ARK INVEST

The Future Of Autos And Trucks Is Electric

Electric Vehicles Taking Hold

Published: June 20, 2017

Author
Sam Korus, Analyst at ARK Invest

EXECUTIVE SUMMARY

ARK EXPECTS GLOBAL EV SALES TO EXCEED CURRENT FORECASTS, SUBSTANTIALLY

ARK expects global sales of Electric Vehicles[1] (EVs) to reach 17 million units by 2022, while agencies like the EIA are forecasting only two to four million units. Given the declining cost curve of lithium-ion battery cells, juxtaposed against the rising cost of internal combustion engines (ICE), EV sales growth is accelerating rapidly. Growth could be curbed by battery supply constraints in the next two to three years, but capital spending in this space should accelerate as battery supplies rise to meet the demand for EVs.

THE INTERNAL COMBUSTION ENGINE SHOULD GIVE WAY TO BATTERY TECHNOLOGY

ARK expects that the superior economics associated with electric vehicles will cause a wholesale shift from the internal combustion engine to battery technology. Two form factors dominate battery technology today: cylindrical cells and pouch cells. Evolving with the consumer electronics industry during the past 30 to 40 years, cylindrical cells are more mature and cheaper than pouch cells. That said, pouch cells are at an earlier stage of development and, while more expensive than cylindrical batteries today, their costs are declining more rapidly. ARK expects pouch cells to reach price parity with cylindrical cells by the end of 2019, though the two cell forms will not be like-for-like at that time, as cylindrical cells are likely to maintain their specific energy advantage through 2020. ARK's analysis demonstrates that overall system efficiency, which is battery form-factor agnostic, will have an out-sized impact on EV range and performance.

TRADITIONAL LONG-HAUL DIESEL TRUCKS SHOULD GIVE WAY TO ELECTRIC SEMI TRUCKS

While automakers are waking up to the realization that electric drivetrains are the future of passenger vehicles, many manufacturers remain skeptical that heavy-duty hauling vehicles will succumb to electrification. They continue to assert that batteries are too expensive, too slow to charge, and too heavy to be incorporated into long-haul fleets. According to ARK's research, conventional wisdom is misplaced: while EV Semis will incur higher upfront costs, total lifetime costs will be significantly lower than those for traditional semi trucks. In fact, during a 15 year life span, the total cost of ownership of an EV Semi should be roughly $500,000 lower than that of traditional diesel models.

ARK EXPECTS THAT LITHIUM WILL NOT FALL SHORT OF THE DEMAND FROM ELECTRIC VEHICLES

Just as the outsized demand for and rising price of copper spurred mining companies to explore and discover more of it, ARK expects lithium reserves to grow even as lithium production rises to meet the demand for EVs. Given the exponential ramp in demand for EVs that ARK is anticipating, lithium prices should continue to rise to the marginal cost of extracting it, giving mining companies with access to large reserves an opportunity to benefit disproportionately.

ARK EXPECTS PEAK OIL WILL BE MORE A FUNCTION OF DEMAND THAN OF SUPPLY

While BP's most recent Energy Outlook[2] forecasts that global oil demand will rise from roughly 94

1 ARK considers an electric vehicle (EV) to be a completely battery powered vehicle, which is not inclusive of hybrid vehicles.

2 Roughly similar to the EIA's oil forecast in its 2016 Annual Energy Outlook

million barrels per day (Mb/d) today to 110 Mb/d by 2035,[3] ARK's research suggests that it will peak below 100 Mb/d before the end of this decade and decline to 90 Mb/d by 2035. Even if autonomous technology does not commercialize as rapidly as ARK anticipates, EV adoption alone should cause peak oil demand by 2025. Though personal cars account for less than 30% of total oil demand,[4] diesel trucks help to explain why transportation makes up 56% of total oil demand.[5] EV Semi trucks could be the real spoiler in the outlook for oil prices.

ARK EXPECTS THAT BATTERIES WILL OUTLIVE THEIR VEHICLES

Battery degradation is one of the biggest concerns that potential buyers express as they evaluate an EV purchase. According to ARK's research, not only will EV batteries retain substantial value after the end of their in-vehicle life, but electric utilities probably will bid to buy them as they curb capital spending associated with peak power capacity needs. By our calculations, the value of a ten year old battery from a Tesla Model S could command as much as $13,000, more than that for an entire internal combustion engine vehicle sold originally at a similar price-point.

THE AUTO SECTOR IS RIPE FOR SIGNIFICANT CONSOLIDATION

After Ford introduced the moving assembly line, the horse-drawn carriage industry consolidated by more than 96% and the automotive market by roughly 80%. ARK's research suggests that the introduction of autonomous technology and manufacturing efficiencies will cause similar levels of consolidation: autonomous vehicle networks should benefit from the network effects now enjoyed by companies like Facebook, Google, and Amazon, all of which have capitalized on "winner take most" data aggregation strategies. Data-driven industries tend to be much more concentrated than hardware-centric industries.

ABOUT THE AUTHOR

SAM KORUS

Research Analyst
ARK Invest

Sam joined ARK as a thematic analyst on the Industrial Innovation team in July 2015. His focus is on automation, robotics, energy storage, alternate energy, and space exploration. Prior to ARK, Sam was a business development intern at Graphiq, a knowledge graph and visualization company. Prior to Graphiq, Sam worked as a captain for Sail Caribbean.

Sam graduated from the University of Pennsylvania where he studied Cognitive Science with a concentration in Computation and Cognition. He has appeared on BNN and Cheddar, and has been quoted in The Wall Street Journal, CNN Money, the Los Angeles Times, and other publications.

3 https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf

4 https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf; https://www.worldenergy.org/wp-content/uploads/2012/09/wec_transport_scenarios_2050.pdf

5 https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf

INTRODUCTION

Not since Henry Ford introduced the moving assembly line more than 100 years ago has the automotive industry experienced a period of fundamental transformation. Obviously cars have improved thanks to nicer interiors, air conditioning, better fuel efficiency, and entertainment options, but the advancements have been incremental. In fact, adjusted for inflation, automobile travel costs have been relatively stable over the past century. While commutes may have become more comfortable, the cost per mile traveled has not changed.

For the first time in a century, the auto industry is on the precipice of dramatic transformation. Drivetrains and manufacturing are changing along with lithium-ion battery technology, bringing into focus an electric powered future. Based on ARK's research, electric drivetrains will be cheaper to produce than those based on the internal combustion engine within the next five years, suggesting that electric vehicle sales could increase more than 30-fold to 17 million units, or 20% of total auto sales globally, in 2022, dominating vehicle sales over time.

This paper will focus on the electrification of the vehicle fleet and is a companion piece to ARK Invest's white paper on autonomous technology.[6] The two papers provide a comprehensive analysis of the transformation looming over the auto industry.

GLOBAL ELECTRIC VEHICLE DEMAND

The automotive industry is approaching a profound inflection point: by 2022 ARK expects the demand for electric vehicles[7] (EVs) will begin to outpace that for gasoline powered cars. As the cost of lithium-ion cells falls faster than most analysts have anticipated and the cost to manufacture traditional internal combustion engine (ICE) powertrains continues to increase, ARK Invest's analysis suggests that 200-mile range EVs will become cheaper to the consumer than the majority of ICE vehicles within five to seven years. Given American travel habits, a 200-mile range vehicle should meet the requirements of 80% of the population. These data points combine to suggest that current forecasts understate the demand for EVs in the 2020s by an order of magnitude.

Accounting for roughly 20% of an EVs total cost,[8] electric drivetrain cost declines are critical to future EV adoption. Current sales of EVs remain low in part because the current cost of battery assembly prevents manufacturers from hitting mass market price points. This dynamic is expected to change soon. Lithium-ion battery prices are declining rapidly as manufacturers scale and automate production. On the other side of the ledger, ICE powertrain costs are rising to accommodate stricter efficiency and emission regulations. Currently, EVs sell at a premium to comparable ICE vehicles,

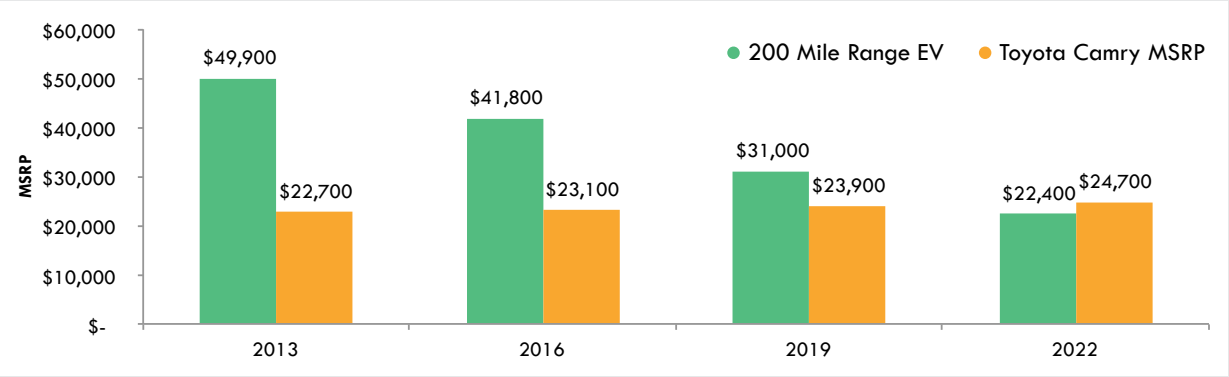
6 http://research.ark-invest.com/self-driving-cars-white-paper

7 Some EV forecasts will group hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, and extended-range electric vehicles (or some combination of those). ARK uses EV to refer to battery electric vehicles only.

