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National Energy Impacts of Heavy Electric Truck Adoption For Freight

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Executive Summary

Freight trucks are projected to account for nearly 30% of transportation sector energy use in 2050 in the United States. Potentially some of the freight energy use and associated emissions can be reduced by electrified vehicle technologies, smart technologies (e.g. platooning, driverless truck), and possible mode shifts. Several U.S. truck makers, new startups, and independent engine manufacturers made announcements of taking commericialized medium- and heavy-duty trucks into production for these emerging technologies. By analyzing the freight shipment by commodity and freight zones, the study objectives are 1) idenfiy long-haul freight miles that could be electrified without on-route charging infrastructure; and 2) quantify future energy consumption impacts. This paper utilized Argonne's NEAT and VISION models to estimate the potential energy impacts of electric truck adoption by 2050 in the United States. Analysis results shows that either a Class 7 and 8 electric truck with 500-mile electric range could potentially reduce the petroleum consumption by 1.61 quad in 2050, while the electricity consumption increases by 0.99 quad.

1 Introduction

In the United States freight trucks are projected to account for nearly 30% of transportation sector energy use by 2040.[1]. Potentially some of the freight energy use and associated emissions can be reduced by electrified vehicle technologies, smart technologies (e.g. platooning, driverless truck), and possible mode shifts. Electric freight trucks offer the greenest and one of the most energy efficient means of transporting goods. "However, these applications have focused mostly on lower-mileage work/vocation trucks or limited-range trucks for drayage operation in and around ports in the United States. Recent improvements in the cost and power density of batteries, as well as the associated power electronics and electric systems, have raised the prospect that battery electric heavy-duty freight movement may also be a viable and competitive alternative to conventional systems. The lower cost per mile compared to existing approaches, combined with high vehicle usage rates, hold the promise to make electric operation more cost-effective than other options for heavy-duty freight applications" [2]. Current announcements in Europe also tend to be for urban deliveries and often smaller payloads. In early 2018 both MAN and Mercedes placed pilot e-trucks with customers. Volvo and Renault have announced that they will start selling electric trucks by 2019. In the case of the Volvo, there is a claimed range of 300 km. VDL has partnered with MAN to develop a 37 ton truck; however, the range is mainly targeted for deliveries at 100 km. The long haul and larger segment sectors are technically more challenging than the urban delivery truck segment. Trucks are driven further between towns and cities, and they also tend to require a larger payload capacity. To accommodate these higher demands, Nikola Motors has announced a battery electric truck with hydrogen fuel cell range extender, and Toyota announced a hydrogen fuel cell truck [3]. However, other manufacturers see the potential of battery electric trucks in the long haul sector. too. Several U.S. truck makers, new startups and independent engine manufacturers made announcements of taking commericialized electric medium-and heavy-duty trucks into production. Notably, U.S. company Tesla unveiled its battery powered Class 8 truck in late 2017, and Chinese manufacturer BYD added long haul trucks to its increasing number of offerings of electric trucks in 2016 [4].

The conditions for battery electric trucks have drastically changed since 2010, a year when lithium-ion battery prices were around $US 750-1000/kWh [5] with energy densities of around 110 Wh/kg. Compared to 2018, prices have come down by around a factor of four, and densities have more than doubled. In simple terms, batteries are cheap and dense enough to be considered as viable for powering trucks. These trends in the reduction in cost and improvement in specific density have lead to (and conversely been driven by) a rapid increase in both passenger electric vehicles, electric urban buses, and the emergence of electric heavy-duty trucks. A previous study also found that the more aerodynamic trucks require 0.98 kWh/km compared to 1.23 kWh/km to overcome the load weight to maintain a constant highway speed on a flat surface [6].

Commercial vehicles are highly cost driven,with the overall price of running and maintaining a fleet the deciding factor when it comes to purchasing new trucks. Higher unit costs can generally be offset by lower total cost of ownership (TCO), and both established and new entrants in the market see this as an opportunity to explore new technologies.This implies Tesla will have to make up for the longer-range cost somehow - perhaps by selling fast charging electricity. However, even with the price tag claimed by Tesla, electric combination long-haul trucks are still much more expensive than diesel counterparts in the United States [7]. Electrification and automation could potentially lower the fuel cost, maintenance and driver costs. Tesla predicts a cost reduction to $1.26/mile due to lower costs of fuel and maintenance. However, business costs may be offset by charging logistics costs. According to the American Transportation Research Institute, fuel costs represent 30-40% of the total cost per mile in the long-haul freight sector [8]. Moreover, price isn't the only question. Federal rules limit trucks' gross weight to 40 tons. Considering the heft of the battery pack, plus items such as the cab, trailer, and wheels, researchers determined a 600 mile-ready Tesla truck could carry just nine tons of cargo [9]. That's two-thirds of the current average payload of 16 tons. Even the lower operating costs and fuel savings of electric propulsion may not balance out such a disadvantage in an industry where efficiency in time rules. **However, this study assumes in the future there is no reduction in payload capacity due to larger battery in a 300-mile or 500-mile electric truck**.

