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WHAT WILL THE GLOBAL LIGHT-DUTY VEHICLE FLEET LOOK LIKE THROUGH 2050?

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Abstract

This study examines several scenarios using the Light-Duty Vehicle Fleet Projection Tool ("Tool"), which is designed to project the size and composition of the global light-duty vehicle (LDV) fleet through the year 2050. The initial size and composition of the 2015 fleet was determined through a comprehensive literature review, while the age of the fleet was determined via a back-casting methodology. The interactive Tool incorporates user-supplied growth rates by vehicle powertrain to project vehicle sales, fleet size, and composition through 2050.

This study input nine scenarios into the Tool, based on Low, Medium, and High LDV fleet growth scenarios and three electric vehicle (EV) sales growth scenarios. The EV sales growth scenarios were derived from reports from the International Energy Agency (IEA), Bloomberg New Energy Finance (BNEF), and Goldman Sachs (GS). In the year 2050, all nine scenarios modeled showed increases in the EV fleet, the alternative fuel vehicle (AFV) fleet, and the overall fleet size, and all but one showed increases in the size of the internal combustion engine (ICE) fleet. Two of the nine scenarios found EV sales exceeding ICE vehicle sales in future years, and only one scenario found EVs to comprise a larger portion of the fleet than ICE vehicles. The highest EV fleet penetration, with EVs comprising 49 percent of the LDV fleet in 2050, was found in the scenario combining low overall fleet-growth with IEA targets for EV sales. It showed that even under the IEA's optimistic forecast for EV growth, combined with a slow growth of the fleet overall, there would still be more than 900 million ICE vehicles on the road by 2050. The lowest EV fleet penetration in 2050, with EVs comprising 16 percent of the LDV fleet, was found in the high fleet-growth scenario with EV sales derived from GS projections. Under this scenario, the global ICE fleet would contain almost 3 billion vehicles – nearly triple what it is now.

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Executive Summary

The Light-Duty Fleet Projection ("Tool") was designed to project the size and makeup of the global light-duty vehicle (LDV) fleet through the year 2050, broken out between internal combustion engine (ICE) vehicles, electric vehicles (EVs), and other alternative fuel vehicles (AFVs). The Tool allows users to input assumptions on global sales growth rates for each vehicle type, and uses those assumptions to project global growth in each category through 2050.

Our study used the Tool to examine nine different scenarios with varying growth rates for total LDVs and EVs. It found the following:

- Under the most aggressive scenario for EV sales growth, EVs are projected to account for — at best — just under 50 percent of the total fleet by the year 2050. The rest were internal-combustion engine (ICE) vehicles (and a relatively small fraction of alternative-fuel vehicles like hydrogen fuel cells).
- Through 2050, only one scenario projected the size of the EV fleet surpassing the size of the ICE fleet, and only two scenarios projected EV sales surpassing ICE sales.
- The projected average size of the EV fleet in 2050 was 819 million, with a low of 611 million and a high of 1.11 billion. The projected average size for the ICE vehicle fleet in 2050 was 1.97 billion, with a low of 900 million and a high of 3 billion.
- The overall LDV fleet was projected to number somewhere between 2.28 and 3.87 billion.

Considering these findings, a singular reliance on EVs to solve transportation related problems associated with emissions and petroleum dependence appears to be an inadequate strategy.

Policies that address the continued prevalence of ICE vehicles through the use of alternative liquid fuels, fuel efficiency, etc. in tandem with an EV growth strategy could not only help us reach climate, urban pollution, economic, and petroleum reduction goals faster, but provide us with more confidence that those goals will indeed be reached.

Allowing industry, policymakers and consumers to choose between multiple plans (including, but not limited to, biofuels, high-octane fuels, fuel cells, etc., or a combination), could ensure a robust, competitive marketplace that drives innovation and brings us closer to a less polluted world.

1. Introduction

Since the mainstreaming of the automobile in the early 1900s, personal mobility has exploded: Today, there are more than 1.2 billion vehicles around the world, and more than 95 percent of those are light-duty vehicles (LDVs) [1] — cars and trucks weighing less than 8,500 pounds. By 2050 that number is likely to be significantly higher than it is now, with many forecasts estimating that the global vehicle fleet will number 2 billion or more [2] [3] [4]. Others project fleet sizes of nearly 3 billion [5], and as large as 4 billion [6]. In support of these estimates is the fact that global vehicle sales have steadily increased by almost 3 percent every year for two decades [7], and vehicles are staying on the road for longer periods of time [8].

While it is a near empirical certainty that the LDV fleet of 2050 will be larger than it is today, exactly how much larger, and what type of vehicles it will be composed of, is still very much in question. More than 95 percent of LDVs in use today are powered by an internal combustion engine (ICE) fueled with gasoline or diesel [9]. The remainder of LDVs are alternative fuel vehicles (AFVs) that are either natural gas vehicles (NGVs), petroleum autogas vehicles (PAVs), or hydrogen fuel cell vehicles (FCVs), and battery/plug-in hybrid electric vehicles (EVs) propelled by electricity. Combined, the AFV powertrains make up about 4 percent of the global fleet, with EVs accounting for less than 1 percent.

Currently, policymakers around the world are working to figure out how to combat climate change. Emissions from the transportation sector constitute 23 percent of energy-related global greenhouse gas (GHG) emissions, of which 72 percent is from on-road transport [10]. When accounting for the emissions from the full life cycle of production, distribution and consumption of transportation fuels, that figure is even higher.