8 ARK Investment Management LLC

but ARK anticipates that a 200-mile range EV with the same amenities as today's best-selling Toyota Camry will sell at a lower price point in 2022, as shown in Figure 1.[9]

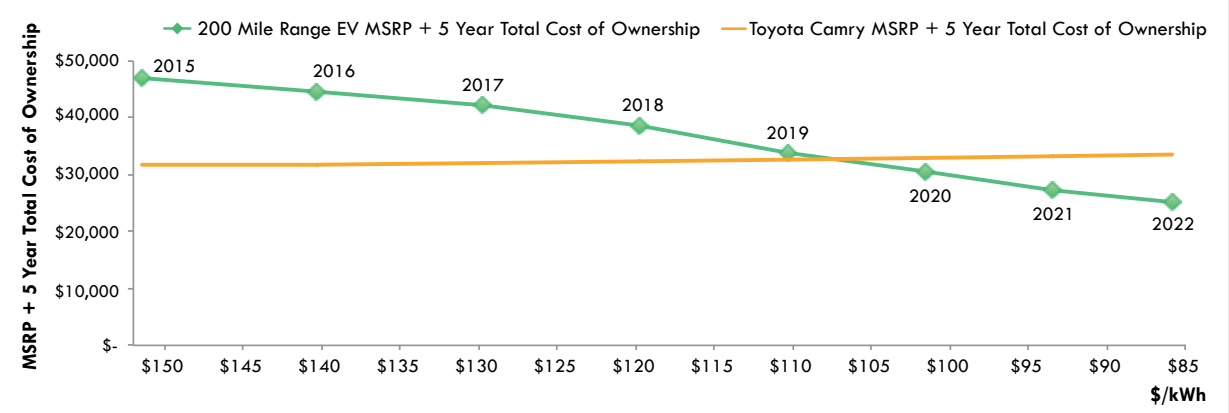
FIGURE 1
Projected Price Parity for 200-Mile Range EV



Source: ARK Investment Management LLC, NADA Guides

While EVs will remain more expensive based on sticker price until 2022, ARK anticipates that the crossover point will occur even sooner based on total cost of ownership (TCO). For EVs the per-mile cost of electricity is roughly 25% the per-mile cost of gasoline. In addition, EV maintenance bills are roughly $2,000 cheaper than those for ICE vehicles over a five year period.[10] As shown below, car buyers taking into account the TCO probably will find that mass market EVs have become cost competitive before 2020.

FIGURE 2
Projected Price Parity Point for 200-Mile Range EV
Inclusive of Five Year Total Cost of Ownership



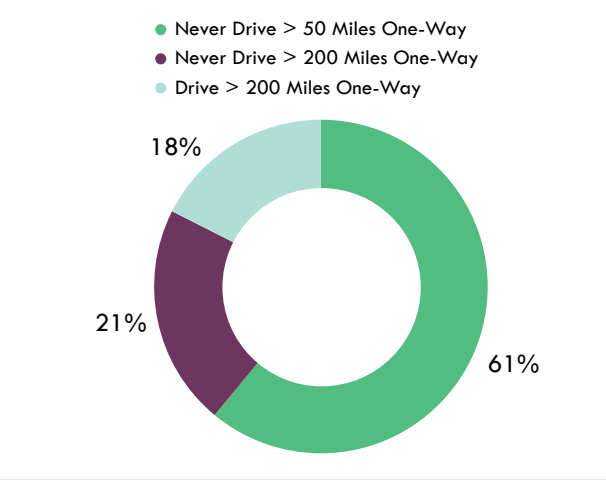
Source: ARK Investment Management LLC, NADA Guides

9 ARK's expectation for EV manufacturer's suggested retail price (MSRP) parity is largely based on decreasing lithium-ion battery costs and increasing ICE powertrain costs. Other factors could influence MSRP. The MSRP prices shown do not include any government subsidies.

10 http://www.greencarreports.com/news/1080925_electric-car-maintenance-a-third-cheaper-than-combustion-vehicles

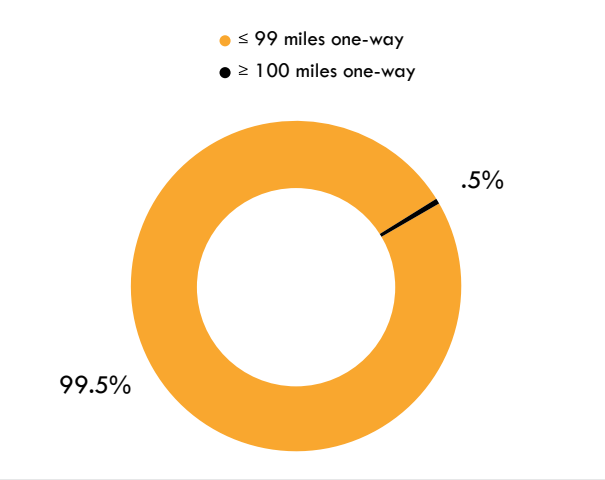
Major auto manufacturers have focused their research and development efforts on the 200-mile range EV for a reason. As shown below, roughly 60% of the U.S. population does not travel long distance in an average year.[11] Among those consumers who do, more than half travel fewer than 200 miles per trip. Meanwhile, among those commuting with a personally owned vehicle (POV), 99.5% travel fewer than 99 miles one-way. Consequently, a 200-mile range EV could accommodate roughly 80% of the U.S. population's travel needs and prove sufficient for nearly every commuter who drives to work.

FIGURE 3
Consumer Driving Behavior in an Average Year



Source: ARK Investment Management LLC, U.S. Department of Transportation

FIGURE 4
U.S. Commuters Using a Personally Owned Vehicle (POV)



Source: U.S. Census Bureau, U.S. Department of Transportation, ARK Investment Management LLC

Based on ARK Invest's research, a 200-mile range EV will be comparable in price and feature-set to a Toyota Camry by 2021, after which time EVs will extend their competitive advantage. In 2022, ARK expects the cost of a 200-mile range EV to drop below $23,000, placing it at a lower price point than 50% of passenger cars sold in the U.S. and just under 50% of those sold globally. Once EVs and ICE based cars reach price parity, the adoption of EVs should accelerate rapidly.

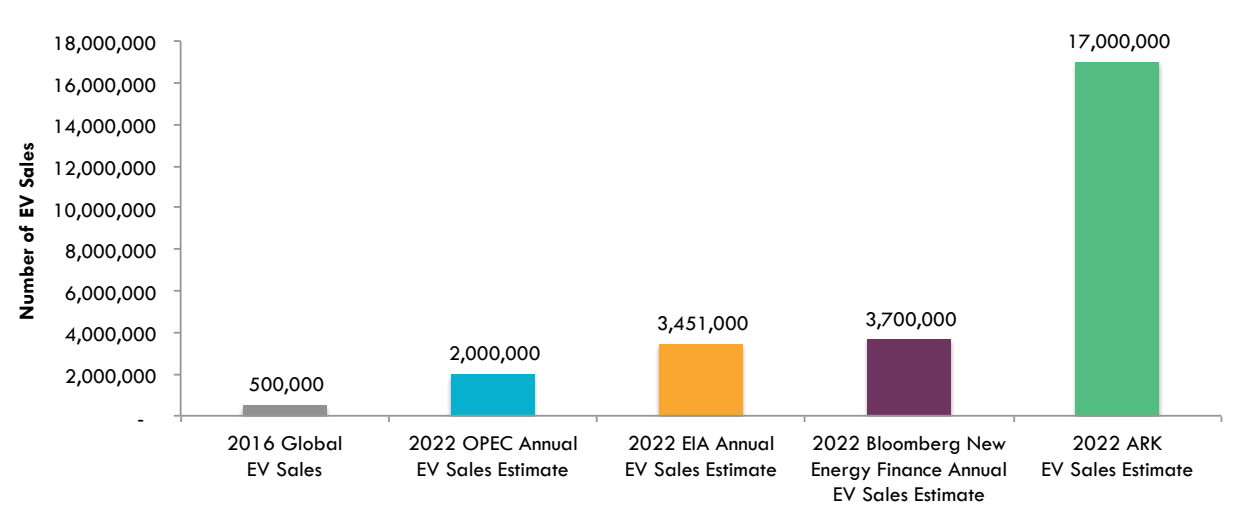
Based on their forecasts, however, many well-known institutions are not anticipating that EVs will reach price parity or achieve broad adoption in the next five years. Both OPEC and the EIA increased their forecasts ten-fold between 2015 and 2016. In 2017 the EIA increased its forecast by over 70%.[12] By contrast, according to ARK's analysis, the demand for EVs will approach 20 million units in the early 2020s, as shown in Figure 5.[13]

11 Bureau of Transportation Statistics National Household Travel Survey

12 At the time of publishing OPEC has not released its 2017 World Oil Outlook; Data is from 2016 World Oil Outlook.

13 ARK is estimating demand based on the price point and volume of current auto sales and the percent of people whose travel habits make them amenable to a 200-mile range EV.

FIGURE 5
Forecasted 2022 Annual EV Sales (As of 2017)



Source: ARK Investment Management LLC, OPEC World Oil Outlook, EIA Annual Energy Outlook, EV-Volumes.com, BNEF Electric Vehicle Outlook

Auto manufacturers such as Tesla, Volkswagen, Volvo, and GM have already committed to volume EV production during the next few years; however, others are just beginning to sense the opportunity. Audi, Mercedes, Porsche, and others have indicated that they will incorporate volume production into their future plans.[14]

Given the significant demand that ARK anticipates, EV sales may be subject to ongoing supply-constraints. As the true scope of the opportunity becomes clear, ARK expects that companies like Tesla, Panasonic, Samsung, LG Chem, GS Yuasa, and Contemporary Amperex Technology will invest aggressively and fill the void. Already, from 2016 to 2017 commissioned and announced battery capacity more than doubled from 117 GWh to 236 GWh.[15]

LITHIUM-ION BATTERY FORMATS

As companies plan to bring new battery manufacturing capability online, they will have to make choices among battery components. Currently, EV manufacturers are choosing between two battery form factors: cylindrical cells and pouch cells, both pictured below. Tesla is one of the few car manufacturers using cylindrical cells.