The research questions are 1) with announced electric truck models and projected freight demand, how many miles could be electrified without on-route charging infrastructure; and 2) how energy consumption is impacted. This paper 1) Summarizes performance characteristics, including efficiency (kwh/mi) and electric range of future Class 7 and 8 electric trucks from simulation results and announcements made by several truck makers, 2) estimates the percentages of inter-city freight movement (ton-miles) that is within a 300 or 500 mile electric-range using the U.S. Federal Highway Administration's freight demand projections by 2045 [10], assuming charging only at origin and destination (not on-route); and 3) utilizes Argonne's NEAT and VISION models to estimate the potential energy impacts of electric truck adoption by 2050 in the United States [11-12].

2 Literature

Earl et.al. stated the success of battery electric trucks in the European Union (EU) is technically feasible, owing to improvements in battery density, the efficiency of electric power trains, and advancements in aerodynamics and tire rolling resistance. This study also found that the biggest sensitivity to cost competitiveness is the electricity price, and to a lesser extent the road charging discount that may be applied to zero emission trucks on motorways [6]. One report [13] on decarbonising road freight found that electric trucks are the most energy efficient solution for decarbonisation. E-highway technology being developed by Scania and Siemens is an example of how to decarbonise long haul freight. E-highways are an intriguing proposition and may be more cost effective than battery electric trucks for long-haul trucking (including infrastructure building), as indicated by [14] - the ongoing trials in Sweden and Germany showing that they are already technically feasible. Other zero emission technologies, namely hydrogen fuel cells and power to liquid 'drop-in' fuels for internal combustion engines, would require 3 to 5 times more electricity than a pure electric drivetrain. In the simplest terms, this would result in an equivalent cost increase factor for the energy/fuel. The report's addendum considered the impact of using battery electric trucks for long-distance transport (rather than e-highways), arriving at the key conclusion that the main technical hindrance to battery electric trucking is current trip lengths in the EU would demand a necessary charging network.

Some researchers are still concerned about the payload issue due to a bigger battery needed for longer range. Before the unveiling of the Tesla Semi, Earl et al[6] carried out an analysis that rather dampened the expectations of battery electric trucks for long haul, showing that with current technology batteries would be both too heavy and costly for long range trucks. Sripad and Viswanathan stated that payload capacity of an electric Class 8 vehicle is an important parameter for the trucking industry, and in a fully electric vehicle, the payload capacity would be reduced significantly because the battery pack weight forms a significant fraction of the gross vehicle weight with current Li-ion battery tehnology. Sripad and Viswanathan analyzed the trade-off between the initial investment and the operating costs to compare a Class 8 diesel semi-truck and an electric truck with a range of 500 miles [15]. They identified four targets in the 2020-2030 time frame, each of which needs to be met in order to ensure a payback period of about ~5 years: (i) an optimized vehicle design with a drag coefficient of 0.4 ± 0.04 for lowering the pack size and meeting the payload demands; (ii) pack price of <US$150/kWh; (iii) a price of electricity <US$0.2/kWh with a peak power of over 500 kW per truck; and (iv) a battery pack cycle life such that less than 50% of the fleet requires battery pack replacements over their lifetime. Achieving these targets will enable economic competitiveness of electric semi-trucks for hauling ranges of up to 500 miles [15].

3 Methodology

Argonne first summarized **electric range** of future medium-duty (Class 3-6) and heavy-duty (Class 7-8) electric trucks recently announced by several auto makers, shown in Table 1 [16-22]. Energy consumption are claimed to be tested under full payload at highway driving speed of 55 mph. This study focus on the energy impact of Class 7 and 8 electric trucks for long-haul freight in the future.

