FORECAST OF ON-ROAD ELECTRIC TRANSPORTATION IN THE U.S. (2010 - 2035)

IEE Whitepaper
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Forecast of On-Road Electric Transportation in the U.S. (2010–2035)

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In 2010, the transportation sector comprised 29 percent of total national energy consumption in the U.S., making it the second largest consumer of energy, behind only the industrial sector. Within transportation, the 225 million light duty vehicles (LDVs) in the U.S. (i.e., cars and light trucks) today consume almost 60% of energy in the transportation sector.[1] This is expected to grow to as many as 276 million LDVs by 2035. Fossil fuels currently make up about 99 percent of the fuel in transportation and 31 percent of U.S. greenhouse gas emissions can be tied to the burning of fossil fuels in the transportation sector.[2] Electrification of transportation makes sense from both an economic and environmental perspective and is beginning to gain traction in a variety of applications. This report provides a forecast of electricity use in transportation from 2010 to 2035 based on the progressive adoption of electric vehicles, primarily electric light duty and commercial vehicles.

Various policy, technology, and economic drivers as well as consumer demand will determine the ultimate levels of electric vehicle adoption, including: advances in battery technology, oil prices, and government mandates on fuel economy (e.g., CAFE standards). And, in turn, electric vehicle adoption will impact greenhouse gas emissions. For illustrative purposes, IEE developed *low, medium,* and *high* electric transportation scenarios. These scenarios provide projections based on EIA's Annual Energy Outlook (AEO) 2012 Reference Case, advances in battery technology (e.g., improved battery chemistry that allows for faster and deeper charging and reductions in battery cell and other component costs), and oil prices increasing to $200 per barrel:

- Under the *low* electric transportation scenario, based on the AEO 2012 Reference Case, electric light duty vehicles (LDV) comprise 2 percent of the registered vehicle stock (5.3 million out of 276 million light duty vehicles), and electricity consumption increases by 33 TWh in 2035. The switch to electric LDVs reduces vehicle emissions by about 9 to 22 million metric tons of CO_2 equivalent in the year 2035 based on a 2035 power generation mix. The specific reduction depends on improvements in internal combustion engine (ICE) technologies, as well as changes in the electric power generation fuel mix.[3]

[1] DOE, Annual Energy Outlook 2012

[2] EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. April 2013

[3] Emission reduction estimates are based on data from DOE's Alternative Fuels Data Center, EIA's Annual Energy Outlook 2012, improvements to ICE vehicle fuel economy, and the PHEV and AEV share of vehicle

- Under the *medium* electric transportation scenario, based on advances in battery technology, electric LDVs comprise 10 percent of the registered vehicle stock (24.8 million out of 261 million light duty vehicles), and electricity consumption increases by 112 TWh in 2035. The switch to electric LDVs reduces vehicle emissions by about 41 to 94 million metric tons of CO_2 equivalent in the year 2035 based on a 2035 power generation mix. The specific reduction depends on improvements in ICE technologies, as well as changes in the electric power generation fuel mix.

- Under the *high* electric transportation scenario, based on the advances in battery technology and high oil prices ($200/barrel in 2035), electric LDVs comprise 12 percent of the registered vehicle stock (30.4 million out of 256 million light duty vehicles), and electricity consumption increases by 147 TWh in 2035. The switch to electric LDVs reduces vehicle emissions by about 51 to 116 million metric tons of CO_2 equivalent in the year 2035 based on a 2035 power generation mix. The specific reduction depends on improvements in ICE technologies, as well as changes in the electric power generation fuel mix.

Table 1 shows the stock of registered electric LDVs in the low, medium, and high scenarios. As demonstrated in Table 1, advances in battery technology alone will have a major impact on electric vehicle adoption resulting in almost 25 million EVs by 2035. Combining advanced battery technology with high oil prices will spur the adoption of EVs even more resulting in more than 30 million EVs by 2035.

Table 1: Light Duty Electric Vehicle Stock: Forecast by Scenario (thousands)

Light Duty Electric Vehicle Stock by Scenario	2010	2015	2020	2025	2030	2035
Low Scenario: AEO 2012 Reference Case	20	230	900	1,960	3,430	5,330
Medium Scenario: Advanced Battery	20	839	3,711	8,079	15,560	24,800
High Scenario: Advanced Battery & High Oil ($200/barrel in 2035)	20	1,117	5,354	11,069	19,295	30,400

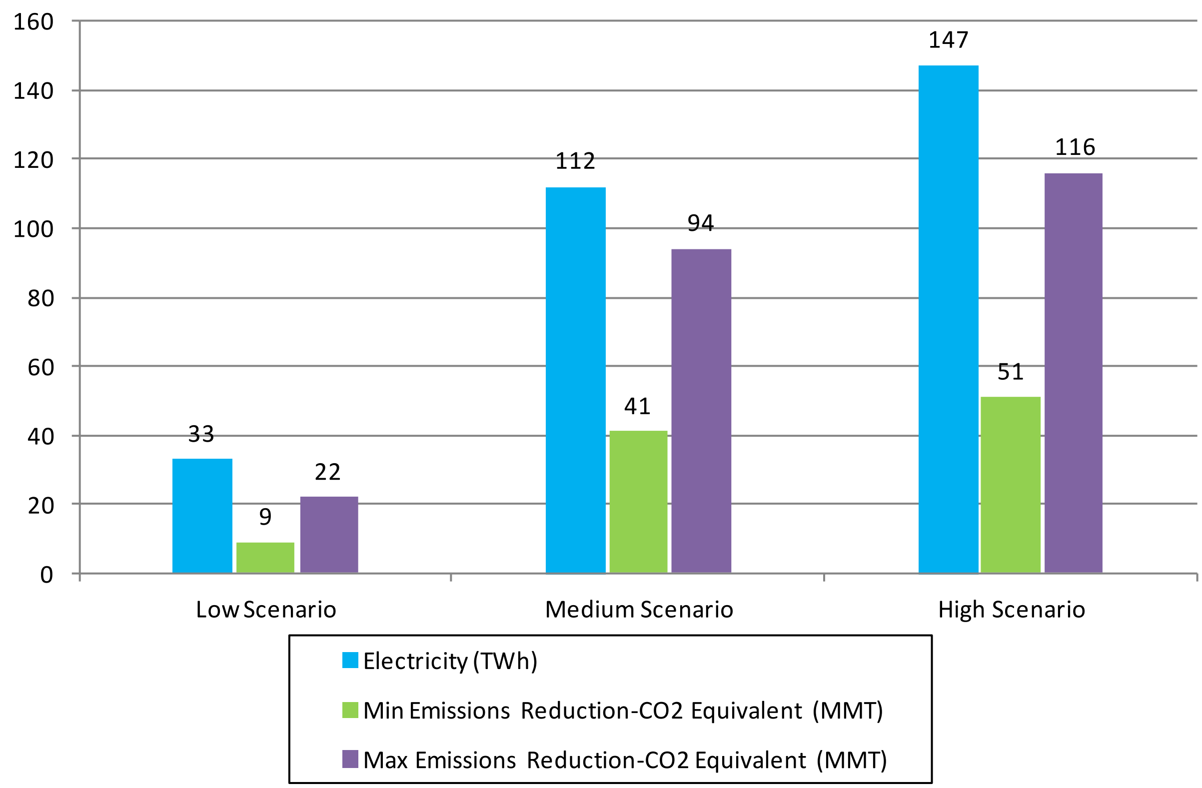
Figure 1 shows the results of the low (33 TWh), medium (112 TWh), and high (147 TWh) electric transportation scenarios in terms of electricity usage and carbon reduction. Under the medium scenario, based on advances in battery technology, if EVs comprise 10% of the registered vehicle stock in 2035, this would result in a reduction of 41 to 94 million metric tons of CO_2 equivalent depending on the improvements to ICE technologies and the carbon intensity of the 2035 power generation mix.