Understanding the composition of the LDV fleet has important implications for policy development, meeting emissions goals, infrastructure investment, business planning and more. Such knowledge could aid in developing strategies for energy security, global development and for meeting climate goals and emissions-reduction targets. Knowing the potential market size for various vehicle technologies and fuels could help in business planning for producers and suppliers in the relevant industries. The number of vehicles on the road could also influence urban planning and traffic management.

The Light-Duty Vehicle Fleet Projection Tool ("Tool"), was built to help provide information on all of the above issues. It allows users to input their assumptions on the growth rate of the overall fleet, the growth rate of EVs, and the growth rate of AFVs, in order to show what LDV sales and the total LDV fleet will look like each year from 2016 through 2050. The goal is to allow users and policymakers to look at multiple scenarios with differing assumptions and plan accordingly.

2. Methodology

To construct the Tool, first we had to establish the size and composition of the current LDV fleet. From this initial assessment, we built a worksheet in Microsoft Excel to calculate annual sales for each vehicle technology, their market share, and their respective share of the total LDV fleet in any given year through 2050. The numbers calculated by the Tool are dependent on the growth rate percentages input by the user for LDV sales, EV sales, and AFV sales. To account for vehicle retirement, we used components from Argonne National Laboratory's VISION model [11] to develop three worksheets for vehicle retirement by age and technology type.

2.1 Establishing the global 2015 fleet

We began with a literature review to determine the size and makeup of the current fleet, assess forecasted sales, and analyze historical sales data. We relied on Navigant's "Transportation Forecast: Light-Duty Vehicles" for the approximate 2015 LDV fleet size [12].

To begin, we needed to define each vehicle powertrain classification. Because one of the goals of this project was to investigate the proliferation of grid-connected vehicles, we classified the two types of these vehicles – plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) — as EVs. The rest of the vehicles on the road were then classified into one of two categories: ICE vehicles or AFVs. The ICE vehicle category is comprised of vehicles that rely on an internal combustion engine primarily powered by gasoline, diesel, or ethanol. Despite having an electric motor, hybrid electric vehicles (HEVs) are included in this category, as they require liquid fuels to function. Other technologies that did not fall into that category — including natural gas vehicles (NGVs), propane autogas vehicles (PAVs), also referred to as liquid propane gas (LPG), and fuel cell vehicles (FCVs) — were classified as alternative fuel vehicles (AFVs). The technologies in the AFV category require fuels and infrastructure that are mostly incompatible with either EV or gasoline/diesel ICE technologies.

For the various vehicle platforms, we assembled data from a multitude of sources: For the EV fleet, we summed the annual sales of EVs from 2010 through 2015 [13] [14] [15] [16], assuming that sales before 2010 were negligible. For the AFV fleet, we summed the size of the light-duty NGV fleet [17], the PAV fleet [18], and the hydrogen FCV fleet [19]. To determine the size of the ICE fleet, we subtracted the sum of the EV fleet and the AFV fleet from the size of the total LDV fleet. To establish the age of the fleet, we relied on sales growth rates derived from McKinsey's report "A Road Map to the Future of the Auto Industry" [20]. From this, we determined the vehicle sales growth rates in 10-year periods dating back to 1964, and used these rates to back-cast vehicle sales from 2014 to 1970. The combined data gave us the approximate size, composition, and age of the 2015 fleet.

2.2 Projected sales growth rates

After assessing the size and makeup of the 2015 fleet, we began building the primary mechanism that the Tool relies on to make projections — how different sales growth rates assumed by the user for LDVs, EVs, and AFVs affect annual sales and fleet makeup through 2050.

User assumptions on the growth rates for LDVs, EVs, and AFVs can be entered for 5-year periods from 2016 through 2050. These assumptions are used to calculate sales with the following formula:

*Previous year's sales + (Previous year's sales*Sales growth rate)*

For ICE vehicle sales we took a different approach: Since ICE vehicles are the dominant technology in the market today, are generally the most affordable LDV option, and have the largest fueling distribution network, we assumed that any demand for LDVs that is not met by EV or AFV sales would be met by ICE vehicle sales. Thus, ICE vehicle sales are calculated as the difference between overall LDV demand and combined EV and AFV sales.

2.3 Limits on EV, AFV and ICE sales

As mentioned above, ICE vehicle sales are determined by the gap between LDV demand and the sum of EV and AFV sales. This methodology necessitated the development of boundaries for sales for each technology type. No single vehicle platform could outsell LDVs in total, nor could the combination of the three types be greater than LDV demand. Therefore, we developed columns in the “Outputs” worksheet to take into account the above assumptions that new technology vehicle types will offset sales of ICE vehicles, and that any vehicle demand not met by new technology types will be met by ICE vehicles.

To account for this, we created separate columns in the worksheet that show vehicle sales for each technology if they were not bound by LDV demand, and columns that made use of “IF” formulas to prevent EV and AFV sales from exceeding LDV demand. Since the Tool prioritizes EVs as the preferred alternative technology, AFV sales are further bound by EV sales — that is, if AFV sales and EV sales combined exceed LDV demand, AFV sales are adjusted downward to equal the difference between LDV demand and EV sales. Such a scenario could crowd out ICE vehicle sales, as well as AFV sales, if EV sales were sufficiently high.