Table 1: Performance Characteristics of Existing and Future Electric Trucks

Manufacturer	Name	Capacity (lbs)	Energy Consumption* (kWh/mi)	Battery Pack (kWh)	Range (mi)	Base Price	Available
Tesla	Tesla Semi - 500	80,000	2.00	1000	500	$ 150,000	2019
Tesla	Tesla Semi - 300	80,000	2.00	600	300	$ 180,000	2019
Tesla	Tesla Founders Semi	80,000	2.00			$ 200,000	2019
Daimler	E-FUSO Vision ONE	24,250	1.40	300	215		2021
Daimler	FUSO eCanter	3.5 tons	1.04	83	80		2020
Cummins	AEOS	44,000	1.40	140	100		2022

* Full payload, highway driving speed (55mph)

Second, we used FastSim [23] developed by National Renewable Energy Laboratory to estimate energy comsumption of a 500-mile electric truck. Truck energy efficiency varies with cargo mass and coefficient of aero drag. Figure 1 shows a the energy consumption of a 500-mile range electric Class 8 truck under different driving cycles. As shown in Figure 1, energy consumption varies more by driving speed and aero drag than by cargo mass. The average payload carried by such vehicles for commodities from different industries is about 14,500 kg (16 tons) and can be as high as 20,000 kg (22 tons). This analysis used a weighted highway driving cycle, (5% Transient, 9% Hwy 55mpg and 86% Hwy 65mpg), about 2.4 kwh/mile at 14,000kg/0.6 areo drag, in further analysis. We also simulated a 300-mile electric truck, the energy consumption per mile is similar to the 500-mile electric truck with the same aero drag and cargo mass.