14 https://www.vox.com/energy-and-environment/2017/9/13/16293258/ev-revolution
15 Bloomberg New Energy Finance

CYLINDRICAL CELL

Malcolm Koo, CC-BY-SA 4.0

POUCH CELL

Mpt-matthew, CC-BY-SA 3.0

ARK believes that a combination of the cost, specific energy, and system efficiency of battery pack systems will be the key differentiators determining the price/performance of the vehicle. An analysis of the relative price declines of cylindrical and pouch cells suggests that GM and BMW, both choosing pouch cells, will produce EVs comparing favorably with Tesla's within the next few years. That said, their specific energy and battery pack system efficiency will likely lag behind Tesla's for some time to come.

Adopting the cylindrical cell, the mature consumer electronics-based battery, at launch, Tesla hit an acceptable price point for its vehicles in fairly short order, but it did so at the expense of a less dramatic cost curve decline than pouch cells are experiencing. As shown below, the cost of the more mature cylindrical cell is declining at a rate slower than that of the pouch cell. Cylindrical cells had been the standard solution for most consumer electronic products, but the slimmer pouch cells are taking market share as consumer electronics have become thinner and smaller.[16] Consequently, pouch cells are enjoying a more dramatic price decline and likely will be cheaper than cylindrical cells by 2019.[17]

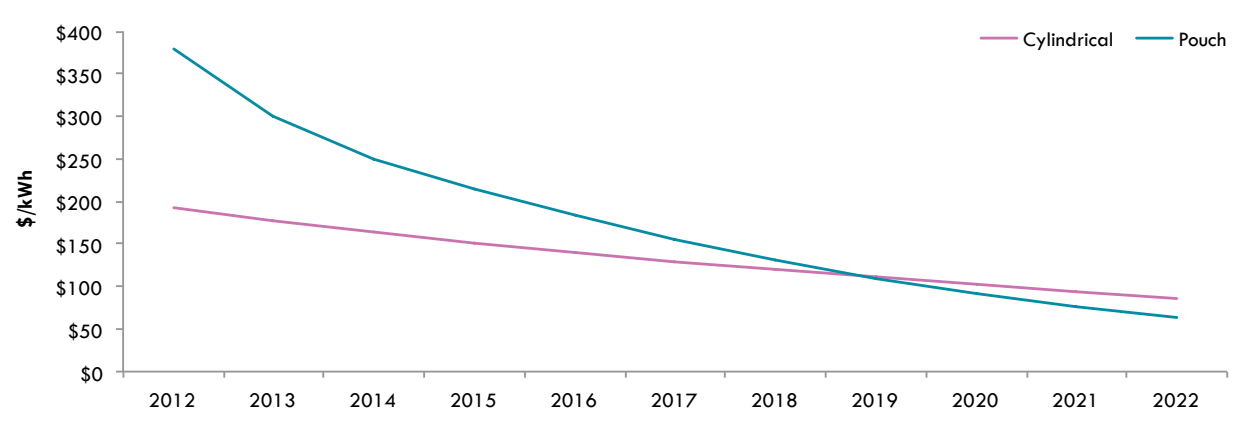
While this trend may seem ominous for Tesla, its cylindrical cells have a much higher specific energy, the amount of energy per mass in each cell. Elon Musk highlights the specific energy advantage of cylindrical cells[18] when addressing questions about future cost curve declines. (Figure 6)

16 http://www.avicenne.com/pdf/BMDCEAIMR_C_Pillot_Presentation_5th_Israeli_Power_Sources_Herzelia_May2015.pdf

17 GM has secured special pricing from LG Chem for $145/kWh for pouch cells. http://insideevs.com/lg-chem-ticked-gm-disclosing-145kwh-battery-cell-pricing-video/

18 https://www.youtube.com/watch?v=sN5HT9mj_4M

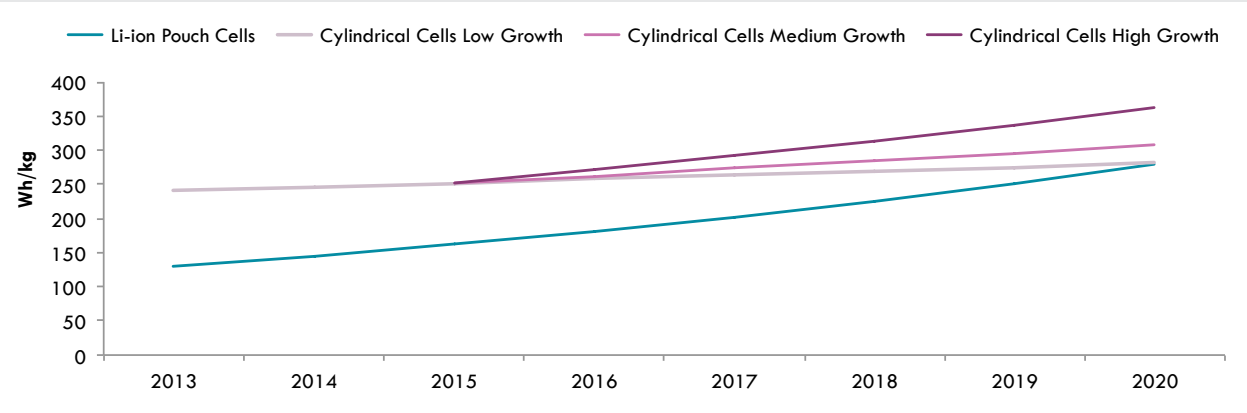
FIGURE 6
Lithium-Ion Cost Decline by Cell Type



Source: ARK Investment Management LLC, Avicenne Energy

As seen below, cylindrical cells have roughly 50% higher specific energy compared to pouch cells.[19] Specific energy is particularly relevant for EV applications compared to consumer electronics because extra weight reduces range. Batteries with higher specific energy will use fewer kWh to achieve a given range, lowering the cost and increasing the range of a given trip. Moreover, silicon can increase the specific energy of a lithium-ion battery when added to its anode. Two years ago, with the introduction of the 90 kWh battery pack, Musk said, "It's a baby step in the direction of using silicon in the anode."[20]

FIGURE 7
Projected Wh/kg of Lithium-Ion Pouch Cells vs. Cylindrical Cells

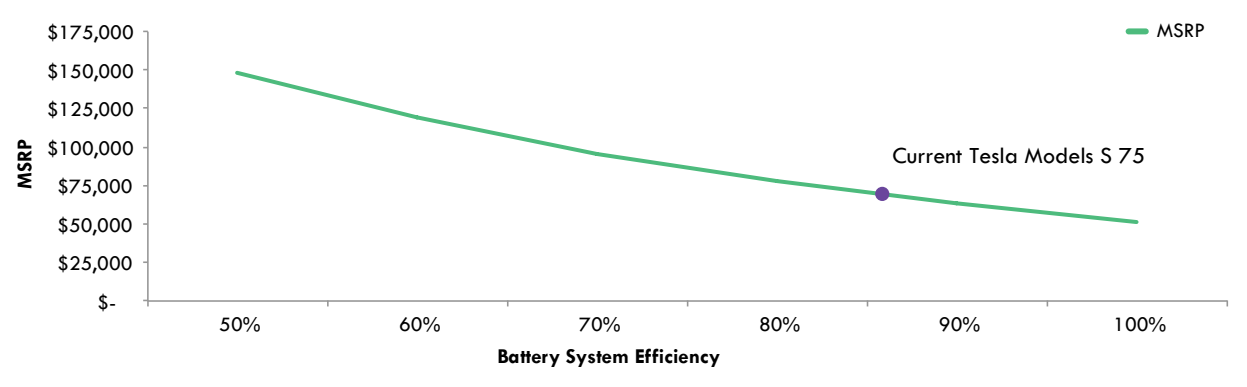


Source: ARK Investment Management LLC, 2006 International Power Sources Conference, Samsung

19 ARK Investment Management LLC, 2006 International Power Sources Conference, Samsung
20 http://www.forbes.com/sites/uciliawang/2015/07/17/why-tesla-rolls-out-better-ev-batteries/;

The third and most significant factor impacting an EV's price relative to performance is battery system efficiency. In a battery pack system, balancing and cooling can impact range significantly because of energy dissipation and loss.[21] ARK's research indicates that the two most efficient battery systems are Tesla's cylindrical cell system at roughly 90% efficiency, and the Chevy Bolt's pouch cell battery system, which lags Tesla's only slightly. Seemingly, overall system efficiency has less to do with cell format and more to do with battery pack management expertise and power electronics. For example, a drop from 90% to 80% in the Tesla Model S 75 battery pack system efficiency would require an added 20kWh in battery capacity to achieve the same range. As seen in the chart below, that change in battery system size and efficiency would add more than $15,000 to the price, changing its price/performance completely.

FIGURE 8
Theoretical Price of Model S 75 to Maintain Its Current Range Given Different Battery System Efficiency



Source: ARK Investment Management LLC, Tesla

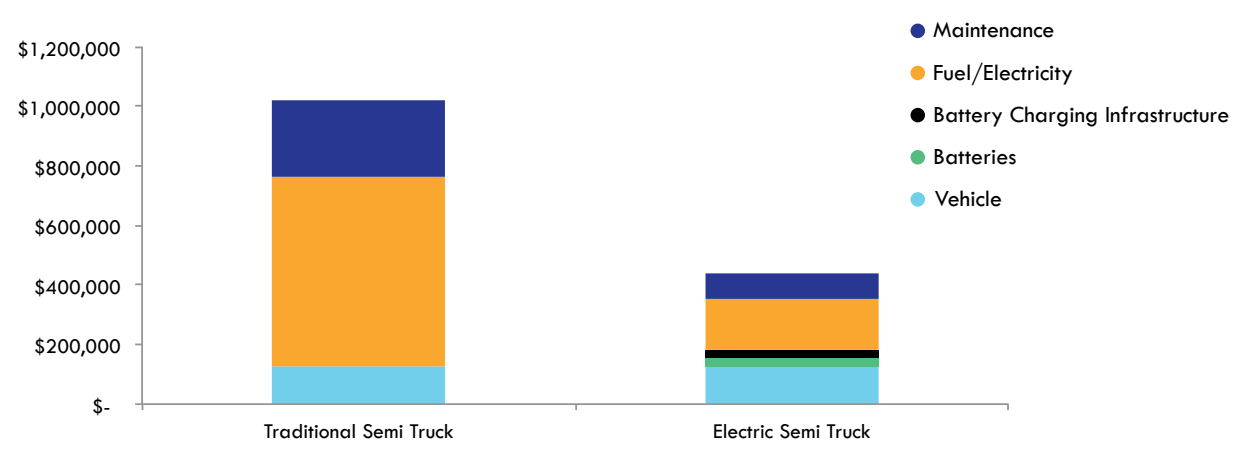
ELECTRIC SEMI TRUCKS

From a strategic planning point of view, while automakers recognize that electric drivetrains are the future of passenger vehicles, heavy and long-haul truck manufacturers seem skeptical. Not surprisingly, they scoffed when Tesla announced plans to launch an Electric Semi Truck (EV Semi) later this year, suggesting that the cost, weight, and time-to-charge would be prohibitive for a long-haul fleet.