Lastly, we considered a scenario in which a minimum number of ICE and AFV vehicles continue to be sold even if EVs become the dominant powertrain. We did this to account for areas of the world that face challenges in building out EV charging infrastructure, as well as other constraints on electricity production and transmission, and also to consider niche applications for the other technologies. For this scenario, we assumed a minimum of 5 percent of LDV demand would be ICE vehicles, and a minimum of 4 percent (the current rate of AFV fleet penetration) of LDV demand would be AFVs. To incorporate this, we added more columns that limit EV sales to 91 percent of LDV demand and limit EV and AFV sales combined to no more than 95 percent of LDV demand — ensuring that AFV sales will not fall below 4 percent and ICE vehicle sales will not fall below 5 percent of LDV demand. Unchecking the box marked “Allow Max EV Sales?” in cell B11 of the “Adjustable Inputs” tab enables this scenario.

2.4 Vehicle retirement

Projecting fleet numbers requires not just estimating vehicle sales but also understanding how many vehicles are taken off the road each year. We accounted for this by using the methodology established in the VISION model developed and maintained by Argonne National Laboratory.

We adopted three different worksheets for each vehicle technology type to calculate vehicle retirement rates. Like the VISION model, for every given year from 1970 through 2050, the composition of the fleet by age is determined based on previous year’s sales and retirements, as well as new sales. As a placeholder, we incorporated retirement rates based on vehicle age used by the VISION model. The authors recognize that since the VISION model was developed for domestic use, these numbers reflect U.S. vehicle retirement statistics and may not be fully representative of international retirement rates. However, given the lack of data in this area, we deemed it best to use these established rates while aiming to update our Tool as more information becomes available.

2.5 Fleet composition

The composition of the vehicle fleet for any given year was calculated separately in the “ICE,” “EV,” and “AFV” tabs. This was done by adding up the number of surviving vehicles from each of the past 23 years and adding new vehicle sales. The total for each vehicle type is then linked to the “Outputs” tab and summed to give the user the total size of the LDV fleet.

2.6 Graphs

On the "Graphical Outputs" tab, we built four graphs that display fleet composition and vehicle sales shares by technology type through 2050. The graphs are linked to the results on the "Outputs" tab and automatically update when the adjustable inputs are altered.

The "Vehicles Sold by Powertrain through 2050" graph displays the number of vehicles, in millions, sold for each technology. "Vehicle Fleet through 2050 by Powertrain" shows the total LDV fleet size and composition by technology type through the year 2050. These two graphs summarize the major findings of the Tool: the number of vehicle sales by type and the fleet composition.

To highlight the results specifically for EVs and ICE vehicles, we added the graphs titled "EVs and ICE vehicles sold per year" and "EVs and ICE vehicle fleet size." These graphs more clearly display EV and ICE vehicle sales for each year and the fleet size by powertrain for each year through 2050. Our hope is that these graphs make it easier for the user to both see how many of each vehicle type will be on the road through 2050, and when/if EV sales and/or the EV fleet surpass ICE sales and fleet size.

3. Scenarios

While users can input any LDV growth rate they want, for the purposes of this paper we modeled three scenarios for LDV growth (Low, Medium, High). These numbers were derived from existing literature discussed in Section 1. The Low scenario assumes a growth rate of 2 percent through 2040, then a 1 percent growth rate through 2050 to account for market saturation, ending with an LDV fleet of just under 2.3 billion. The Medium and High scenarios function similarly but with starting growth rates of 3 and 4 percent respectively, decreasing to 2 and 3 percent respectively after 2040. The Medium scenario projects an LDV fleet size of just under 3 billion and the High scenario projects an LDV fleet size of nearly 3.9 billion.

For each of these LDV growth scenarios we also ran three EV growth scenarios based on estimates for the EV market developed by the International Energy Agency (IEA) [21], Bloomberg New Energy Finance (BNEF) [22], and Goldman Sachs (GS) [23]. It's important to note that while the BNEF and GS numbers are forecasts, the IEA numbers are based on a roadmap for EV adoption that they urge governments and people around the world to follow in order to achieve 2050 GHG targets.

The IEA roadmap is based on several key assumptions: First, it assumes that existing government incentives for EV adoption will stay in place through at least 2020 (being phased out sometime between 2020 and 2030), but government support for expanding recharging infrastructure will continue all the way through 2030. Second, it assumes rapid proliferation of different EV models after 2015 and a steep decrease in battery technology cost to below $300 per kWh, with full recycling systems coming online in the 2020s, as well as a new generation of batteries that "significantly outperform" lithium ion batteries in the 2030s. Finally, it assumes fast charging or battery swapping technology will be "well-established" during the 2020s. Also, "OECD and other major economies" will have nearly finished building out their entire charging infrastructure in the 2030s and will begin expanding to the rest of the world.

Goldman Sachs' "The Low Carbon Economy" report predicts compound annual growth rates at 37 percent for EVs through 2025. The report cites "regulatory pressure" and efforts currently being undertaken to decrease production costs — "battery costs are expected to fall by more than 60 percent over the next five years" —as the main developments supporting high growth in EV sales.

Bloomberg New Energy Finance forecasts EV sales to rise to 41 million annually by 2040 as a result of continued decreases in battery production costs, falling "well below $120 per kWh by 2030." Assuming a linear growth rate, we calculated that to represent a 19 percent compound annual growth rate for the years 2016 to 2040. We recognize, however, that if the growth rate were to occur in a non-linear fashion it would alter the age and composition of the fleet.