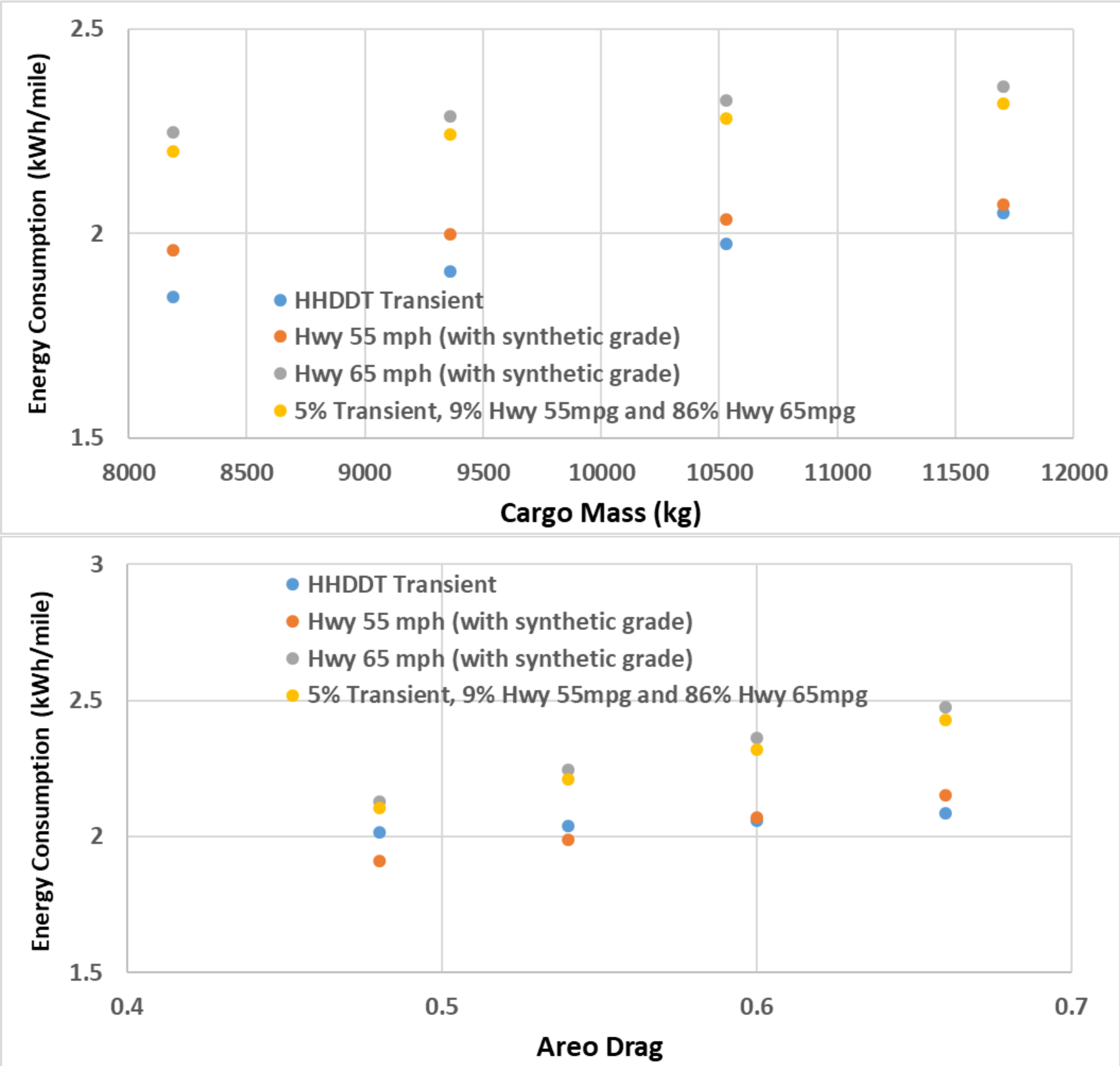

Figure 1: Energy Consumpiton of a 500-mile Class 8 Electric Truck

The Freight Analysis Framework (FAF) baseline edition provides estimates for tonnage and value by regions of origin and destination, commodity type, and mode up to 2045 by every 5 years. FAF is produced through a partnership between the U.S. Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA), and integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation. Starting with data from the 2012 Commodity Flow Survey (CFS) and international trade data from the U.S. Census Bureau, FAF incorporates data from agriculture, extraction, utility, construction, service, and other sectors. The FAF version 4 (FAF4) is the lastest version.

Base on projections of tonnages and ton-miles made by FHWA's FAF 4.0, we first estimated the percentage of truck ton-miles that could be electrified using an **average length of haul** between 123 freight zones (origin/destination) in the United States. For example, if the average length of haul between given zones are lower than 500 miles, we assume those commodities could be moved by a 500-mile Class 7 and 8 electric truck without on-route charging. As shown in Table 2, a total of 48% of freight ton-miles in 2045 have an average length of haul less than 500 miles.

Table 2 Average Length of Haul of Freight Truck between 125 Freight Zones in the United States in 2045

Length of Haul (mile)	**Total Ktons**	**Total Ton-Mile (million)**	**Total M$**	**% of Ton-miles**
< 300 mile	**11,752,171**	**809,400**	**9,703,960**	**31.7%**
300-500 mile	**1,130,754**	**416,428**	**2,065,178**	**16.3%**
500- 1,000	901,625	621,348	2,358,292	24.4%
1,000- 2,000	341,984	457,339	1,469,357	17.9%
> 2,000	99,600	244,922	626,706	9.6%
Total	14,226,134	2,549,438	16,223,493	100%

Then, we estimated number of Class 7 and 8 electric trucks needed in 2045 on the road to fulfill the projected freight movement, in ton-miles, assuing using trucks with 300- or 500-miles electric range. The number of trucks on the road is also known as stock. We extended the projections to 2050 assuming no changes in stock share from 2045 to 2050. From the number of electric trucks on the road, we back calculated the electric truck sales shares, also known as market penetration, from 2017 to 2045 using a logit function, formula (1), and Class 7 and 8 truck survival function from Argonne's VISION model. We assume that an electric truck will have the same survival rate as the diesel counterparts in the future. We used both high and low truck load (tonnage per truck), as well as the average annual truck mileage, to estimate the numbers of trucks needed in two cases. "High" scenario is estimated using an average truck load of 16 tons, while a "low" scenario is estimated using high truck load, of about 22 tons.

$t=\delta+\quad \ln[F\{t\}/(1-F\{t\})]+\mu$ (1)

δ and β are coefficients that become scalar factors determining the shape of the market penetration curve and μ is the error term

Table 3 shows the Class 7 and 8 electric truck stock shares needed for high and low cases with 300-mile or 500-mile electric range per truck. We assumed an age-weighted truck annual mileage of about 60,000. Based on the stock shares, Figure 2 and 3 show sales shares of electric Class 7 and 8 trucks needed in 2050 assuming all trucks have a 300-mile range or 500-mile electric range, respectively. For example, Figure 3 shows 25% of new Class 7 and 8 sales need to be 500-mile electric trucks in 2050 to fulfill all the freight movement with average length of haul less or equal than 500 miles between 123 freight zones, in "high" scenario case.