stock in each scenario. See Appendix B for details on alternative ICE efficiency and power sector mix scenarios. http://www.afdc.energy.gov/vehicles/electric_emissions.php

Given that LDVs comprise nearly 60 percent of energy in the transportation sector today and the recent influx of electric drive vehicles in the domestic auto market, six light duty vehicle scenarios are explored in detail in this report and three are used to illustrate the range of electric LDV opportunities. In addition to LDVs, the electrification of other vehicles that support the movement of goods and people such as commercial light trucks, transit and school buses, freight trucks, air transportation, domestic and international shipping, and military use vehicles are also examined in this report.

Another opportunity in the transportation sector is the electrification of non-road transportation equipment, but that is not included in this report.

Figure 1: Electricity Consumption and Vehicle Emissions Reduction by Scenario in 2035 (TWh and CO_2 Equivalent MMT)



INTRODUCTION

This analysis is based on AEO 2012's Transportation Sector Reference Case for all fuels. Table 2 shows total energy use and electric energy use in 2010 for each of the vehicle classes identified in the AEO. Light-duty vehicles (LDV)—consisting of automobiles, light trucks, and motorcycles—dominate total energy usage in the transportation sector (58.2%), followed by freight trucks and air transportation. Considering electric energy for transportation, however, light duty vehicles consume only 1% of electric energy, with intercity, transit, and commuter rail collectively accounting for 98.6% of electric transportation use today. Hence, LDVs represent a large electrification opportunity.

For each of the vehicle types outlined in Table 2, we identify electrification opportunities in Table 3. LDVs represent the largest transportation electrification opportunity, because although LDVs dominate energy usage in the transportation sector, the penetration of electric LDVs is still small, as indicated in Table 2. The most common options for electric LDVs are all-electric vehicles (AEVs), which operate solely on battery power, such as the Nissan Leaf and Tesla S, and plug-in hybrid electric vehicles (PHEVs), which operate on both battery power and fossil-fuel, such as the Chevy Volt and Prius Plug-in. A typical AEV consumes 3,000 to 4,000 kWh per year, slightly more than an average central air-conditioner. A PHEV consumes between 20-50% of the electricity used by an AEV, depending upon battery range and driving habits, with the remainder of its energy coming from gasoline.[4] This estimate is fairly conservative.[5]

In addition to LDVs, electrification opportunities exist within commercial light trucks, transit bus, school bus, military, freight trucks, air transportation, and domestic and international shipping vehicle types. In this paper, we identify LDVs, commercial light trucks, transit bus, school bus, and on-base military ground vehicles as vehicle types that can be fully electrified. Conversely, the electrification opportunity of freight trucks, air transportation, domestic and international shipping is restricted. These vehicles can be electrified to only a small degree due to physical and economic constraints.

[4] http://avt.inel.gov/evproject.shtml

[5] Data from Volt Stats, which tracks the real world electricity usage and performance of Chevy Volts from a sample set of Volt drivers shows that 70-80 percent of total miles driven are on electric. http://www.voltstats.net/

Table 2: Transportation Sector Energy Consumption by Vehicle Type (2010)

Vehicle Type	2010 Energy Use All Fuels (TBTU)	% of All Energy	2010 Energy Use Electricity Only (GWh)	% of Electric Energy
Light-Duty Vehicle	16,056	58.2%	64	1.0%
Commercial Light Trucks	554	2.0%	19	0.3%
Transit Bus	106	0.4%	3	0.0%
School Bus	116	0.4%	3	0.0%
Military Use	765	2.8%	6	0.1%
Freight Trucks	4,822	17.5%	0	0.0%
Air Transportation	2,515	9.1%	0	0.0%
Domestic Shipping	218	0.8%	0	0.0%
International Shipping	861	3.1%	0	0.0%
Freight Rail	453	1.6%	0	0.0%
Intercity Bus	30	0.1%	0	0.0%
Intercity Rail	15	0.1%	448	6.7%
Transit Rail	15	0.1%	4,370	64.8%
Commuter Rail	18	0.1%	1,826	27.1%
Recreational Boats	254	0.9%	0	0.0%
Miscellaneous	787	2.9%	0	0.0%
Totals	**27,586**	**100.0%**	**6,741**	**100.0%**

Source: EIA, Transportation Sector Key Indicators & Delivered Energy Consumption. AEO 2012 Reference Case
Note: Highlighted values identify vehicles with electrification opportunities.

For example, the energy density required for shipping freight overseas and over rail exceeds the limits of current and foreseeable electric and battery technologies. These modes of transit are simply too heavy and require too much range for electrification of the primary drive systems. The same applies for aircraft when in flight. However, particular applications within these segments may offer efficiencies from electrification when idling. A jetliner idling at the gate which typically runs a small turbine on jet fuel to produce auxiliary power for lighting and air conditioning can reduce jet fuel use by connecting to the terminal's electric supply. Electrification of freight trucks at rest stops when idling/stopped is also a viable option. Domestic and international container ships can also be powered by electricity while docked at the port. Appendix A shows the transportation electrification modeling strategy by vehicle type in greater detail.

Non-road transportation equipment at airports, seaports, mines, warehouses, intermodal facilities, and agriculture production sites also represent tremendous electrification opportunities, but this report primarily focuses on on-road transportation opportunities.