Since both the Goldman Sachs and the Bloomberg forecasts do not extend to 2050, we modeled the growth in the remaining years based on the IEA roadmap. As noted above, the IEA growth rates experience an initial ramp-up, attributed to advances in battery technology and regulations, among other things, and then decline as the technology matures and market saturation begins to set in. Goldman Sachs and Bloomberg cite similar reasons for a ramp-up in EV sales. Thus, to extend the projections to 2050, we deemed it appropriate to model a slowdown in the growth rate in the same fashion as in the IEA report. To do this, we first determined the percentage decrease in the growth rate from each 10-year period compared with the previous 10-year period. Then, to extend the Goldman Sachs projections, we applied the same percentage decrease in the growth rates for each 10-year period after 2025, the last year for which their report has projections. We applied the same methodology for extending the Bloomberg projections from 2040 to 2050.

The EV sales growth rate assumptions for each of the three estimates are listed below:

IEA		**BNEF**		**GS**	
2016-2020	67%	2016-2020	19%	2016-2020	37%
2021-2025	16%	2021-2025	19%	2021-2025	37%
2026-2030	16%	2026-2030	19%	2026-2030	8.7%
2031-2035	8.8%	2031-2035	19%	2031-2035	8.7%
2036-2040	8.8%	2036-2040	19%	2036-2040	4.9%
2041-2045	3.6%	2041-2045	7.8%	2041-2045	4.9%
2046-2050	3.6%	2046-2050	7.8%	2046-2050	2.0%

Table 1: EV roadmaps and forecasts (rows in blue indicate the source had no projection for those years, and to continue the projections through 2050, we used the IEA rate of growth depreciation for that period).

For all nine of these scenarios an AFV growth rate of 10 percent (consistent with the growth of AFV sales from 2014 to 2015 [24] [25] [26] [27]) was used through 2020, followed by a growth rate of 5 percent for the remainder of the time as EVs become ubiquitous. For the purposes of developing findings for these scenarios, we only bound EV sales by total LDV demand, allowing ICE vehicle and AFV sales to fall to zero should EV sales prove sufficiently high.

3.1 Scenario findings

Table 2 shows the percentage of EVs in the global vehicle fleet in the year 2050 for each of the nine scenarios we ran. The estimated EV penetration for 2050 is never higher than 50 percent, nor is it lower than 15 percent. The average penetration percentage in 2050 is 28 percent.

Table 3 illustrates EV sales' share percentage in the year 2050. This share ranges from 62 percent in the IEA Low growth scenario to 16 percent in the GS High growth scenario. The average sales share in the nine scenarios modeled is 36 percent in 2050.

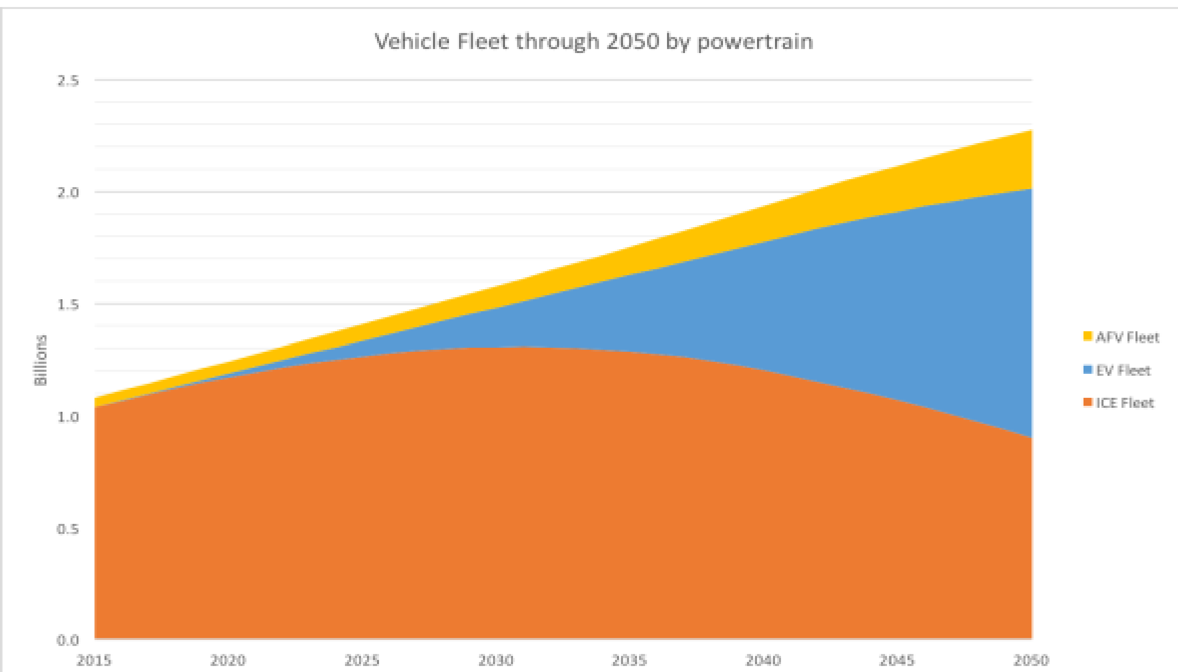
	IEA	BNEF	GS
Low	49%	32%	27%
Medium	37%	25%	21%
High	29%	19%	16%