Table 3 Electric Class 7&8 Truck Stock Share Needed in 2045

	300-mile Class 7&8 Truck		500-mile Class 7&8 Truck	
	High	Low	High	Low
Total Ton-miles (million)	2,549,438			
%Ton-miles could be electrified	31.7%		48%	
% E-truck needed	843,125	613,182	1,304,405	948,658
Total Class 7&8 Truck Stock	5,472,842			
% Stock Share	15.4%	11.2%	23.8%	17.3%

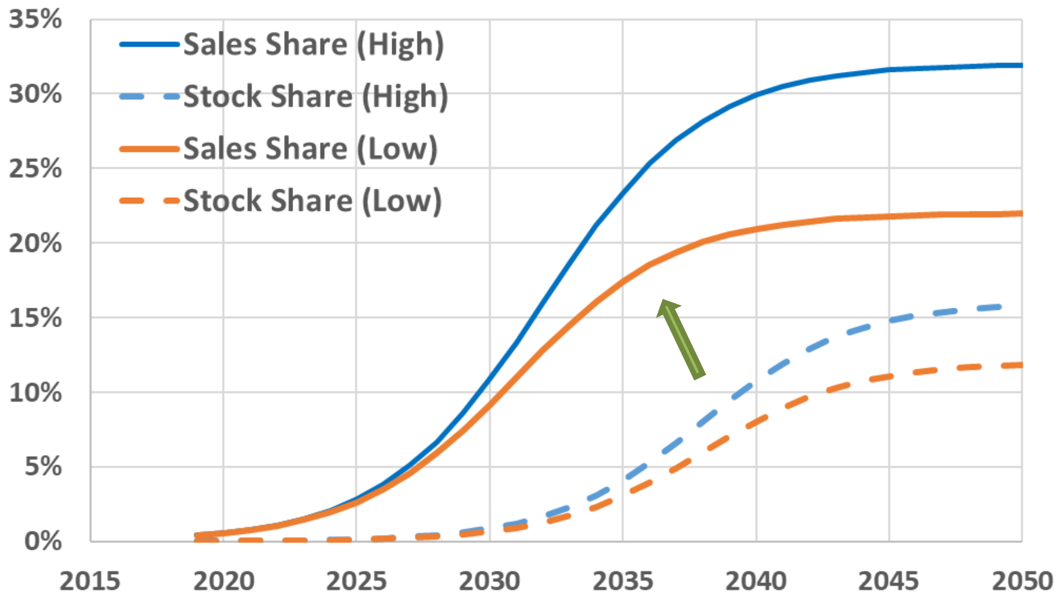

Figure 2 Electric Class 7&8 Truck Market Shares (300-mi electric range)

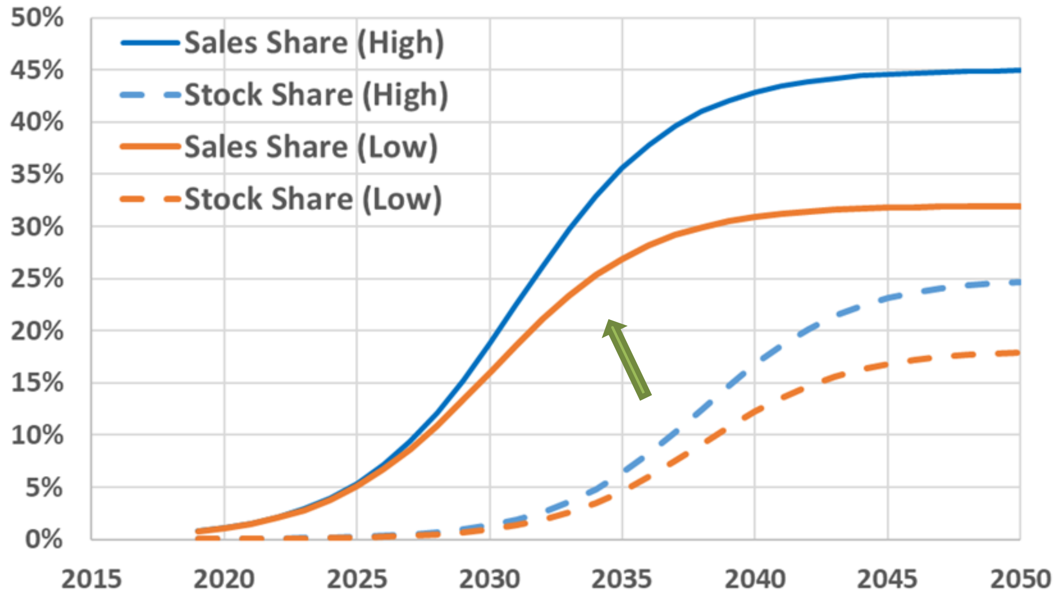

Figure 3 Electric Class 7&8 Truck Market Shares (500-mi electric range)

With stock, annual mileage and energy consumption per mile per truck, we estimated the petroleum consumption and electricity consumption using Argonne's VISION and NEAT model. We also compared the estimated petroleum and electricity consumption with projections made by the U.S. Energy Information Administration (EIA). EIA publishes projections in their annual energy outlook (AEO) [1].