In contrast, ARK's research illustrates that EV Semis could prove superior to existing long-haul trucking options. Though the upfront cost of EV Semis will be higher than that for traditional models, their total cost of ownership (TCO) will be significantly lower. As shown in Figure 9, an EV Semi owner will enjoy roughly $500,000 in savings over the 15-year life of the vehicle.

21 http://batteryuniversity.com/learn/article/discharging_at_high_and_low_temperatures

FIGURE 9
Traditional vs. Electric Semi Truck Lifetime Cost Over 15 Years



Source: ARK Investment Management LLC

While controversial on the surface, this conclusion incorporates three factors often overlooked in determining the total cost and efficiency of an EV Semi:

- The power of regenerative braking with multiple electric motors
- The decreased importance of battery weight given regenerative braking and long-haul load sizes
- The importance of a supercharging network, lowering range-requirements.

According to ARK's research, two factors will play outsized roles in determining the range efficiency (kWh per mile) of an EV Semi: multiple motors and regenerative braking.

On its first quarter earnings call in 2017, Elon Musk announced that the Tesla EV Semi will have "a bunch" of Model 3 motors with different power requirements, allowing each to operate at maximum efficiency. The Model S 75D (Dual motor) has a longer range than the Model S 75 for this reason.[22] By combining motors, Tesla should be able first to provide the output necessary when an eighteen-wheeler accelerates, and then, critically, to reclaim the energy as the eighteen-wheeler brakes. Fully loaded semis require much more power than a single 250 kW motor can provide. With multiple motors, EV Semis can satisfy power requirements as they accelerate and brake.

While multiple motors are critical to performance, regenerative braking has a more profound impact on the performance of an EV Semi. Vehicles spend a lot of energy getting up to speed,[23] with eighteen-wheelers expending proportionately more so. When a non-EV Semi applies the brakes to

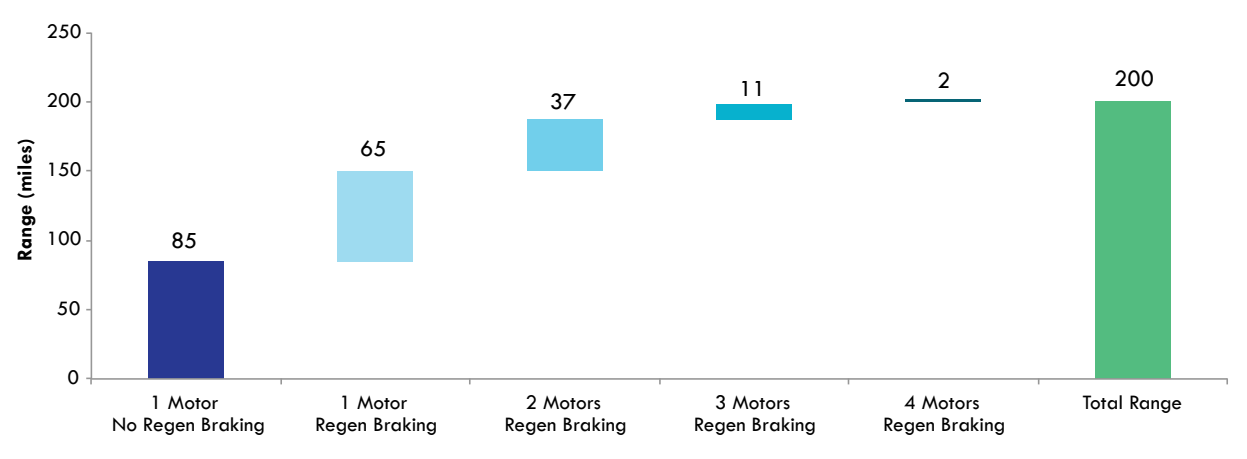
22 https://www.tesla.com/models/design

23 To be a little more precise, the vehicles convert the chemical energy of their battery or fuel into the kinetic energy of motion.

slow down, it loses all of that energy: all of the fuel used to get the rig up to highway speed dissipates via heat and sound. Not so with an EV Semi: the electric motor can run in reverse, harnessing the energy and recharging the battery. In that way, EV Semis can recoup up to 90%[24] of their kinetic energy, compared to 0% for non-EV Semis.

In other words, an EV Semi that is heavier than a traditional semi can be just as efficient thanks to regenerative braking. Alternatively, as shown below, ARK estimates that, at the same weight and the same energy input, an EV Semi with a single electric motor and regenerative braking should be capable of traveling 75% farther than a traditional semi. With multiple motors maximizing regenerative energy-capture, EV Semis should be able to travel more than twice the distance.

FIGURE 10
EV Semi Truck Range (355kWh battery; truck and payload weighing 54,000lbs)



Source: ARK Investment Management LLC

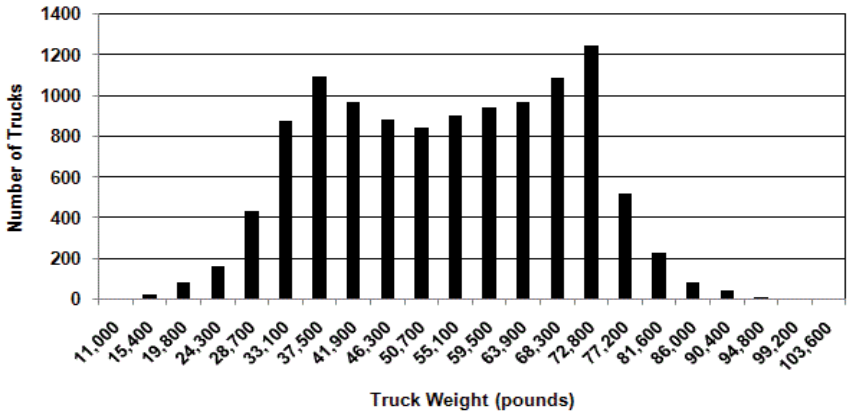
Two factors will limit the amount of energy recoverable through regenerative braking: first, the amount of power produced by running the electric motors backwards and second, the battery pack efficiency.[25] That said, an EV Semi hauling around tons of weight should not kill range efficiency. According to ARK's estimates, if the EV Semi has roughly 900kw of motor power, the sum of four motors and 87% efficiency, it can recover a significant amount of energy.

While EV Semis pay less of an energy penalty than do traditional semis for taking on more weight, analysts question whether the additional battery weight will negate that benefit. In most cases, the answer is no.

24 https://www.wired.com/2016/09/new-electric-bus-can-drive-350-miles-one-charge/
25 https://www.tesla.com/blog/magic-tesla-roadster-regenerative-braking

As shown below, most trucks "cube-out," or run out of space in the trailer, before they "weigh-out," or hit the maximum 80,000 lbs weight limit.[26] The net weight difference between an EV Semi and traditional semi is less than 3,000 lbs. As shown in the chart illustrating the distribution of trips by weight, the battery would impose a limitation only on trucks weighing greater than 77,000lbs, which comprise less than 7% of trips.

FIGURE 11
Distribution of Class 8 Trucks by On-Road Vehicle Weight, 2008



Source: Oak Ridge National Laboratory, Figure 5.5
Note: Study reported data on 5-axle tractor trailers which are class 8 trucks. Single-unit class 8 trucks were not considered in the study.

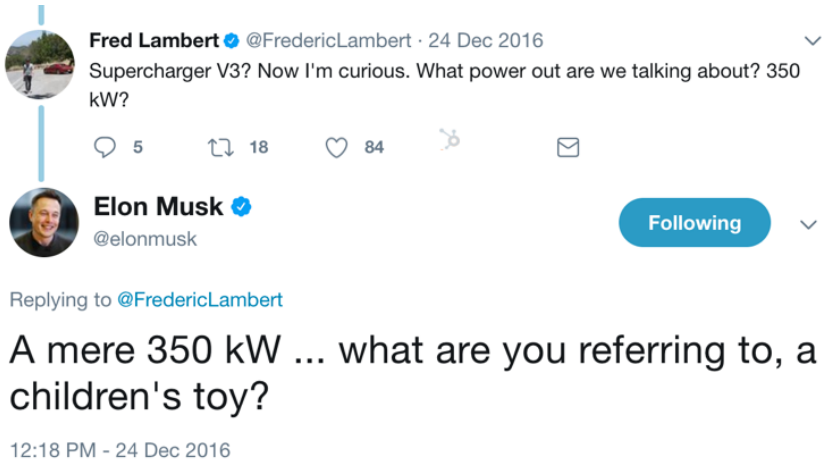
Range is another risk frequently cited in forecasts for both passenger EVs and long-haul EV Semis. To date, many analyses have concluded that EV Semis will not gain traction in the absence of a 400-mile+ range. In our view, because most truckers stop every two to four hours to stretch their legs, use the bathroom, or check on their loads,[27] such an assumption seems off base. Because these frequent stops typically last a few minutes, an EV Semi simply needs to be able to recharge quickly.