Table 3: Transportation Electrification Opportunities

Vehicle Type	Description	Electrification Opportunity
Light-Duty Vehicle	Automobiles, Light Trucks, Motorcycles in both personal and commercial fleet usage	Electrify primary vehicle drive
Commercial Light Trucks	Trucks from 8,501-10,000 lbs gross vehicle weight	Electrify primary vehicle drive
Transit Bus	Buses with routes inside a single metropolitan area, traversing relatively short distances with more frequent stops	Electrify primary vehicle drive
School Bus	Buses that carry students to and from educational facilities, frequent stops	Electrify primary vehicle drive
Military Use	Mix of military ground, air, and sea vehicles	Ground vehicles only, Electrify primary vehicle drive
Freight Trucks	Trucks greater than 10,000 lbs gross vehicle weight	Utilize electric umbilical for auxiliary power when idling
Air Transportation	All air carriers of passenger and cargo, as well as general aviation and small aircraft	Replace onboard mini turbine with electric umbilical for auxiliary power when idling at gate
Domestic Shipping	Water vessels with both departure and arrival at a U.S. port	Shore power: shipyard auxiliary tether to prevent idling in Domestic Oceanliners
International Shipping	Water borne vessels with either a departure or an arrival at a U.S. port, but not both	Shore power: shipyard auxiliary tether to prevent idling in International Oceanliners
Freight Rail	Locomotive drawn freight railroad cars	Range and weight requirements prohibitive
Intercity Bus	Buses with routes between metropolitan areas, traversing mostly highways with infrequent stops	Range and weight requirements prohibitive
Intercity Rail	Trains with routes between metropolitan areas, traversing relatively long distances with infrequent stops	Virtually all practicable electrifications complete.
Transit Rail	Trains with routes inside a single metropolitan area, traversing relatively short distances with more frequent stops	Virtually all practicable electrifications complete
Commuter Rail	Trains with routes to and from a metropolitan area, traversing moderate distances with somewhat frequent stops	Virtually all practicable electrifications complete
Recreational Boats	Personal boats and watercraft	Not modeled
Miscellaneous	Alternative and miscellaneous uses of fuel substances: lubricants and transportation of natural gas	Not modeled

LIGHT DUTY VEHICLE SCENARIOS

LDVs represent a significant opportunity for electrification in the transportation sector. To assess electrified LDV potential, we considered a range of scenarios, including several assessed in the AEO, as described below.

- *AEO 2012 Transportation Reference Case* — This scenario aligns with the AEO 2012 baseline assumptions for economic growth (2.5% annual GDP growth from 2010 through 2035), oil prices (light, sweet crude rises to $145 per barrel in 2010 dollars in 2035), and technology development. It assumes that renewable fuel standards (RFS) targets will be met as soon as possible. The number of electric plug-in light-duty vehicles grows. However, ethanol-flex vehicles grow at a considerably higher rate. Fuel efficiency across all vehicle types is increasing as a result of Corporate Average Fuel Economy (CAFE) standards and technology improvements.

- *AEO CAFE Standards* — This scenario reflects the U.S. Department of Energy's perspective on LDV CAFE and greenhouse gas (GHG) emissions standards for years 2017–2025. Under this case, the number of electric vehicles is about 50 percent higher than the Reference case.[6]

- *High Oil ($200/barrel in 2035)* — High oil prices, resulting from a combination of higher demand for petroleum and other liquid fuels in the non-OECD nations and lower global supply, stimulate the market for electric vehicles. Compared with the Reference case, GDP growth rates for China and India are higher (1.0% higher in 2012 and 0.3% higher in 2035). GDP growth rates for other non-OECD regions average about 0.5% above the Reference case. OPEC market share remains at about 40% throughout the projection, and non-OPEC petroleum production expands more slowly in the short- to middle-term relative to the Reference case. Light, sweet crude oil prices rise to $200 per barrel (2010 dollars) in 2035.

- *Center for Automotive Research (CAR) CAFE* — Based on a 2011 report from the Center for Automotive Research (CAR), this scenario estimates manufacturer responses to technology improvements needed to meet CAFE standards for 2017–2025, based on discrete, least-cost analysis of potential improvements to vehicle components such as stop/start technology, light weighting, new spark-ignited engine technologies, and plug-in hybrids. As a result, in 2025, 10% of new light duty vehicle sales are electric drive (9.1% PHEV, 0.9% AEV). In 2035, 16.5% of new light duty vehicle sales are electric drive.

- *Advanced Battery* — This scenario is based on the AEO High-Tech Battery case, but with strategic alterations developed by the project team. It assumes significant improvements in vehicle battery costs and performance that promote higher market penetrations of electric vehicles. Such improvements include enhanced battery chemistry to allow for faster and deeper charging, expansion of pubic charging infrastructure, and superior battery energy

[6] The Environmental Protection Agency and National Highway Transportation Security Agency issued a proposed rule on CAFE and GHG standards in December, 2011 that had not been finalized when the AEO 2012 was released. http://www.eia.gov/forecasts/aeo/sector_transportation_all.cfm#energyimpact. The new CAFE standard was adopted in summer 2012.

density. Based on these improvements, the project team adjusted the AEO scenario from AEVs at 52% of the electric LDV market and zero presence of 200-mile vehicles to AEVs at 63%, some of which will have a 200-mile range. These assumptions better represent the advances in battery technology.

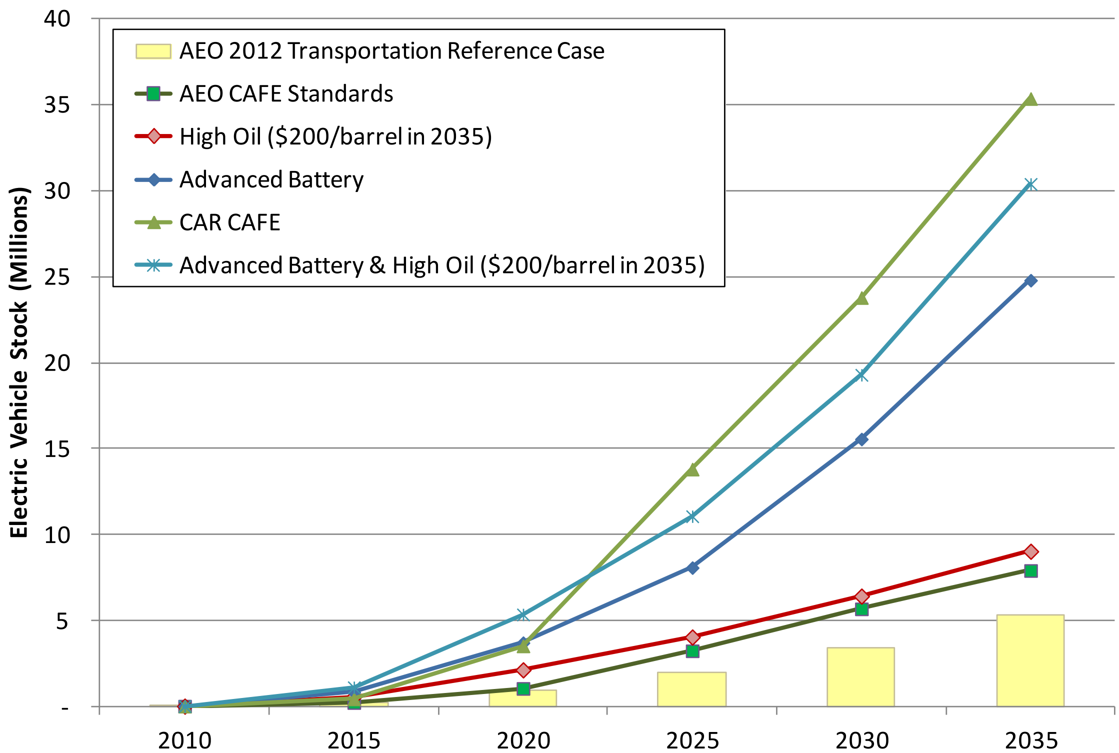
- *Advanced Battery & High Oil ($200/barrel in 2035)* — This scenario is a combination of two of the previously described scenarios: *Advanced Battery* and *AEO High Oil Price.* This scenario models the impact of both high oil prices and rapid advancements in battery technology. The vehicle stock and new EV sales resulting from those two scenarios are summed, then multiplied by 0.90 to reflect that these sales would not be simply additive. A portion of the purchases driven by high oil prices would also occur under the drivers of advanced battery technology.