Table 2: EV percentage of the LDV fleet in 2050

	IEA	BNEF	GS
Low	62%	54%	32%
Medium	44%	38%	23%
High	32%	27%	16%

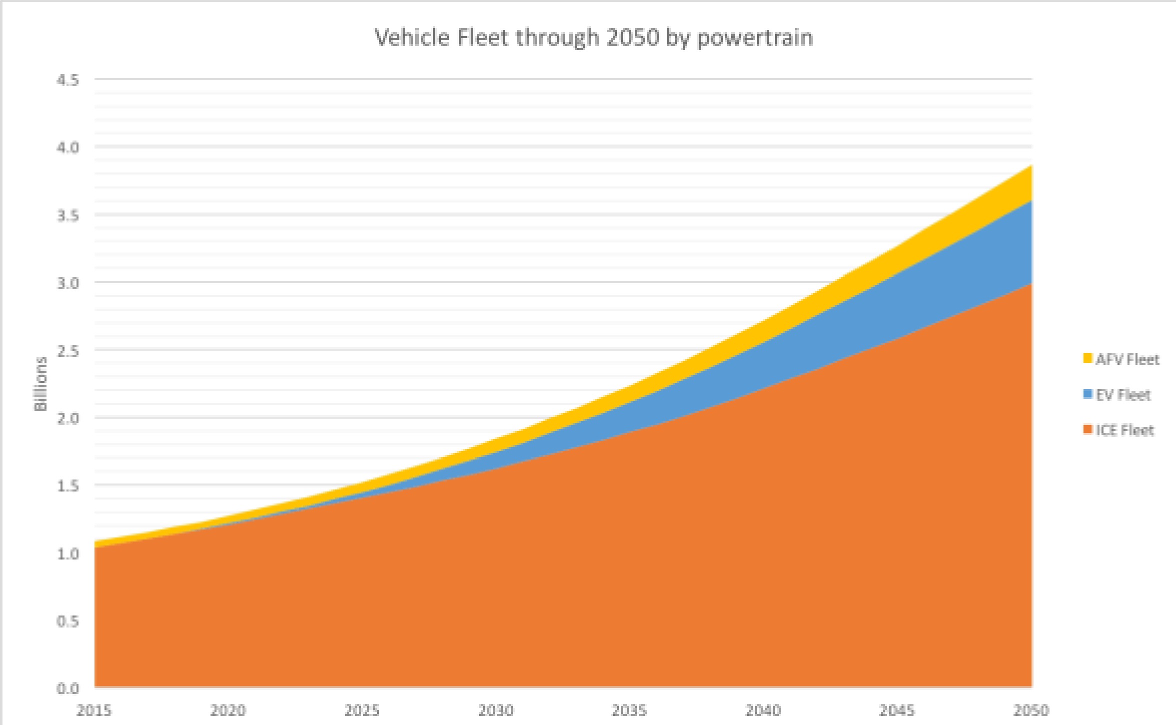
Table 3: EV percentage sales share of LDVs sold in 2050

The scenario that shows the strongest EV adoption, at 49% of the overall fleet, is the Low LDV growth scenario combined with IEA's EV roadmap projections (Graph 1). In this scenario, there are still 903 million ICE vehicles on the road in 2050, comprising 40 percent of the LDV fleet and 23 percent of new sales. Despite EV sales outstripping ICE sales in 2039, EVs on the road don't surpass ICE vehicles on the road until 2048. This is also the only scenario in which this occurs with no other scenario showing EVs making up more of the fleet than ICE vehicles by 2050. The ICE vehicle fleet peaks in 2031, at 1.3 billion.



Graph 1: Global LDV fleet composition in the Low growth, IEA roadmap EV projections scenario

The least-friendly scenario for EV adoption is the High LDV growth scenario with GS' market projections (Graph 2). In this scenario, the ICE vehicle fleet has still not peaked by 2050 and EVs only comprise 16 percent of the LDV fleet, compared to ICE vehicles' 77 percent share. 611 million vehicles in the LDV fleet are EVs, while 3 billion are ICE vehicles.



Graph 2: Global LDV fleet composition in the High growth, GS EV projections scenario

	IEA	BNEF	GS
Low	2039	2047	—
Medium	—	—	—
High	—	—	—

Table 4: Year EV sales surpass ICE vehicle sale

As shown in Table 4, only two of the nine scenarios project EV sales exceeding ICE vehicles sales before 2050. In those two scenarios — as well as in the Low growth, GS projection scenario and the Medium growth, BNEF projection scenario —the ICE fleet peaks sometime between 2031 and 2047, with ICE vehicles numbering somewhere between 1.3 and 2 billion. In the other five scenarios, the ICE vehicle fleet continues to grow through the year 2050.

4. Discussion

Although some results varied greatly, one constant across all the scenarios was that projected and targeted EV growth alone will not sufficiently decrease the number of ICE vehicles on the road to levels that allow the world to meet climate, air quality, energy security, and other transportation goals. While EVs may hold many advantages over ICE vehicles, it is becoming more apparent that ICE vehicles will not disappear anytime soon. This implies that if the ill effects from a growing vehicle fleet are to be further mitigated, additional strategies (besides increasing EV growth) must be considered. Such efforts could include development of other alternative vehicle technologies; improving the efficiency of ICE vehicles; or employing less polluting fuels (like ethanol and methanol) to power the engines already on the road — and the many more expected to be there in the future.