4 Results and Conclusions

Comparing to AEO 2017 reference case, we estimated that electrified Class 7 and 8 electric truck with 500-mile electric range could potentially reduce the petroleum consumption by 1.61 quad in 2050, while the electricity consumption increases by 0.99 quad, shown in Figure 4. However, this analysis assumed no reduction in payload due to bigger battery. Battery energy density needs to be improved in the future to make the class 7 and 8 truck have the same payload capacity as a diesel counterparter. Some people may argue that depending on commodity type and shipping appications, we may not need every loung-haul truck to have the same range or same capacity as the diesel truck. Therefore the future research questions become 1) with current battery technology, how much freight movement would be affected meaning the truck is either "volume out" or "weight out", and 2) what is the battery energy density needed so 100% freight movement would be satisfied without "volume out" or "weight out"?

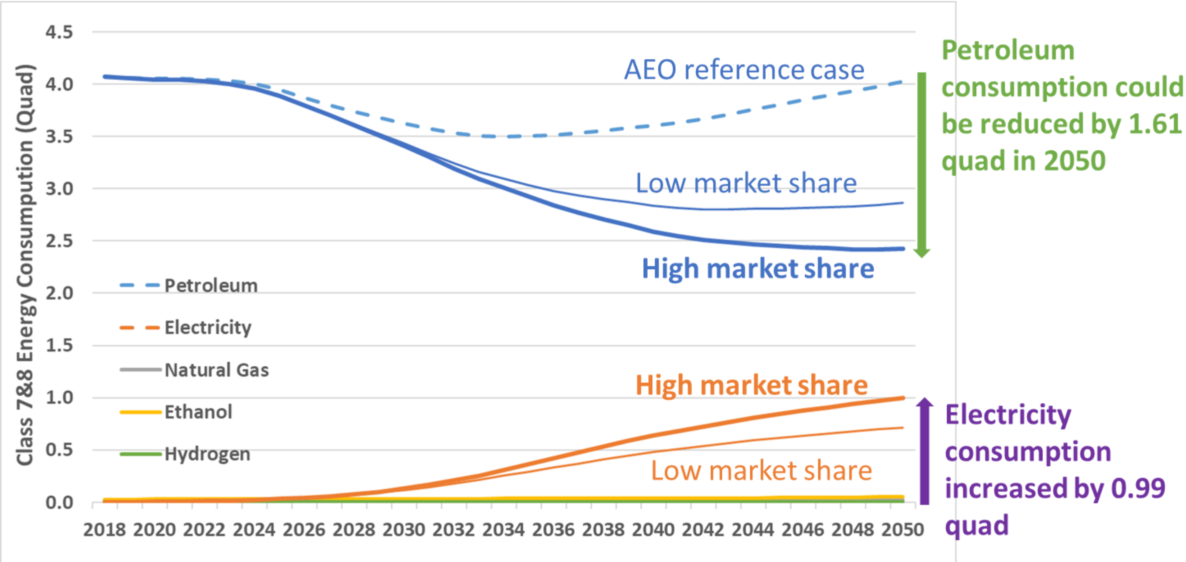

Figure 4 Energy Impact of Electrified Class 7&8 Electric Truck in the United States (500-mi electric range)

Moreover, this analysis assumes there is no infrastructure along the routes. As we stated earlier, comerical truck business is driven more by the time efficiency. Tesla Megachargers are expected to be up to 2 MW power electronic monsters, because it needs to replenish 400 miles (640 km) of range (or 80% of the 500-mile version) in 30 minutes. With electric long-haul trucks on the way, utilities need to prepare for higher power charging and related grid impacts. Also, in order to electrify more freight miles and overcome the on-road electric range deduction due to high driving speed, weather conditions and AC/heat use, on-route charging are also needed in the future to ensure the smooth freight movement by electricity.

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