LIGHT DUTY VEHICLE SCENARIO RESULTS

Figure 2 and Table 4 show how the electric LDV stock develops over the forecast period. The AEO 2012 Transportation Reference Case is the most conservative scenario and electric LDV stock reaches 5.3 million in 2035 (approximately 2 percent of all registered LDVs on the road in the U.S.). The AEO CAFE and High Oil ($200/barrel in 2035) scenarios forecast a higher penetration of electric LDVs , projecting 7.9 million and 9 million electric LDVs, respectively (equivalent to 2.9 and 3.3 percent of all registered LDVs on the road in the U.S. in 2035).

The Advanced Battery scenario shows substantial penetration of electric LDVs with 24.8 million vehicles on the road in 2035 (9.5 percent of all LDVs). This scenario shows the importance of the initial purchase price (influenced by battery costs), and the value of having enhanced vehicle utility through range extension and reduced charge time. The CAR CAFE scenario shows the highest penetration of electric LDVs with 35.4 million LDVs on the road in 2035 (14.7 percent of the vehicle stock). However, we believe the distribution of electric LDVs in the CAR report is not representative because it assumes a very uneven distribution of PHEVs relative to AEVs (roughly 9 to 1). The final scenario, Advanced Battery & High Oil shows penetration of 30.4 million electric LDVs on the road in 2035 (11.9 percent of the vehicle stock).

Figure 2: Light Duty Electric Vehicle Stock: Forecast by LDV Scenario (millions)



It is interesting to note that the High Oil price alone does not induce that many more consumers to purchase electric LDVs. One reason for the lack of response is because the increase in the price of oil (and its derivatives, motor grade gasoline and diesel) is gradually phased into the forecast; hence consumers do not experience a sudden and extreme price shock that would fundamentally alter their vehicle purchase decisions. Additionally, this scenario does not directly influence the initial purchase price of the electric LDV, a large barrier for many consumers.

Table 4: Light Duty Electric Vehicle Stock: Forecast by LDV Scenario (thousands)

Light Duty Electric Vehicle Stock by Scenario	2010	2015	2020	2025	2030	2035
AEO 2012 Transportation Reference Case	20	230	900	1,960	3,430	5,330
AEO CAFE Standards	20	230	1,050	3,240	5,680	7,910
High Oil ($200/barrel in 2035)	20	570	2,130	4,040	6,420	9,030
Advanced Battery	20	839	3,711	8,079	15,560	24,800
CAR CAFE	20	439	3,523	13,811	23,792	35,369
Advanced Battery & High Oil ($200/barrel in 2035)	20	1,117	5,354	11,069	19,295	30,400

Figure 3 and Table 5 show the impact of electric LDV penetration on electricity consumption in the transportation sector. The two main drivers of LDV electricity consumption over the forecast period are the accumulation of electric vehicles within the stock of registered vehicles and the electric drive range (i.e., based on battery capacity) of the vehicle. The AEO 2012 Transportation Reference Case scenario shows total electricity consumption of 13.1 TWh in 2035. The AEO CAFE and High Oil ($200/barrel in 2035) scenarios project electricity consumption of 18.9 TWh and 29.3 TWh, respectively in 2035.

The CAR CAFE scenario projects the highest number of electric LDVs by 2035, 35.4 million, yet has only 52 TWh associated with these vehicles. In comparison, the Advanced Battery and High Oil scenario projects the largest increase in LDV electricity consumption with 87.8 TWh consumed in 2035 associated with 30.4 million LDVs. While the result may seem counterintuitive given a comparison of the electric vehicle stock across the two scenarios, it is because the Advanced Battery and High Oil scenario includes a higher share of AEVs, some with a 200-mile range, than the CAR CAFE scenario.

Figure 3: Light Duty Vehicle Electric Energy Consumed: Forecast by LDV Scenario (TWh)

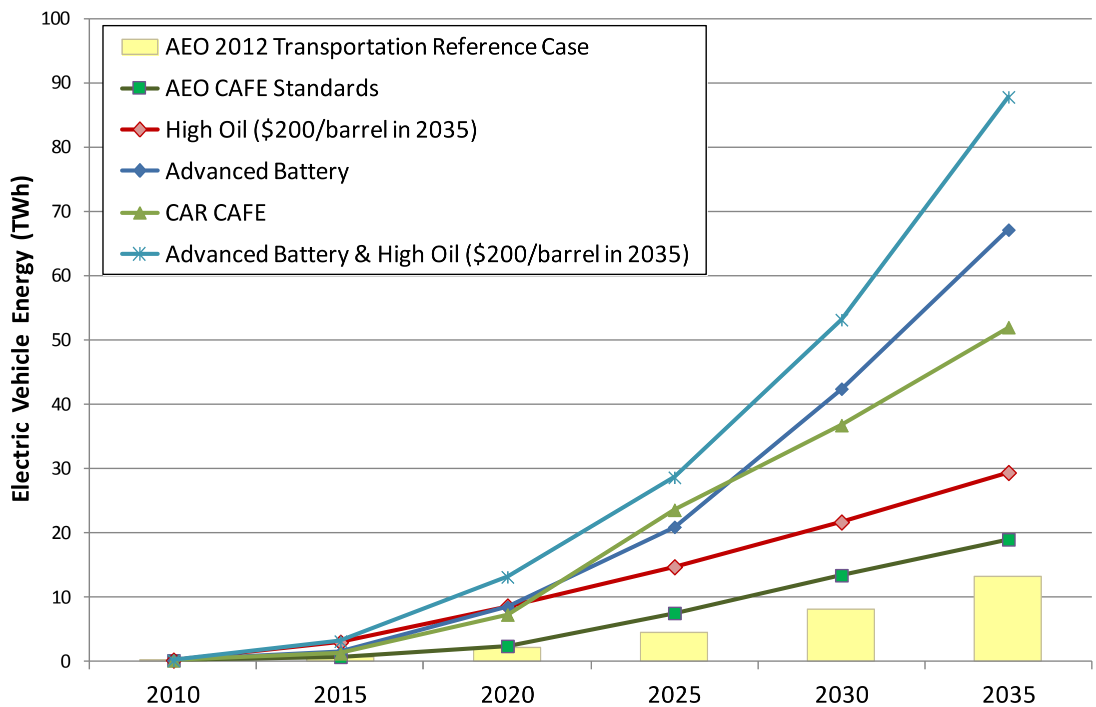


Table 5: Light Duty Vehicle Electric Energy Consumed: Forecast by LDV Scenario (TWh)