4.1 Impact on emissions

Across every scenario, without exception, the number of LDVs projected to be on the road in 2050 was more than double the current number. Regardless of the makeup of the fleet, be it overwhelmingly electric or ICE — or more likely a mix of the two — this is problematic for GHG emissions and air quality.

4.1.1 GHGs

In recent years, anthropogenic greenhouse gas (GHG) emissions have been a growing cause for concern. Efforts to reduce GHG emissions and mitigate the potential impacts have received increased attention, culminating in the Conference of Parties gathering in Paris. EVs are the most talked about option for achieving these goals in the transportation sector. However, even if optimistic EV adoption rates are realized, the findings in this report suggest that it still might not be enough to meaningfully decrease the number of ICE vehicles on the road. If ICE vehicles remain a dominant mode of personal transport throughout most of the 21st century, as they were during the 20th century, any strategy to decrease transportation-related emissions should not overlook pathways to achieve significant emissions reductions from ICE vehicles.

In considering GHG emissions, the full life-cycle emissions of fuel production, distribution and marketing, known as “upstream emissions,” as well as “downstream emissions” from vehicle use, must be considered. While downstream emissions in ICE vehicles represent a majority of life-cycle emissions, upstream emissions increasingly contribute a larger share as vehicles become more efficient.

This trend is especially noticeable in EVs, which produce no tailpipe GHG emissions. Argonne Lab’s GREET model shows that an EV powered by electricity derived only from coal can have nearly the same GHG impact as the average gasoline powered U.S. vehicle, and can have higher emissions than a new, efficient ICE vehicle [28]. In India and China, two fast-growing vehicle markets where approximately three-fourths of electricity is generated from coal [29], rapid EV adoption may actually increase overall GHG emissions. This complex interaction of both the life-cycle carbon intensity of the transportation fuel and the mix of vehicles in use highlights how complicated it will be to achieve GHG goals.

4.1.2 Air quality

Another important concern regarding air pollution are harmful emissions from tailpipes as well as fuel production and its transport.

This has important ramifications for developing countries and markets where most vehicle growth is likely to occur [30], and where urban air pollution is already exceeding World Health Organization (WHO) limits. According to the latest report from WHO, “98 percent of cities in low- and middle-income countries with more than 100,000 inhabitants do not meet WHO air quality guidelines.” [31] This problem will only be exacerbated by the increasing number of vehicles on the road. This should raise red flags for policymakers as poor air quality can lead to increased risk of a range of health problems, including, but not limited to, stroke, lung cancer, respiratory disease, and heart disease. There is also a growing body of evidence linking air pollution to brain diseases like Alzheimer’s and Parkinson’s [32].

4.1.3 Potential mitigation strategies

To mitigate the risk of negative air quality and GHG externalities associated with increased vehicle ownership worldwide, various strategies could be pursued.

In addition to putting in place policies that support increased EV ownership, equally important is ensuring that the electricity powering those cars comes from cleaner sources, such as renewables and natural gas. For further discussion on this issue, refer to Section 4.2.2.

Another significant area on which policymakers might focus will be expanding liquid fuel options for ICE vehicles to include high-octane fuels and biofuels that produce fewer emissions. For further discussion on this issue, refer to Section 4.4.1. Even greater benefits can potentially be achieved by developing engines that are optimized to run on such fuels (see Section 4.4.2). Consideration should also be given to the method of fuel production and their distribution networks.

4.2 Impact on infrastructure

As noted in Section 4.1, the number of vehicles is likely to at least double, and may even increase three-fold. This large increase in vehicles will have a substantial impact on resources and infrastructure. Below, we highlighted some of these issues specifically related to EVs, but note that many other issues related to vehicle growth in general should not be overlooked. These include the ability to manufacture and distribute a significantly higher number of vehicles (regardless of powertrain); the burden on global resources; and the ability of cities and towns to accommodate a greater number of vehicles, among other issues.

4.2.1 Battery production capacity

A common theme throughout the literature on forecasting growth in EV sales is the need to decrease battery production costs. In doing so, it appears that economies of scale, advances in battery technology and development in production infrastructure are needed. Advances in the production and distribution of the raw materials for battery production are also important.

GM and others are now securing batteries for their EVs at a cost of $145 per kWh [33], less than half the cost seen in the market recently. Tesla Motor Company took this effort to build batteries at a larger scale by building a “gigafactory” in Nevada [34]. This project, and perhaps others to follow, could have the potential to realize efficiencies in the manufacturing of batteries that would in turn help lower the per unit cost of EV production. Research initiatives such as those spearheaded by the U.S. Department of Energy [35] can also advance battery technology, and in turn reduce battery prices through either battery efficiency or reductions in production costs, or both.

With global reserves of lithium, cobalt, nickel, manganese, and other raw inputs of battery production both limited and geographically diverse, the production and transportation system of these materials might become taxed as EV demand increases. Investments and advancements in safe mining and transportation practices for these materials, as well as recycling where possible, could help prevent shortages and price spikes, ensuring continued growth in battery production.

4.2.2 Charging infrastructure

For developed countries that already have established electrical grids and blossoming renewable energy sectors, developing a more robust EV charging infrastructure is already a challenging prospect. In the United States, 98 percent of charging is done either at home or at the workplace, yet much of the capital invested in expanding EV charging infrastructure is not going toward building stations in those two places [36]. This is especially problematic when you consider that many multi-family residences do not have the appropriate electrical capacity and conduits for EV charging. Changing this dynamic in both existing dwellings and in the building codes applied to new ones could help to accelerate EV adoption in OECD countries. However, even in developed countries, electrical grid capacity and infrastructure development and repairs may need to be addressed as grids are faced with higher loads that may come from EV charging.

