than the BEV stock percentage. This is because the base case assumes that the on-road stock of PEVs is almost 6% of LDVs. In addition, some PEVs are PHEVs (about 20% of plug-in electric cars, and about 40% of plug-in electric light trucks), which do use some gasoline and emit some GHGs, and because PHEVs (like BEVs), with 40–45% lower cost per mile for energy, are assumed to be driven 20–25% more miles per year than the ICEVs they replace.

FIGURE 19 Illinois LDV GHG Emissions, TTW (Tailpipe) for the Five Accelerated Growth Rate Scenarios and Base Case

Changes in GHG emissions for the accelerated scrappage/replacement scenario were about 1.5% of the GHG emissions for LDVs in the base case, much less than for the accelerated growth rate scenarios, since the increase in BEV stock shares (and resulting decrease in ICEV stock share) was smaller. Likewise, small changes in GHG emissions were projected for the medium- and heavy-duty scenario — about 2.5% of GHG emissions from MDVs and HDVs — since the PEV stock fraction was low.

In all these scenarios, the projected driving (as measured by VMTs) and resulting emissions depend on assumptions about driver behavior and vehicle efficiency. Note that a more comprehensive accounting of GHG emissions would include emissions from well-to-wheels (WTW), from power plants used to provide the electricity for PEV charging as well as emissions from extracting and refining fuel used to power these generating plants and to power ICEVs. GHG emissions, calculated for the full WTW cycle, would be higher, unless the electricity were generated from a zero-GHG source. All scenarios would show similar emissions, that is, a smaller percentage change would be seen in the accelerated EV adoption scenarios.

4.3 POTENTIAL REDUCTIONS IN CRITERIA POLLUTANT EMISSIONS

Criteria air pollutants (CAPs), including volatile organic compounds (VOCs), nitrogen oxides (NO_x), particulate matter of 10-micron diameter (PM₁₀) and 2.5-micron diameter (PM_{2.5}), and sulfur oxides (SO_x), emitted by on-road vehicles are regulated by the U.S. Environmental Protection Agency (EPA 2019, 2020). BEVs emit little or no CAPs (very small amounts of PM₁₀ are emitted from tire and brake wear), so the TTW emissions can be almost eliminated by replacing ICEVs by BEVs. However, emissions from the full fuel cycle (WTW) should be considered, since upstream emissions from electricity generation can be significant, depending on how electricity is generated. Figure 20 compares examples of TTW and WTW emissions from typical cars with gasoline engine, diesel engine, or battery electric powertrains, as estimated using the Argonne GREET model (Argonne 2019b). WTW NO_x emissions of the BEVs are less than those of gasoline and diesel vehicles, but still significant. The WTW SO_x emissions of the

BEV are considerably higher than that of the gasoline and diesel vehicles. WTW emissions shown here were estimated assuming the average U.S. electricity generation mix. The WTW NO_x and SO_x emissions of the BEVs would be much lower if electricity were generated using nuclear, wind, or solar power.

FIGURE 20 TTW and WTW CAP Emissions from Gasoline, Diesel, and Battery-electric Powered Vehicles

These results are examples of vehicle lifetime-weighted averages for new midsize cars under typical driving conditions. Actual emissions will depend on the specific vehicle, vehicle age and condition, and driving conditions. Emission control equipment on vehicles can deteriorate with age, which means older vehicles may produce higher emissions. Even more significant, because emissions standards have become more stringent over the past decades, newer vehicles are built with more effective emission controls, and emissions from earlier model-year vehicles can be several times the amount emitted by current model-year vehicles. Because of these complexities, stock-level CAPs emissions were not estimated for the scenarios analyzed above. However, it can be concluded that greater adoption of BEVs can certainly reduce tailpipe emissions, depending on how electricity used for charging PEVs is generated. High levels of PEV adoption with clean electricity sources can greatly reduce vehicle CAP emissions.

4.4 CHARGING DEMAND IN 2032

Following the methodology developed by coauthors previously, we conducted a grid impact analysis to quantify the charging demand when there are 15% of PEVs in the on-road stock in Illinois by 2032 (Elgowainy et al. 2012). Three separate charging strategies were assumed:

- End-of-day charging: drivers plug in as soon as they arrive home from their final trip of the day and charge as long as necessary to attain a full state of charge.

- Departure charging: PEVs are scheduled to charge overnight, starting at a time such that the battery is fully charged right when the driver leaves for their first trip of the day.
- Opportunity + end-of-day charging: drivers who have an opportunity to charge while at work do so, but also do end-of-day charging. Drivers who do not have an opportunity to charge at work do end-of-day charging as described above.

2017 *National Household Travel Survey* (NHTS) data (FHWA 2017) were used to determine home and work departure and arrival times as well as VMTs in order to calculate required charging lengths. Vehicles were grouped into four NHTS-defined classes in order to more accurately reflect distances traveled by vehicle type: cars, SUVs, vans, and pickup trucks. Projections from EIA's 2020 Annual Energy Outlook (EIA 2019) were combined with *Highway Statistics* data (FHWA 2018) to estimate the number of PEVs in Illinois in a 15% adoption scenario. On top of the analysis for Illinois, we also used the same methods for a grid impact analysis in the Chicago area. For the Chicago analysis, we used data from the 2008 *Chicago Household Travel Survey* (CMAP 2008) instead of the NHTS. Figures 21 and 22 show the results of the Illinois and Chicago analyses.

FIGURE 21 Hourly Charging Load by Charging Strategy in Illinois in 2032

The departure and end-of-day scenarios are nearly mirror images of each other, with the departure-only charging resulting in a higher peak. This may be more acceptable, however, since its peak falls outside of the likely peak from non-EV energy use. Coming between 6:00 and 9:00 p.m., the end-of-day charging peak may worsen the non-EV peak. The opportunity charging scenario shows how such an overlap may be lessened. When some drivers take care of their charging at work, the end-of-day peak is around 20% lower. Enabling or encouraging this type of broken-up charging behavior — at work or elsewhere — during the day could help prevent excess strain on the grid during peak hours.

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Energy Systems Division

Argonne National Laboratory
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439

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