With a supercharging network in place, EV Semis would be able to operate efficiently at a range of roughly 200 miles with an average weight load.[28] The supercharging implementation could be an extension of Musk's comment regarding the use of Model 3 components in the truck. Much like SpaceX created the Falcon 9 rocket with nine Falcon 1 rockets, Tesla could combine four or five Model 3 drivetrains and produce a fast-charging EV semi. As shown in his tweet below, Musk says that the next generation of superchargers could provide much more than 350 kW of power. While a 350 kWh battery would take roughly an hour to charge, four or five Model 3 batteries could be charged simultaneously in ~15-20 minutes.

26 http://cta.ornl.gov/data/chapter5.shtml

27 https://www.classadrivers.com/forum/new-truck-drivers-get-help-here/15374-how-long-do-you-drive-without-stopping.html ; https://www.thetruckersreport.com/truckingindustryforum/threads/how-often-do-you-truck-drivers-stop-for-breaks-leg-stretching-etc.199315/

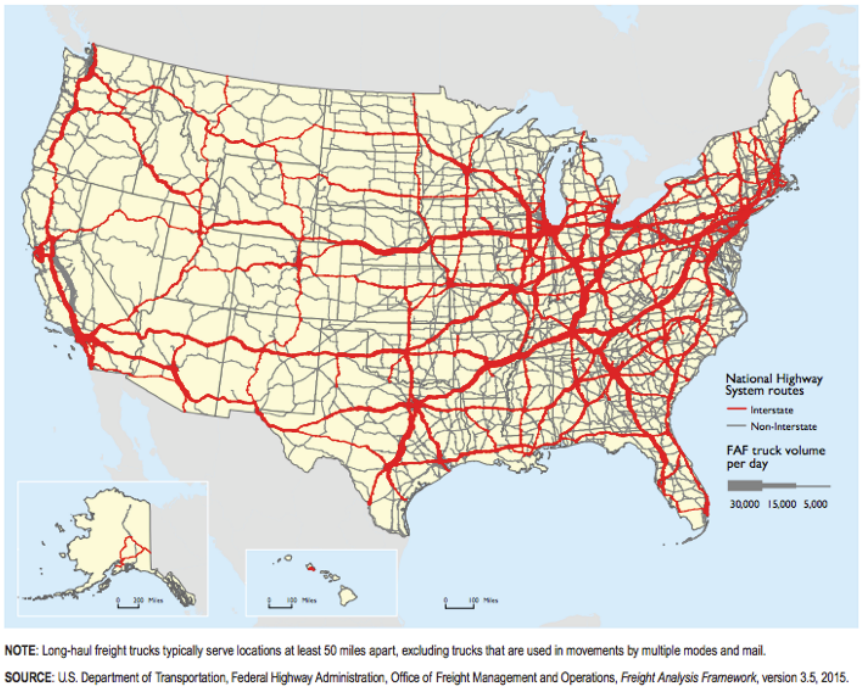
28 ARK used the EPA Heavy Duty Urban Dynamometer Driving Schedule in its range model



Source: Twitter, 2017

A supercharging network could offer EV Semis unlimited range without the extra weight of a bigger or spare battery. In addition, given the traffic density of most trucking corridors as shown below, the infrastructure could be built out efficiently while accommodating the majority of demand.

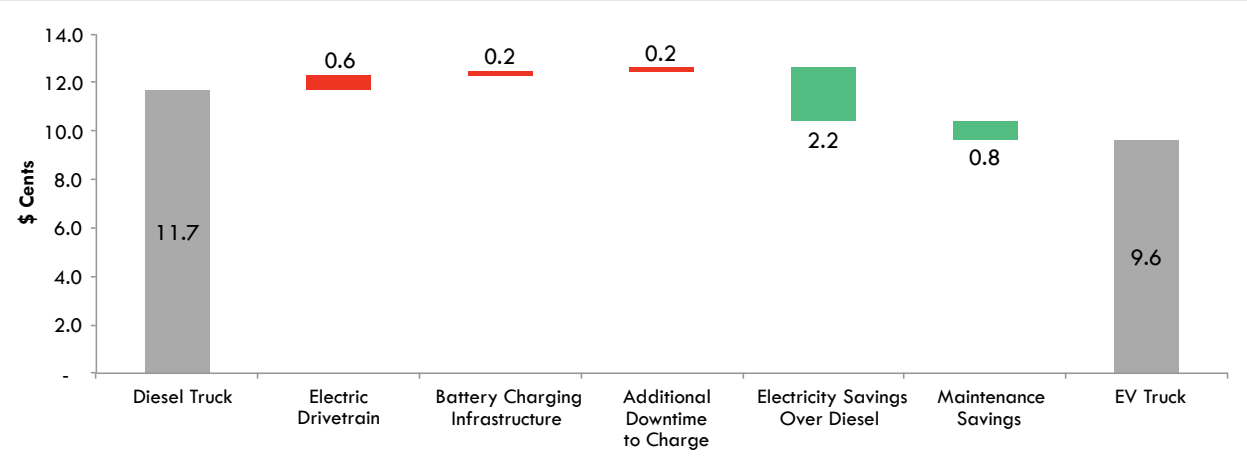
FIGURE 12
Average Daily Long-Haul Truck traffic on the National Highway System: 2011



Source: U.S. Department of transportation, Federal Highway Administration, Office of Freight Management and Operations, 2015

An EV Semi has the potential to lower the total cost of ownership without sacrificing the performance of a traditional semi truck. Indeed, according to our research, EV Semis could reduce the cost per ton-mile by roughly 18%, as shown in the chart below, without taking into account other performance enhancements like autonomous driving that Tesla is likely to incorporate. With lower labor costs and higher truck utilization, an autonomous EV Semi could reduce the cost of shipping substantially, a topic we will address in a future research piece.

FIGURE 13
Semi Truck Cost Per Ton-Mile



Source: ARK Investment Management LLC

ARK anticipates that EV Semis with autonomous capabilities could drop the shipping costs to less than 3 cents per ton-mile, with much of the savings accruing to consumers via lower cost e-commerce offerings and faster deliveries. From Tesla's perspective the commercial prospects could prove quite compelling, as the North American addressable ton-mile market today is roughly $200 billion per year. At $0.03 per ton-mile, the market would shrink by more than half, but at such a low price point trucking could take ton-mile share from rail. Moreover, leveraging the Model 3's infrastructure to build a number of different vehicles in the same factory provides Tesla with a competitive advantage.

LITHIUM SUPPLY

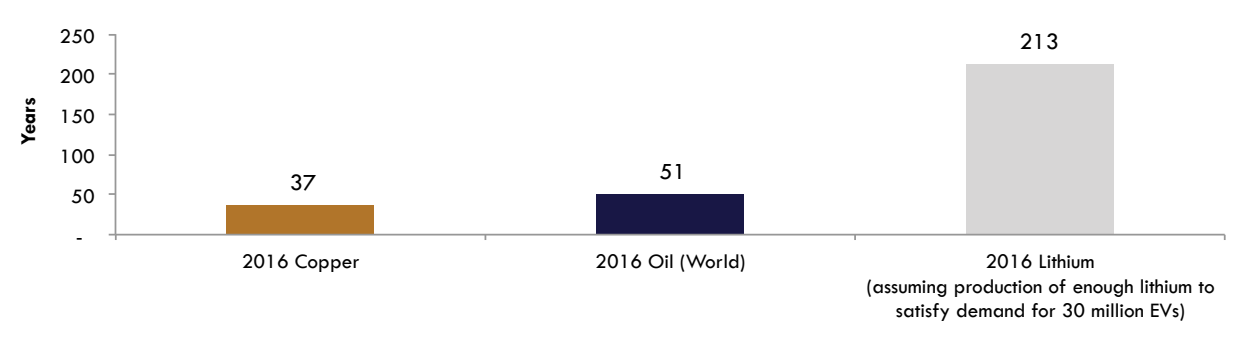
Despite speculation to the contrary, lithium resource constraints are unlikely to short-circuit an acceleration in the growth of EV sales. ARK believes global lithium reserves[29] will continue to increase even as lithium production rises to meet EV demand. Lithium mining companies with low-cost

29 The United States Geological Survey (USGS) defines reserves as the part of the reserve base, which could be economically extracted or produced at the time of determination. Reserves do not signify that extraction facilities are in place and operative. http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcsapp2015.pdf

resources stand to benefit as higher cost supply comes online. During the next six years, as the global demand for EVs increases roughly 30 fold,[30] lithium and lithium-related companies could prove to be productive investments.

The shortage thesis typically includes an assumption that lithium reserves will stagnate at current levels while production rises to meet the demand for EVs.[31] Even at today's lithium reserve levels, however, EV manufacturers could produce 30 million units annually for 213 years, as shown below. That reserve-to-production ratio is higher than that for copper or oil.[32] According to BP[33] oil reserves never have topped 55 years of oil production. Lithium is unlikely to drop to 55 years of reserves despite the massive acceleration in EV uptake that ARK anticipates.