Yet the problems faced by OECD countries pale in comparison to the challenges involved with increasing EV ownership in developing countries, where getting enough reliable electricity to charge a mobile phone — much less a vehicle — is a commonplace issue for large segments of the population [37]. Before EVs can even begin penetrating those markets, a strong and reliable electrical infrastructure must be developed.

How those countries generate the electricity that flows into their grids is a critical component. The largest source of power generation worldwide is coal [38], a resource that — as discussed in section 4.1 — has significant negative externalities in terms of both GHGs and air quality. Looking to EVs to solve climate and air quality problems could be counter-intuitive if the electricity powering them does not provide significant life-cycle emissions benefit over ICE vehicles. Policymakers must take this into consideration as well when planning for high EV penetration scenarios.

4.3 Energy security

As is mentioned above, today more than 1 billion ICE vehicles are powered by petroleum derived gasoline and diesel. Likewise, total global petroleum consumption was nearly 94 million barrels per day in 2015 [39], or about 34 billion barrels for the entire year. This level of petroleum consumption already has significant geopolitical and emissions implications. The continued proliferation of petroleum-dependent ICE vehicles, potentially three times as high as the current amount, would serve to exacerbate the situation and may even be unattainable.

However, strategies exist to reduce or eliminate the need for petroleum consumption in ICE vehicles. Chief among these is employing non-petroleum fuels that are either compatible with existing vehicles, can be used in new vehicles that may or may not be specifically designed to run on these fuels, or both. These could include alcohol fuels derived from a multitude of sources, gasoline-like fuels from pyrolysis of biomass, as well as renewable diesel, biodiesel, DME and more.

4.4 Potential pathways to reduce the impact of ICE vehicles

As there is still a significant probability that ICE vehicles will continue to dominate the world's roads in the coming decades, strategies that aim to reduce emissions of GHGs and other pollutants from light-duty transport should not overlook this segment of vehicles.

4.4.1 Addressing the need for more liquid fuel options

Given that this study finds that, at best, there will still be 900 million ICE vehicles on the road in 2050, and, at worst, 3 billion (2 billion more than are in-use today), it is imperative to introduce cleaner liquid fuel options into the marketplace.

There are multiple avenues toward cleaner liquid fuels in ICE vehicles, and it will be up to individual policymakers to decide which path is best for them and their countries. But there are a few options that could feasibly be used in fleets around the world.

One of these is the expanded use of high-octane fuels that, when run in a properly designed engine, can significantly increase fuel economy and decrease air pollution and GHG emissions [40]. Sources of high-octane fuels include gasoline that has had its octane increased through refining and with additives, or alcohol fuels like ethanol and methanol that can be derived from plants, natural gas, or waste.

Biofuels are a promising option, and Brazil already has successfully implemented an ethanol biofuels program that has reduced their GHG emissions [41], while it appears that regulations on vehicle emissions will lead to the program bringing an overall improvement in air quality as well [42]. Biofuels likely will be attractive to many policymakers because they can be made from a wide variety of locally available sources.

High-octane fuels and locally sourced low-carbon fuels can be complementary to each other as well. Biomass, waste, natural gas and other sources for low-carbon fuel can create high-octane ethanol or methanol to be used either as a fuel, an octane enhancer, or both.

4.4.2 Combining advanced ICE technology with fuel development

In recent years, engine efficiency and technology have been greatly improved, leading to decreased fuel consumption and other benefits. These technologies include making use of advanced engine techniques such as direct injection, multiple spark ignition, turbocharging, and more. Other, more established techniques for increasing engine efficiency, such as increasing the compression ratio, have also seen greater deployment in recent years.

Further, fuel properties inherently effect how an engine reacts and how efficiently or inefficiently it operates. Fuel properties that could greatly affect advanced combustion regimes include octane, boiling point, solubility, and more. For example, high-octane fuels are more resistant to pre-ignition and thus could allow for high-compression, turbocharging or other such techniques that could increase efficiency.

A strategy that optimizes engine design and combustion regimes with fuels specifically designed to run in advanced engines could help to better take advantage of both advanced engine designs and inherent fuel properties to achieve greater efficiencies and reduced emissions

4.5 Model Limitations

We recognize that there are many difficulties associated with a Tool that makes global projections 35 years into the future and below we address some of those deficiencies. This is a working model and we welcome feedback and suggestions on how to improve the Tool.

4.5.1 Regional variation

While this Tool attempts to provide a picture of the world at large, we recognize that the makeup of fleets around the world varies significantly from region to region. NGVs are much more prevalent in East Asia, the Middle East, and South America [43], while PAVs are highly concentrated in Russia, Turkey, and Eastern Europe [44], and EV proliferation is the highest in the U.S., China, Japan, and Scandinavian countries [45].

What’s more, certain areas of the world like Western Europe are much more reliant on diesel ICE vehicles as opposed to gasoline ICE vehicles, with diesel cars composing more than 53 percent of new vehicle registrations in Europe in 2014 [46].

Thus, while the Tool can be especially useful to policymakers thinking on a macro, global scale, consideration of regional variation should be taken into account when applying the results of the Tool to specific regions of the world.