Light Duty Vehicle Electric Energy by Scenario	2010	2015	2020	2025	2030	2035
AEO 2012 Transportation Reference Case	0	1	2	4	8	13
AEO CAFE Standards	0	1	2	7	13	19
High Oil ($200/barrel in 2035)	0	3	9	15	22	29
Advanced Battery	0	1	8	21	42	67
CAR CAFE	0	1	7	24	37	52
Advanced Battery & High Oil ($200/barrel in 2035)	0	3	13	29	53	88

TRANSPORTATION SCENARIO RESULTS

For illustrative purposes, we defined three electric transportation scenarios, low, medium, and high, as defined below.

- The *low* electric transportation scenario includes:
    - The penetration of electric LDVs from the AEO 2012 Transportation Reference Case (5.3 million electric LDVs).
    - Electrification of commercial light trucks, transit bus, school bus, and military vehicle type stock at 50 percent the growth rate for electric LDVs in the AEO 2012 Transportation Reference Case. The battery and charging infrastructure technology used by these vehicles types is similar to electric LDVs.
    - Freight trucks, air transportation, and domestic and international shipping vehicle types displace 20 percent of their fossil fuel energy demands with auxiliary electric power while idled.
    - Transit and commuter rail electrification are based on the AEO 2012 Transportation Reference Case.

Figure 4 and Table 6 show electricity consumption under the low scenario by six transportation sector end uses including electric LDVs. The “all other” category includes transit bus, school bus, freight trucks, air transportation, and domestic and international shipping vehicle types. The impact of the individual electric vehicle types that comprise the “all other” category are combined for this report.

- Under the low scenario, U.S. electricity consumption increases by 33 TWh in 2035. Electric LDVs, commercial light trucks, and commuter rail are the primary drivers for the increase with LDVs making up 13 of the 33 TWh, about 40 percent of the total.

- Under the low scenario, depending upon the carbon intensity of the electric power sector and the fuel economy of ICE vehicles, the switch to electric LDVs reduces emissions by 9 to 22 million metric tons of CO_2 equivalent in 2035 (as shown in Figure 1). For illustrative purposes, taking the midpoint of the range, a reduction of 16 MMT is comparable to the emissions from the electricity used annually in 2.4 million homes, or reducing gasoline consumption by 1.8 billion gallons.[7]

Figure 4: Electricity Use in Transportation Sector –Low Scenario (TWh)

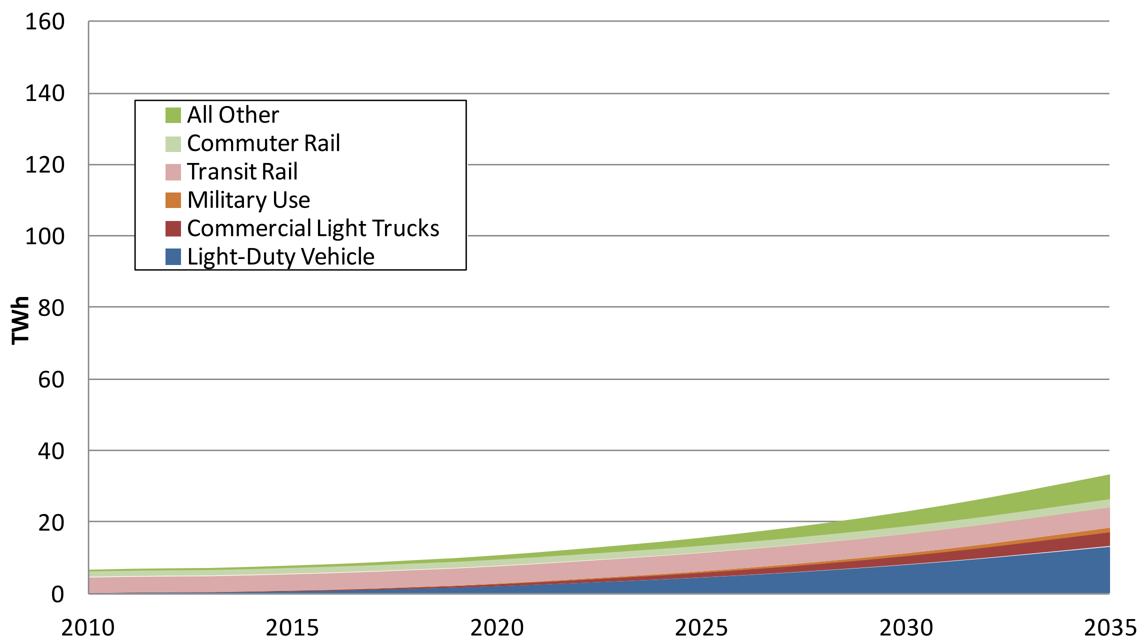


Table 6: Electricity Use in Transportation Sector – Low Scenario (TWh)

Electricity Use by Vehicle Type	2010	2015	2020	2025	2030	2035
Light Duty Vehicle	0	1	2	4	8	13
Commercial Light Trucks	0	0	1	1	2	4
Military Use	0	0	0	0	1	1
Transit Rail	4	5	5	5	5	6
Commuter Rail	2	2	2	2	2	2
All Other	0	1	1	2	4	7
Total	7	8	11	16	23	33

[7] Emission reduction estimates are based on data from DOE's Alternative Fuels Data Center, EIA's Annual Energy Outlook 2012, improvements to ICE vehicle fuel economy, and the PHEV and AEV share of vehicle stock in each scenario. See Appendix B for details. EPA's Greenhouse Gas Equivalencies Calculator provides various equivalency statements associated with emissions reductions, including gallons of gasoline and electricity use in home equivalencies.

- The *medium* electric transportation scenario includes:
  - The penetration of electric LDVs from the Advanced Battery Scenario (24.8 million electric LDVs).
  - Electrification of commercial light trucks, transit bus, school bus, and military vehicle type stock at 50 percent the growth rate for electric LDVs in the AEO 2012 Transportation Reference Case. The battery and charging infrastructure technology used by these vehicles types is similar to electric LDVs.
  - Freight trucks, air transportation, and domestic and international shipping vehicle types displace 35 percent of their fossil fuel energy demands with auxiliary electric power while idled.
  - Transit and commuter rail electrification are based on the AEO 2012 Transportation Reference Case.

Figure 5 and Table 7 show the medium scenario where advances in battery technology induce consumers to purchase electric powered vehicles.