FIGURE 14
Reserve to Production Ratio



Source: USGS, BP, ARK Investment Management LLC

The assumption that commodity reserves are static is misleading. In 1970, according to the U.S. Geological Survey, for example, copper reserves were 280 million tons. Since then, cumulative global copper production has totaled over 500 million tonnes, and today the current estimate of copper reserves is 720 million tons. Clearly, after China joined the World Trade Organization (WTO) in 2001, its outsized demand for copper incentivized mining companies to discover more of it, developing technologies that would allow them to access a higher percentage of the known resources. In other words as shown in Figure 15 and 16, despite increased rates of extraction, reserves in both copper and lithium have expanded rather than contracted over time.[34]

30 https://ark-invest.com/research/electric-vehicles

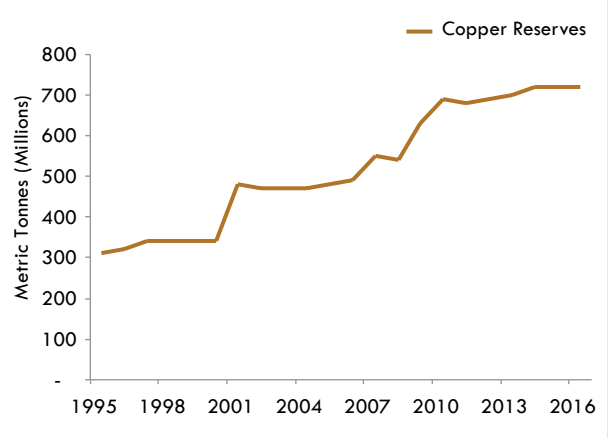
31 http://energyskeptic.com/2016/not-enough-lithium-for-electric-car-batteries/

32 http://tools.bp.com/energy-charting-tool.aspx#/st/oil/dt/rp/unit/Years/region/NOA/SCA/EU/MIE/AFR/AP/view/line/; ARK Investment Management LLC

33 Since 1980. http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/oil-review-by-energy-type/oil-reserves.html

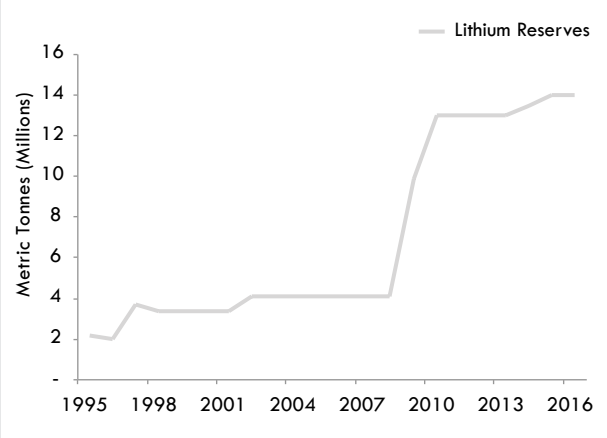
34 http://minerals.er.usgs.gov/minerals/pubs/mcs/2016/mcsapp2016.pdf

FIGURE 15
Copper Reserves (Million Metric Tonnes)



Source: USGS, ARK Investment Management LLC

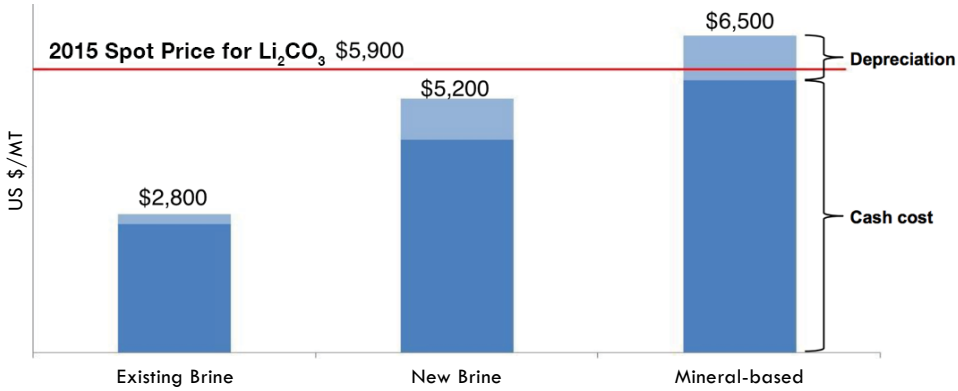
FIGURE 16
Lithium Reserves (Million Metric Tonnes)



Source: USGS, ARK Investment Management LLC

Not all lithium reserves are high enough in quality or low enough in cost to produce EV batteries. As shown below, the economic efficiency of extracting lithium differs by method.[35] For example, extracting lithium from existing brine costs less than half that of extracting it from hard rock spodumene.

FIGURE 17
Relative Costs by Lithium Source



Source: FMC, Modified ARK Investment Management LLC
http://www.fmclithium.com/Portals/FMCLithiumEnergy/Content/Docs/Jefferies%20Conference%20Feb%202012%20FINAL.pdf,
http://www.smh.com.au/business/mining-and-resources/lithium-prices-tipped-to-rise-by-20-per-cent-by-2017-on-demand-for-electric-cars-20151026-gkid4z.html
http://oilprice.com/Finance/investing-and-trading-reports/Lithium-Market-Poised-For-Growth-As-Demand-Spikes.html

35 Cost to extract lithium per unit weight.

Lithium prices already have appreciated considerably, with spot prices in China escalating five-fold to $20,000 per metric tonne since 2011.[36] Given the nearly exponential ramp in EV demand that ARK anticipates during the next five to ten years and the recent increase in lithium prices, large mining companies like FMC, Sociedad Quimica y Minera de Chile, Albermarle, and Orocobre have a significant incentive to increase both reserves and production.[37]

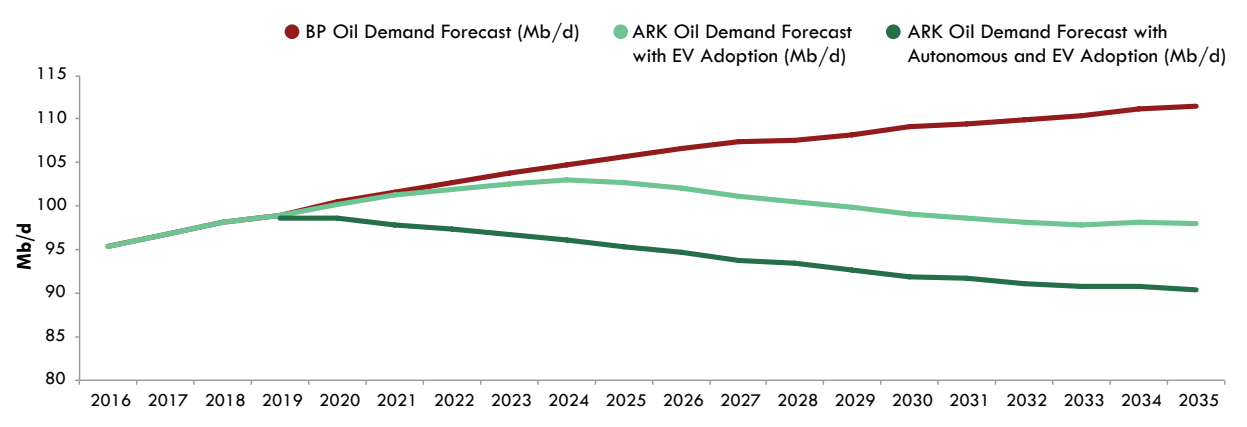
To satisfy future demand, the lithium industry should commit to massive investment in new projects. It's not surprising then, that the world's largest active lithium mine already has announced plans to double production.

Given the lower capital costs associated with existing vs greenfield lithium mines, companies with access to large reserves stand to benefit disproportionately. That said, mining is a low-margin, complicated, and capital intensive business, leaving companies vulnerable to supply-demand imbalances even in the short term. Importantly, as with all commodity value-chains, the industry is vulnerable during periods of rapid supply expansion when exhuberance and hubris often cause poor capital-deployment decisions and punish shareholder returns.

PEAK OIL DEMAND

If lithium is one side of the EV energy story, then oil is the other. Combined with a move toward autonomous networks, EV adoption could cap oil demand within the next two to three years. As discussed earlier in this paper, ARK's forecast for EV sales is significantly above policymakers'

FIGURE 18
Oil Demand Forecast



Source: ARK Investment Management LLC, BP Energy Outlook

36 http://fortune.com/2016/06/06/lithium-price-tesla-metal-future/

37 http://investors.albemarle.com/phoenix.zhtml?c=117031&p=irol-newsArticle&ID=2254337

expectations. In addition, Uber-like autonomous taxi services will lower the price of transportation precipitously, further increasing the share of miles driven on electric drivetrains. As a result, while BP's 2017 Energy Outlook[38] forecasts an increase in global oil demand from roughly 94 million barrels per day (Mb/d) today to 110 Mb/d by 2035,[39] ARK's research is pointing to a peak below 100 Mb/d and a drop to 90 Mb/d by 2035, as shown in Figure 18. Even in the absence of autonomous technology, EV demand alone should lead to peak oil demand by 2025.

ARK believes that most forecasting agencies are underestimating the market share that EVs will take from internal combustion engine (ICE) vehicles. Today, EVs like the Nissan Leaf, the BMW i3, and the Kia Soul EV offer limited range models priced at a premium to their gas-powered counterparts. Forecasting agencies seem to be basing future EV adoption on more of the same: higher prices for lower performance. In contrast, ARK's battery cost model suggests that EVs will be cheaper than ICE-powered cars like-for-like on performance and quality by the early 2020s. As the price of EVs drops below that for ICE vehicles, ARK expects rapid adoption globally, pushing the share of EV sales from less than 1% of total auto sales today to 20% by 2022, as shown in Figure 19.

FIGURE 19
2022 EV Share of Vehicle Sales

Source: ARK Investment Management LLC, U.S. Energy Information Administration

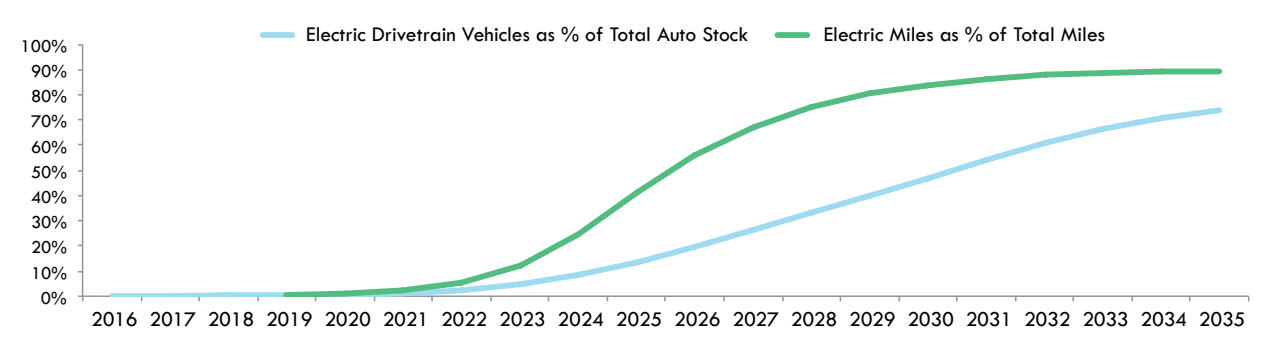
The graph in Figure 20 depicts ARK's forecast of how much faster EVs will rise as a percent of vehicle miles traveled than of the auto installed base globally. The introduction of autonomous cars explains most of the difference. ARK expects that autonomous vehicles will be powered by electric drivetrains and that individuals will rely less on personally owned vehicles because autonomous taxis will be much cheaper. Even if the number of EVs on the road were to remain constant, activating their autonomous capability would increase their share of total vehicle miles travelled.