4.5.2 Vehicle retirement

Developing vehicle retirement rates proved to be one of the biggest challenges in developing the Tool. We were unable to identify any preexisting research on the longevity of LDVs worldwide, despite well documented information on this within the U.S. Given the importance of understanding the global fleet composition when considering global issues, we hope that more effort will be invested in this area. We will update our Tool when and if such data become available in order to improve projections.

4.5.3 AFV variability

Given our focus on EVs, in this first version of the Tool we decided to combine all other alternative technologies into one category. We believe this can still allow for users to account for growth or decline in new and established alternative technologies, such as fuel cells and natural gas-powered vehicles. But we acknowledge that it requires the user to combine assumptions for those technologies and does not return individual results for each type. This is an area we hope to improve in a future update.

4.5.4 Uncertainties in the market

There are other emerging technologies for light-duty vehicle transport beyond advances and alternatives in powertrains that could impact fleet growth, composition, and age. Such technologies include autonomous vehicles and ride-sharing services like Lyft, Uber, ZipCar, and others.

While we did not attempt to model these technologies' impact on the fleet, we note that they might meaningfully alter the results — although there is still much debate as to what their impact will be. Questions surrounding these uncertainties may include: Will increased access and decreased costs due to ride-sharing increase the demand for light-duty transportation, resulting in more vehicle miles traveled? Will the sharing of vehicles be enough to overcome any increased demand for light-duty transport and keep fleet growth low? Or will the increased demand accelerate fleet growth? Will accelerated vehicle degradation due to sharing cause the fleet to turn over more quickly, decreasing the average age? How would accelerated fleet turnover affect adoption of new powertrain technologies? What powertrain technologies are better suited for vehicle-sharing and autonomous driving? Will existing infrastructure require updating to support autonomous vehicles? While our tool does not answer these questions, we believe it has the ability to estimate the fleet impact, based on the yet-to-be-determined answers to these questions. Lastly, these technologies may also not affect the fleet uniformly across the globe. For example, developed nations may adopt these technologies quickly, while developing nations may be slower to adopt. More densely populated areas may be better suited for adopting these technologies, while rural and possibly suburban areas will be less likely.

4.6 Opportunities for further building out the model

While users can generate findings from the Tool regarding the number of vehicles on the road and their makeup, the Tool does not project the implications those vehicles will have on emissions nor does it focus on specific regions. It is our hope that future versions of the Tool will incorporate more of those aspects.

4.6.1 Adding emissions outputs

As policymakers continue to grapple with strategies to reduce emissions, understanding the impacts of transportation policy-related emissions reductions will be crucial. Light-duty vehicles account for the majority of transportation-related GHG emissions in the U.S. [47], the E.U. [48], and are major sources of harmful emissions worldwide. Knowing total emissions levels from LDVs and the impacts of emissions-reduction strategies will be helpful in assessing the effectiveness of policies and their potential to reach emissions goals. As this Tool helps to determine projections for the global LDV fleet, incorporating additional processes and data to derive the emissions impact of the fleet could be a beneficial addition to this endeavor.

Similar to other such efforts to model emissions impacts from transport, this could require adding modules to account for vehicle miles traveled, carbon intensity, and emissions of various fuels and fuel production pathways, as well as greater detail on the types of vehicles and their uses, including differences within vehicle powertrains.

4.6.2 Localized versions of the model

Due to the widely varying fleet makeups and vehicle preferences of regions and countries around the world — as discussed in section 4.4.1 — we realize that the Tool might miss some of the nuances that would surface if the Tool were customized for different regions. Future region-specific iterations of the model could take this into account by changing the initial global assumptions on the fleet size and sales for LDVs, EVs, NGVs, PAVs, and FCVs, and historical sales for each type of vehicle used by the Tool and replacing them with regional numbers. The fleet scrappage rate could be altered as well to reflect the scrappage rate of the region in question.

5. Conclusion

When looking at the future of light-duty vehicle transport, much focus is given to sales of new vehicles while the current fleet of existing vehicles that will remain on the road for many years receives less attention. The findings of this report highlight that vehicles contribute to the fleet for many years after their original sale. When considering the effects of transportation on climate change, urban pollution, congestion, the economy, and dependence on oil, industry and policymakers would be well served by accounting for all of the different types of vehicles on the road.

Today there are already over one billion ICE vehicles on the world's roads, and many more will continue to enter the fleet, even if alternative technologies experience unprecedented growth. This does not imply that we should not embrace EVs or programs and policies that support their proliferation, but rather that we should consider multiple avenues to mitigate the negative externalities that will accompany a larger overall vehicle fleet.

The one commonality of the nine scenarios we explored is that the LDV fleet will almost certainly be significantly larger than it is right now. Further, much of the literature suggests that a large portion of this growth will come in developing markets that lack clean sources of electricity or reliable electrical grids, making clean EV adoption in a growing fleet even more challenging.

Supporting efforts to develop and expand availability of alternative liquid fuels and other strategies, in tandem with an EV growth strategy, could not only help us reach our goals sooner, but provide us with more confidence that those goals will indeed be reached. Such a strategy could also ensure that we are not overly burdened with unanticipated externalities related to rapid EV adoption. Encouraging industry, policymakers and consumers to choose between multiple strategies (including, but not limited to, biofuels, high-octane fuels, fuel cells, etc., or a combination of strategies), could ensure a robust, competitive marketplace that drives innovation and brings us closer to a less polluted world.

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