- Under the medium scenario, U.S. electricity consumption increases by 112 TWh in 2035. Electric LDVs account for 67 TWh, or nearly 60 percent, of the total, and commercial light trucks account for 19 TWh, or 17 percent of the total.
- Under the medium scenario, depending upon the carbon intensity of the electric power sector and the fuel economy of ICE vehicles, the switch to electric LDVs reduces emissions by 41 to 94 million metric tons of CO_2 equivalent in 2035 (as shown in Figure 1). For illustrative purposes, taking the midpoint of the range, a reduction of 68 MMT is comparable to the emissions from the electricity used annually in 10.2 million homes, or reducing gasoline consumption by 7.6 billion gallons.

Figure 5: Electricity Use in Transportation Sector – Medium Scenario (TWh)

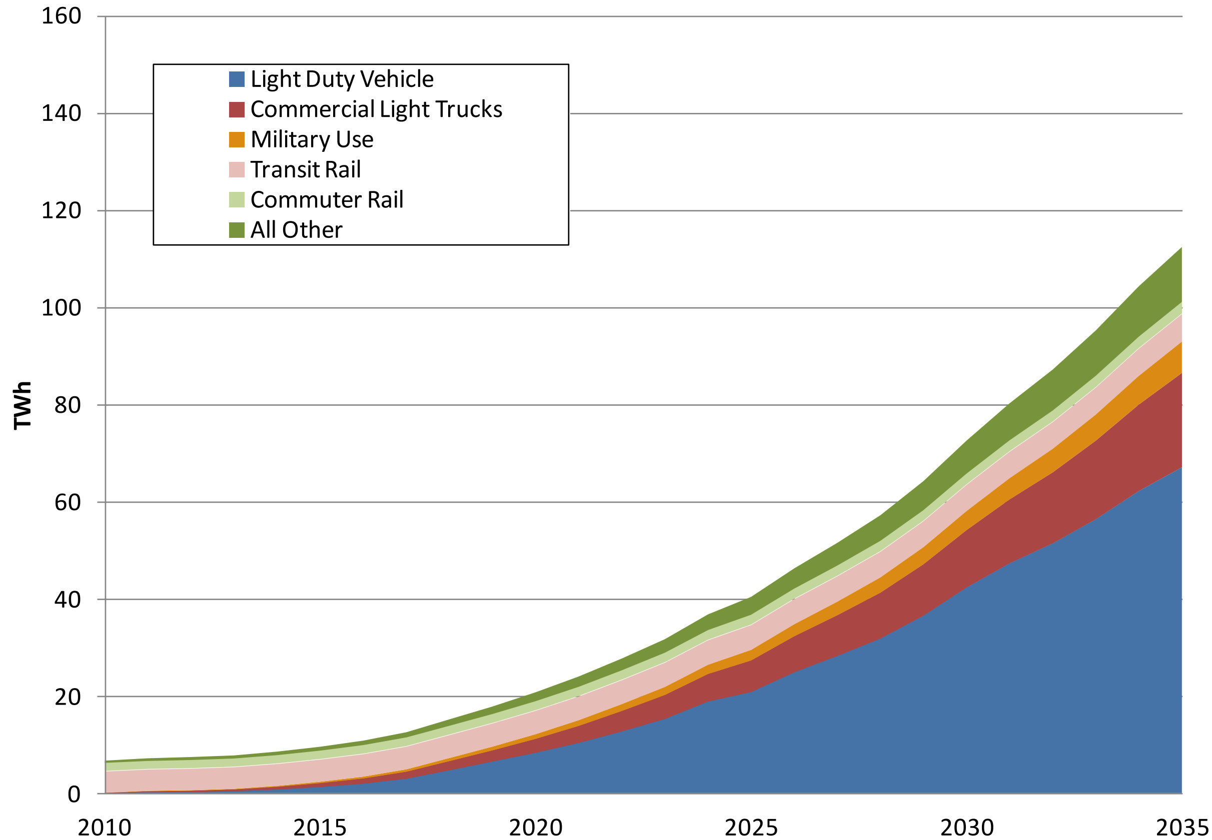


Table 7: Electricity Use in Transportation Sector – Medium Scenario (TWh)

Electricity Use by Vehicle Type	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Light Duty Vehicle	0	1	8	21	42	67
Commercial Light Trucks	0	1	3	7	12	19
Military Use	0	0	1	2	4	6
Transit Rail	4	5	5	5	5	6
Commuter Rail	2	2	2	2	2	2
All Other	0	1	2	4	7	11
Total	7	10	21	40	73	112

- The *high* electric transportation scenario includes:

    - The penetration of electric LDVs from the Advanced Battery & High Oil ($200/barrel in 2035) scenario (30.4 million electric LDVs).

    - Electrification of commercial light trucks, transit bus, school bus, and military vehicle type stock at 50 percent the growth rate for electric LDVs in the Advanced Battery &High Oil ($200/barrel in 2035) scenarios. The battery and charging infrastructure technology used by these vehicles types is similar to electric LDVs.

    - Freight trucks, air transportation, and domestic and international shipping vehicle types displace 50 percent of their fossil fuel energy demands with auxiliary electric power while idled.

    - Transit and commuter rail electrification are based on the AEO 2012 Transportation Reference Case.

Figure 6 and Table 8 show the high scenario where battery advancements and rising oil prices induce consumers to purchase electric powered vehicles.

- Under the high scenario, U.S. electricity consumption increases by 147 TWh in 2035. Electric LDVs account for 88 TWh, or nearly 60 percent, of the total, and commercial light trucks account for 26 TWh, or 18 percent of the total.

- Under the high scenario, depending upon the carbon intensity of the electric power sector and the fuel economy of ICE vehicles, the switch to electric LDVs reduces emissions by 51 to 116 million metric tons of CO_2 equivalent in 2035 (as shown in Figure 1).. For illustrative purposes, taking the midpoint of the range, a reduction of 84 MMT is comparable to the emissions from the electricity used annually in 12.6 million homes, or reducing gasoline consumption by 9.4 billion gallons.