Given our forecast of autonomous auto adoption, liquid fuel demand should drop 50% - before incorporating the impact from autonomous long-haul trucks – by 2030, as shown in Figure 21. Even if autonomous vehicles were to hit technological obstacles, or government regulations were to delay their commercialization, the uptake of EVs alone would curb liquid fuel demand in the early 2020s.

38 Roughly similar to the EIA's oil forecast in its 2016 Annual Energy Outlook

39 https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf

FIGURE 20
Electric Vehicle Share as a Percent of Total Auto Stock and Miles Travelled

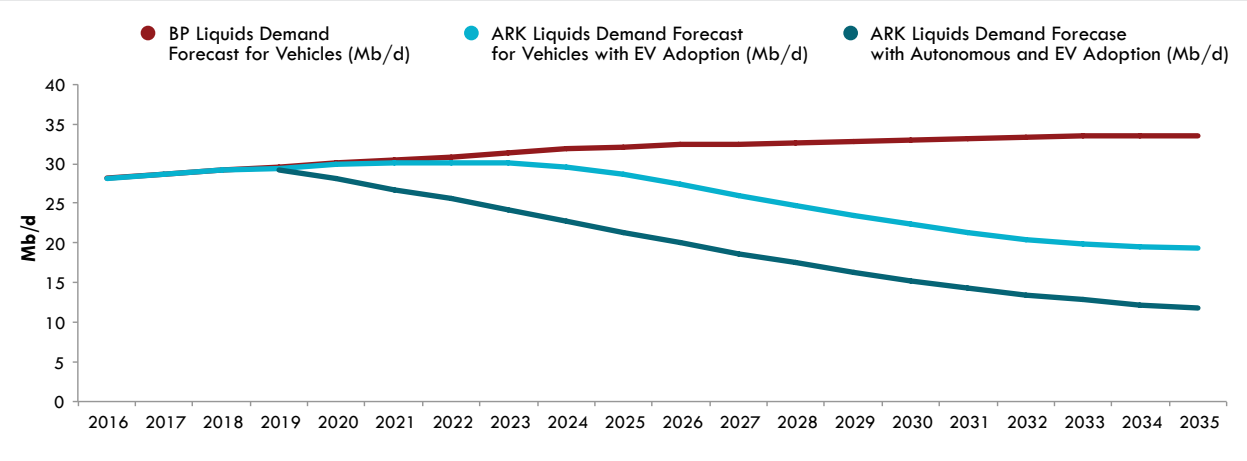


Source: ARK Investment Management LLC

Although cars account for less than 30% of total oil demand,[40] oil prices are highly sensitive to marginal demand. Potentially compounding the problem for the oil industry, Tesla and Cummins have announced that EV semis are on the drawing board, if not close to their debut, and Elon Musk has proclaimed publicly that electric passenger jets are feasible. All in, transportation makes up 56% of total oil demand,[41] most of which could give way to electrification and other sources of energy.

Even narrowing the scope of analysis to automobiles, ARK believes that global oil demand could peak

FIGURE 21
Liquids Demand for Cars



Source: ARK Investment Management LLC

40 https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf; https://www.worldenergy.org/wp-content/uploads/2012/09/wec_transport_scenarios_2050.pdf

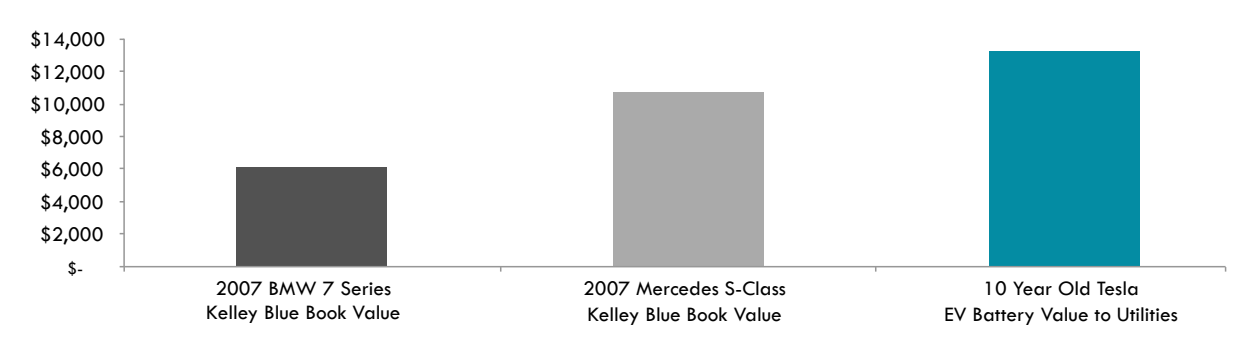
41 https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf

before 2020 and never exceed 100 Mb/d, causing a cascade of responses throughout the energy supply chain. Anticipating a permanent drop in demand, oil companies would cut back capital spending on marginal oil fields, decreasing supply. If adopted faster than oil companies predict, EVs could impact downstream assets, including refineries and pipelines, as well. Furthermore, electrification of the vehicle fleet could prove devastating for the 150,000+ gas stations in the U.S.[42] Beyond the oil industry, the transition from "black gold" to cheap energy would be a windfall for consumers and businesses around the world, albeit a destabilizer geopolitically, the latter a consideration well beyond the scope of this white paper.

RESIDUAL VALUE OF BATTERIES

ARK's research suggests that contrary to a common misperception, EV batteries will retain substantial value after reaching the end of their lives in a vehicle. Electric utilities are a large and willing market for energy storage products: according to our estimates, they could present value a 10 year old Tesla battery at $13,000, or more than an entire gas-powered vehicle of the same age and originally sold at a similar price-point, as shown below.

FIGURE 22
Value After 10 Years



Source: ARK Investment Management LLC, Kelley Blue Book

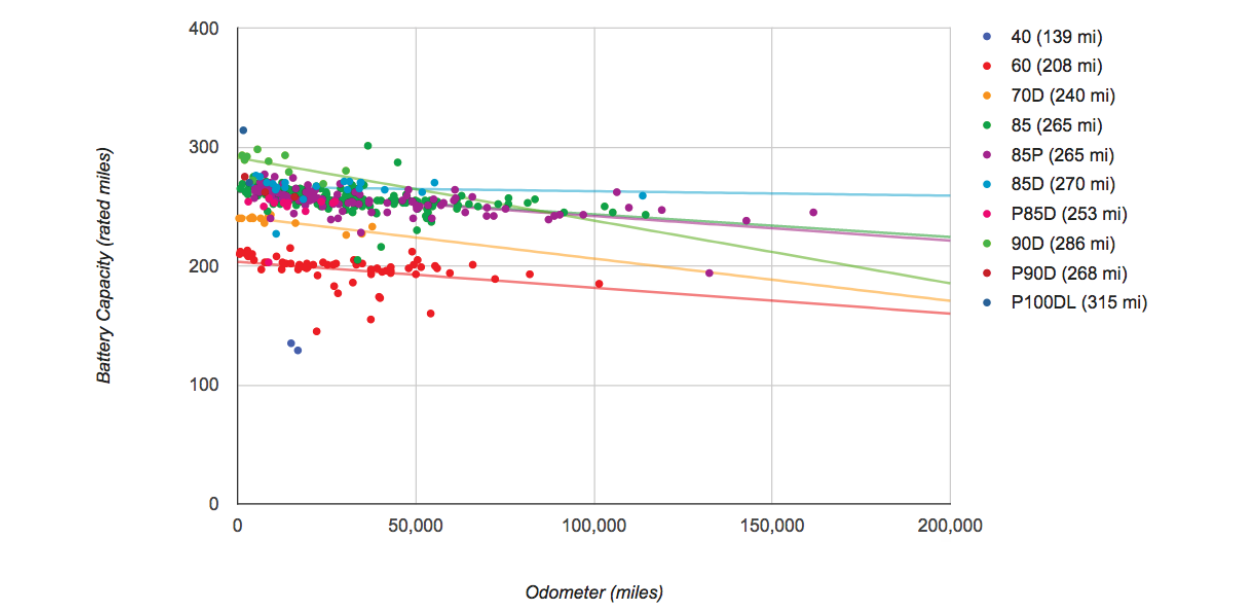
While the average age of U.S. vehicles on the road is 11.5 years old, the number of EVs that old is few to none. That said, as EVs mature and retire, autonomous fleet companies should be able to recoup significant value from the battery packs. While perhaps not acceptable in an EV after a decade of use, battery cells still will hold some value. For example, if the battery cells from a 10 year old Tesla Model S 75 were sold into PJM's utility capacity market they would be worth roughly $13,000 over the remainder of their usable lives. Meanwhile, as shown below, the Kelley Blue Book Value of a BMW 7 series with the same number of miles would be worth less than half the value of just the Tesla battery!

42 http://www.fueleconomy.gov/feg/quizzes/answerQuiz16.shtml

Why would these batteries be so valuable to utilities? While generating kilowatt-hours on a day to day basis is important, a more pressing matter for utilities is the peak load capacity needs that occur just a few times a year. Regional transmission organizations and independent system operators host capacity markets, paying power generators to ensure a reliable supply of capacity, independent of what utilities get paid for producing electricity. An auction guaranteeing capacity several years out determines the market price of capacity. For the 2019/2020 year, for example, PJM is pricing each megawatt per day of capacity at $100.[43] Altogether, utilities are receiving more than $6 billion to guarantee capacity for the 2019/2020 year.[44]

Because they lose a small amount of capacity with each charging cycle, batteries cannot power an EV for its entire lifespan, but they may be able to retain enough reliability and capacity to satisfy utilities. The chart below shows the battery degradation, impacting performance and range, that Tesla owners have reported over time. An EV with only 80% of its original range could prove unacceptable to a car owner but still offer peak power capacity and significant value to a utility.