Figure 6: Electricity Use in Transportation Sector – High Scenario (TWh)

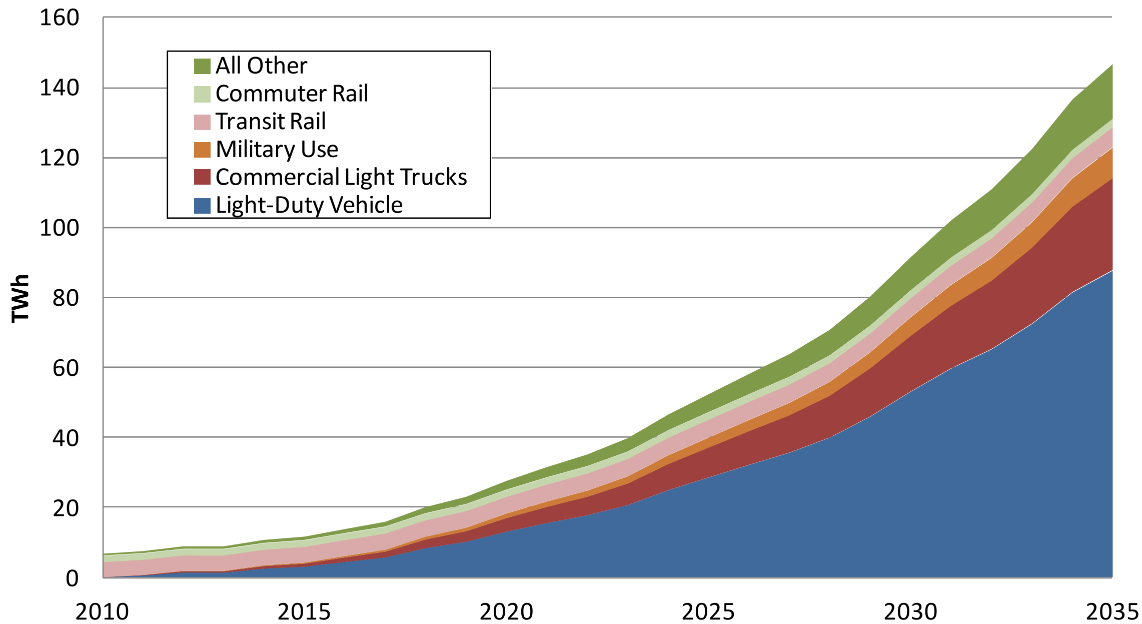


Table 8: Electricity Use in Transportation Sector – High Scenario (TWh)

Electricity Use by Vehicle Type	2010	2015	2020	2025	2030	2035
Light Duty Vehicle	0	3	13	29	53	88
Commercial Light Trucks	0	1	4	9	16	26
Military Use	0	0	1	3	5	9
Transit Rail	4	5	5	5	5	6
Commuter Rail	2	2	2	2	2	2
All Other	0	1	2	5	9	16
Total	7	12	28	52	91	147

SUMMARY

Fossil fuels currently make up about 99 percent of the fuel in transportation and 31 percent of U.S. greenhouse gas emissions can be tied to the burning of fossil fuels in the transportation sector.[8] Electrification of transportation makes sense from both an economic and environmental perspective and is beginning to gain traction in a variety of applications. Various policy, technology, and economic drivers as well as consumer demand will determine the ultimate levels of electric vehicle adoption, including: advances in battery technology, oil prices, and government mandates on fuel economy (e.g., CAFE standards). And, in turn, electric vehicle adoption will impact greenhouse gas emissions.

The results in this report show that advanced battery technology (in the medium scenario) can increases the penetration of electric LDVs from approximately 5 million to 24 million in 2035, or roughly 1 out of every ten cars and light trucks on the road in the U.S. When advanced batteries are coupled with high oil prices (in the high scenario), the number of electric vehicles could rise to more than 30 million by 2035 (about 12 percent of the LDV stock in the U.S. in 2035).

The growth of electric LDVs in the medium and high scenarios is largely due to improvements in vehicle battery costs and performance. Given that the medium and high scenarios project 10 to 12 percent of the vehicle stock to be electrified in 2035, sizable emission reductions of 41 to 116 MMT CO_2 will occur in 2035 through the use of electricity as a transportation fuel.

Based on today's average mix of generation resources, driving an electric car emits roughly half as much pollution as the conventional vehicle. As the U.S. mix of power generation sources gets cleaner and the number of electric vehicles grows, the environmental benefits of driving electric vehicles will only increase. Alternative estimates of emission reductions under different power generation mixes are provided in Appendix B.

To put the results into a larger context, based on the AEO 2012 Reference Case for Residential, Commercial, and Industrial (excluding transportation), electricity use is projected to increase by 710 TWh between 2010 and 2035. Relative to the AEO projected 710 TWh of increased electricity consumption over this 25 year period, both the medium and the high electric

[8] EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2011. April 2013.

transportation scenarios in this report, resulting in 112 TWh and 147 TWh, respectively, are significant additions to electricity consumption. This demonstrates again the important link between a cleaner power generation mix in the future and a higher penetration of electric transportation in the U.S.

APPENDIXES

APPENDIX A
TRANSPORTATION SECTOR ANALYSIS APPROACH

Table A-1: Transportation Electrification Modeling Strategy

Vehicle Type	AEO 2012 Reference	Low Scenario	Medium Scenario	High Scenario
Light-Duty Vehicle	LDV Penetration Data	LDV data from Reference Case of AEO 2012 (13.1 TWh in 2035)	LDV data from High Tech Battery (67.1 TWh in 2035)	LDV data from High Tech Battery + High Oil (87.8 TWh in 2035)
Commercial Light Trucks	No electrification	Electrified Stock% = 0.50 x LDV's Electrified Stock%	Electrified Stock% = 0.50 x LDV's Electrified Stock%	Electrified Stock% = 0.50 x LDV's Electrified Stock%
Transit Bus	No electrification	Electrified Stock% = 0.50 x LDV's Electrified Stock%	Electrified Stock% = 0.50 x LDV's Electrified Stock%	Electrified Stock% = 0.50 x LDV's Electrified Stock%
School Bus	No electrification	Electrified Stock% = 0.50 x LDV's Electrified Stock%	Electrified Stock% = 0.50 x LDV's Electrified Stock%	Electrified Stock% = 0.50 x LDV's Electrified Stock%
Military Use	No electrification	Electrified Stock% = 0.10 x LDV's Electrified Stock% (Ground vehicles only)	Electrified Stock% = 0.10 x LDV's Electrified Stock% (Ground vehicles only)	Electrified Stock% = 0.10 x LDV's Electrified Stock% (Ground vehicles only)
Freight Trucks	No electrification	20% auxiliary power electrification	35% auxiliary power electrification	50% auxiliary power electrification
Air Transportation	No electrification	20% auxiliary power electrification	35% auxiliary power electrification	50% auxiliary power electrification
Domestic Shipping	No electrification	20% auxiliary power electrification	35% auxiliary power electrification	50% auxiliary power electrification
International Shipping	No electrification	20% auxiliary power electrification	35% auxiliary power electrification	50% auxiliary power electrification

APPENDIX B
CO_2 EMISSIONS REDUCTION ESTIMATES: APPROACH AND ASSUMPTIONS

ELECTRIC LIGHT DUTY VEHICLE SCENARIOS (6 SCENARIOS):

For this report, we developed six electric light duty vehicle scenarios based on available sources.

- AEO 2012 Reference Case
- AEO 2012 High Oil Price ($200/barrel in 2035) scenario
- AEO 2012 Proposed CAFE Standards 2017-2025 scenario
- AEO 2012 High Technology Battery scenario (with modifications)
    - The "Advanced Battery" scenario in this report is based on AEO's High Technology Battery scenario with strategic alterations made to the disposition of the electric vehicle mix, including redistributing the electric vehicles to include 63% AEV's, some of which will have a 200-mile range. These assumptions better represent the battery advances than the original AEO scenario, which estimated AEV's at 52% of the electric LDV market and no 200-mile vehicles.
- Center for Automotive Research 2011 Report
    - In addition to the AEO 2012 CAFE Scenario, IEE used a second CAFE scenario based on the Center for Automotive Research's 2011 report, *The U.S. Automotive Market and Industry in 2025* that projects that, in 2025, 10% of new light duty vehicle sales are electric drive (9.1% PHEV, 0.9% AEV), and in 2035, 16.5% of new light duty vehicle sales are electric drive.
- Combined AEO 2012 High Technology Battery scenario & High Oil Price scenario (with modifications)
    - IEE also developed a High Technology Battery and High Oil Price scenario that sums the vehicle stock and new EV sales resulting from those two scenarios are summed, then multiplied by 0.90 to reflect that these sales would not be simply additive.

CO_2 EMISSION REDUCTION SCENARIOS (4 SCENARIOS)

- Efficient ICE; AEO 2012 Reference Case Power Sector Mix in 2035
- Efficient ICE; AEO 2012 Low Cost Renewable Scenario Power Sector Mix in 2035
- Conventional ICE; AEO 2012 Reference Case Power Sector Mix in 2035
- Conventional ICE; AEO 2012 Low Cost Renewable Scenario Power Sector Mix in 2035

To develop the efficient internal combustion engine (ICE) scenario, we divide the annual miles driven per vehicle by the 2035 average vehicle stock miles per gallon (MPG) estimate from AEO 2013 Reference Case to produce an estimate of gasoline consumed annually per vehicle in 2035 (about 441 gallons).[9] Multiplying the gasoline consumption by pounds of GHG per gallon of gasoline provides the pounds of CO_2 emissions from an efficient ICE vehicle of 10,588 annually (versus a conventional ICE vehicle with emissions of 13,043 pounds of CO_2 annually).

- 2035 average vehicle stock MPG = 34[10]
- Estimated annual miles driven = 15,000
- Pounds of CO_2 equivalent per gallon of gasoline = 24
- Estimated pounds of CO_2 equivalent per vehicle = 10,588

CO_2 EQUIVALENT REDUCTION ESTIMATES:

To provide carbon reduction context for transportation electrification, this report also provides CO_2 reduction estimates from electric LDVs in the year 2035, based on 2035 power sector mixes and vehicle fuel economy for three scenarios. Table B-1 provides approximate CO_2 reduction estimates for the year 2035. These estimates are not cumulative, and are meant to be an approximation and not a comprehensive analysis of CO_2 emissions reductions.

- To compute savings we use the DOE Alternative Fuels Data Center's per vehicle "well to wheels" estimate of annual pounds of CO_2 equivalent emitted from vehicles with internal combustion engines (ICEs), AEVs, and PHEVs given the national power sector mix in 2007.[11] This power mix is updated to 2035 using the AEO (as explained below).
- An alternate emissions estimate was developed to represent efficient ICE vehicles due to technology improvements to meet model year 2017-2025 CAFE.
- Subtracting AEV and PHEV well to wheels emissions from the ICE estimates produces emission reduction benefits (i.e., savings) on a per vehicle basis by type.
    - CO_2 Emissions from conventional ICE vehicle (lbs of CO_2 Equivalent per Vehicle) = 13,043

[9] The AEO 2013 Reference Case includes the adoption of the final model year 2017 to 2025 GHG emissions and CAFE standards for LDVS, which increases the projected fuel economy of the vehicle stock.
[10] Rounded from 34.23 MPG.
[11] http://www.afdc.energy.gov/vehicles/electric_emissions.php

- CO_2 Emissions from efficient ICE vehicle (lbs of CO_2 Equivalent per Vehicle) = 10,588
- CO_2 Emissions from PHEV (lbs of CO_2 Equivalent per Vehicle) = 8,875
- CO_2 Emissions from AEV (lbs of CO_2 Equivalent per Vehicle) = 8,035
- CO_2 $Reductions_{PHEV}$ (lbs of CO_2 Equivalent per Vehicle) = ICE $Emissions_{conventional}$ – PHEV Emissions = 4,168
- CO_2 $Reductions_{PHEV}$ (lbs of CO_2 Equivalent per Vehicle) = ICE $Emissions_{efficient}$ – PHEV Emissions = 1,713
- CO_2 $Reductions_{AEV}$ (lbs of CO_2 Equivalent per Vehicle) = ICE $Emissions_{conventional}$ – AEV Emissions = 5,008
- CO_2 $Reductions_{AEV}$ (lbs of CO_2 Equivalent per Vehicle) = ICE $Emissions_{efficient}$ – AEV Emissions = 2,553

▪ Emission Savings in 2035[12]

- AEV Vehicle Stock Emission Savings = CO_2 $Reductions_{AEV}$ * Vehicle $Stock_{AEV}$
- PHEV Vehicle Stock Emission Savings = CO_2 $Reductions_{PHEV}$ * Vehicle $Stock_{PHEV}$

▪ Multiplying the savings by 0.000454 converts pounds to metric tons.

▪ To compute savings for the 2035 power sector mix, savings are scaled by the carbon intensity (MMT CO_2/ TWh) in 2035 relative to 2007. The 2035 power sector mixes are from the AEO 2012 Reference Case and the AEO 2012 Renewable Low Cost scenario which represents a cleaner power source mix in 2035.

- 2007 Power Sector Mix CO_2 Intensity (MMT CO_2/ TWh) = 0.6402
- 2035 Reference Case Power Sector Mix CO_2 Intensity (MMT CO_2/ TWh) = 0.5248
- 2035 Low Cost Renewable Power Sector Mix CO_2 Intensity (MMT CO_2/ TWh) = 0.5011
- Scale savings to 2035 Reference Case Power Sector Mix from 2007 = 1.220
- Scale savings to 2035 Low Cost Renewable Power Sector Mix from 2007 = 1.277

[12] Electric LDV distribution by technology type in 2035—AEO 2012 Reference Case: PHEV:47 percent, AEV: 53 percent; Advanced Battery: PHEV: 37 percent, AEV: 63 percent; Advanced Battery & High Oil: PHEV: 38 percent, AEV: 62 percent.

Table B-1: CO_2 Emission Reductions in 2035 by Scenario (MMT CO_2 Equivalent)

	Low Scenario	Medium Scenario	High Scenario
Efficent ICE; AEO 2012 Reference Case Power Sector Mix in 2035	9	41	51
Efficient ICE; AEO 2012 Low Renewable Cost Scenario Power Sector Mix in 2035	10	43	53
Conventional ICE; AEO 2012 Reference Case Power Sector Mix in 2035	21	90	112
Conventional ICE; AEO 2012 Low Renewable Cost Scenario Power Sector Mix in 2035	22	94	116

APPENDIX C
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