FIGURE 23
Model S Reported Battery Capacity vs. Miles Driven



Source: Model S Survey Data Overview, https://survey.pluginamerica.org/model-s/charts.php

43 https://learn.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2019-2020-base-residual-auction-report.ashx

44 Ideally these payments cover power plants' fixed construction costs for new projects (which could include buying batteries), though there is no requirement that the money is used for that purpose. https://learn.pjm.com/~/media/markets-ops/rpm/rpm-auction-info/2019-2020-base-residual-auction-report.ashx ; http://www.publicpower.org/files/PDFs/PJM's%20Capacity%20Markets%20FS%20June%202011.pdf

A utility can calculate the net present value of a used EV battery. A 75 kWh EV battery configured to store enough energy to generate 2 hours of power would have a capacity of 37.5 kW. After 10 years of use in an EV, the same battery still should be able to provide 34 kW of output, and could help a utility avoid paying for 34 kW in reserves from other sources for the life of the battery. By our calculations, accounting for both the EV-related capacity loss and the degradation associated with peaking power, the net present value of the used battery to a utility would be roughly $13,000 at current rates in the PJM capacity market, as shown below.[45]

FIGURE 24
Net Present Value for Utility

Year	kW	Annual Capacity Payment
1 to 10	Battery is used in an electric vehicle	
11	34	$1,224
12	33	$1,203
13	32	$1,183
14	32	$1,163
15	31	$1,144
16	31	$1,124
17	30	$1,105
18	30	$1,087
19	29	$1,069
20	29	$1,051
21	28	$1,033
22	28	$1,016
23	27	$999
24	27	$982
25	26	$965
26	26	$949
	NPV for Utility	**$13,236**

Source: ARK Investment Management LLC

This analysis suggests that modular hardware will slow an EV's depreciation and enhance its lifetime and residual values. Used EV batteries are one case in point. Tesla also has suggested that recycling raw materials from battery cells could add value, thanks to new chemistries enabling specialized end uses in newer models.

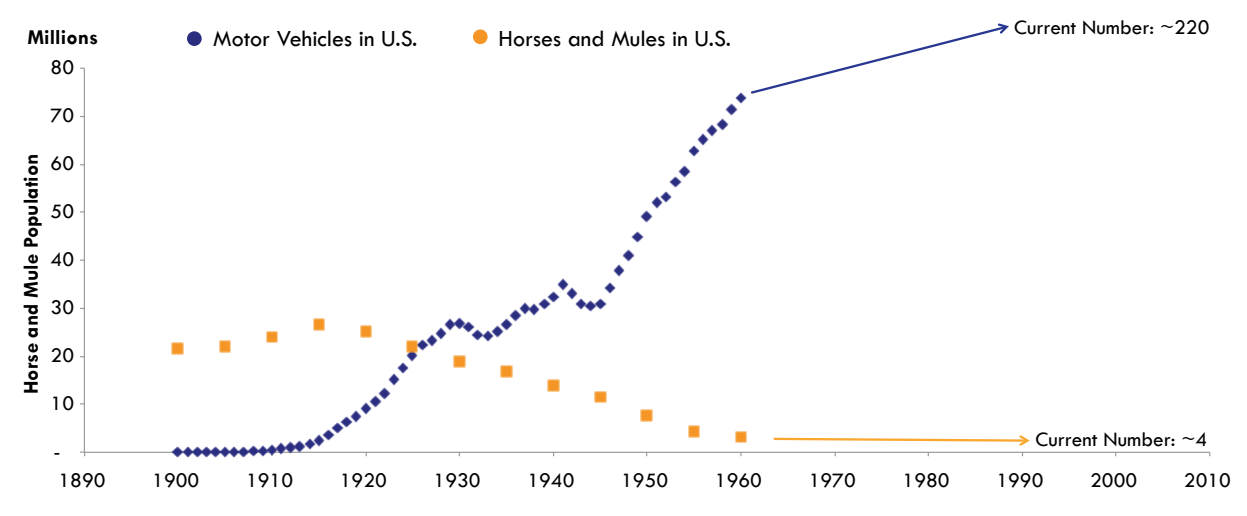
AUTOMOTIVE INDUSTRY CONSOLIDATION

The increase in production efficiency, shift to EVs, and adoption of autonomous technology should precipitate automotive consolidation the likes of which we have not seen since the first half of the 20th century. Throughout history, technological disruption has arrested incumbents' growth prospects.

45 This assumes the battery is used for 15 years as an energy storage device. If it only lasted another 10 years the net present value to the utility would be just less than $11,000. Note that the drawdown characteristics on the battery may be substantially different than they were for the vehicle, so degredation rates at the utility level may be substantially different.

The U.S. horse and mule population peaked when Ford launched the assembly line in 1913.[46] As shown in Figure 25,[47] 1914 was the inflection point for both the equine and the automotive markets. In little more than ten years, the number of motor vehicles surpassed the horse and mule population, and by 1925 the horse population had declined by 17% from its peak while the number of motor vehicles soared by more than 1200%.[48]

FIGURE 25
Motor Vehicle Registration and Number of Horses and Mules in the U.S.



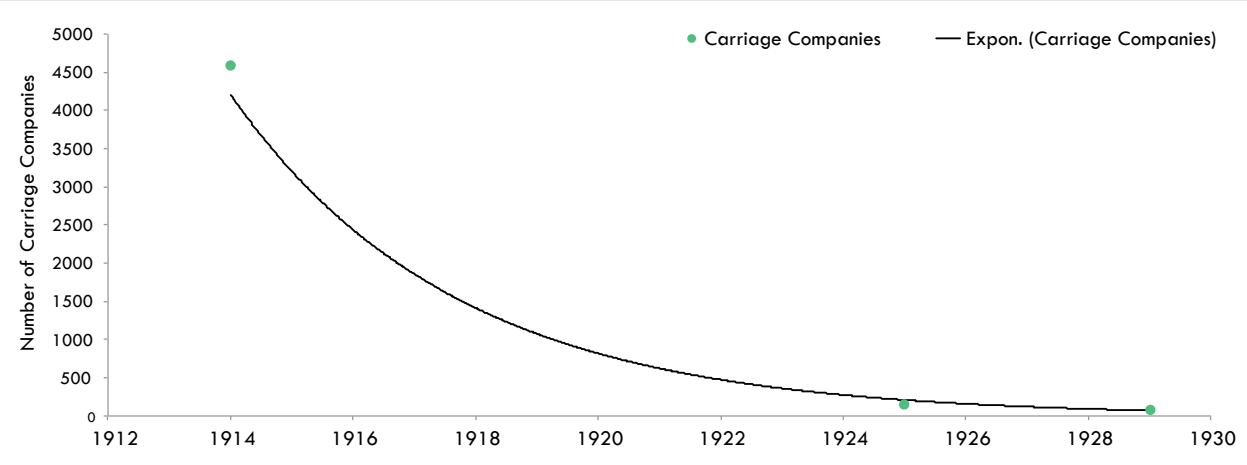
Source: ARK Investment Management LLC, Federal Highway Administration, The State of the Animals IV

This share shift caused other structural transitions in related industries. In 1914, more than 4,500 horse-drawn carriage companies operated in the U.S. Roughly 10 years later, that number dropped by more than 96%.[49] While that consolidation may not seem surprising, as shown in Figure 26 and 27, Ford's innovation also upended the automotive market which consolidated by roughly 80%, from more than 250 manufacturers in 1909 to fewer than 50 by 1930. Perhaps even more notable, since 1930 the number of manufacturers in the U.S. has budged little if at all.[50]

How might the transition from horses to the internal combustion engine parallel the transition from the ICE to autonomous electric vehicles? Consistent with history ARK expects that autonomous EVs will command a majority of incremental sales, as detailed in previous sections as well as our Mobility-as-a-Service white paper, while legacy technology depreciates and drifts out of circulation. Perhaps more important, ARK also believes that the transition will spur dramatic industry consolidation.

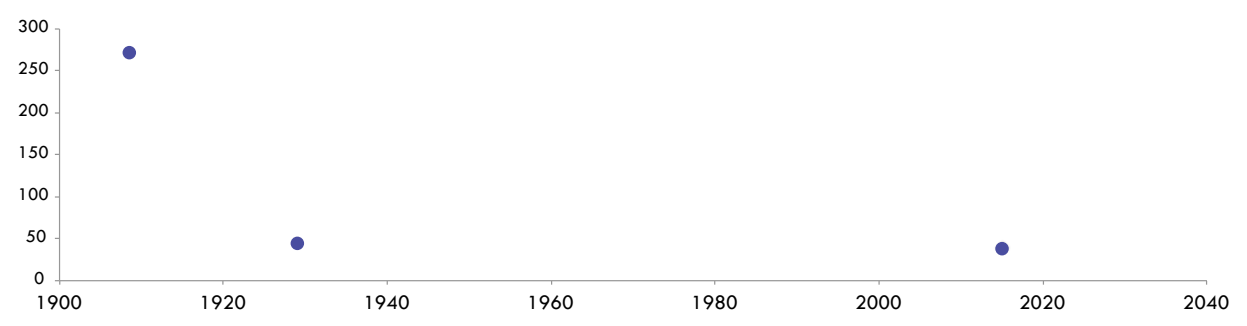
46 https://media.ford.com/content/fordmedia/fna/us/en/features/game-changer–100th-anniversary-of-the-moving-assembly-line.html
47 http://www.fhwa.dot.gov/ohim/summary95/mv200.pdf
48 http://www.humanesociety.org/assets/pdfs/hsp/soaiv_07_ch10.pdf
49 http://parkcityhistory.org/wp-content/uploads/2012/04/Teacher-Background-Information.pdf
50 http://www.history.com/topics/automobiles

FIGURE 26
Decline of Carriage Companies



Source: ARK Investment Management LLC, Park City History

FIGURE 27
Number of Auto Manufacturers in the U.S.



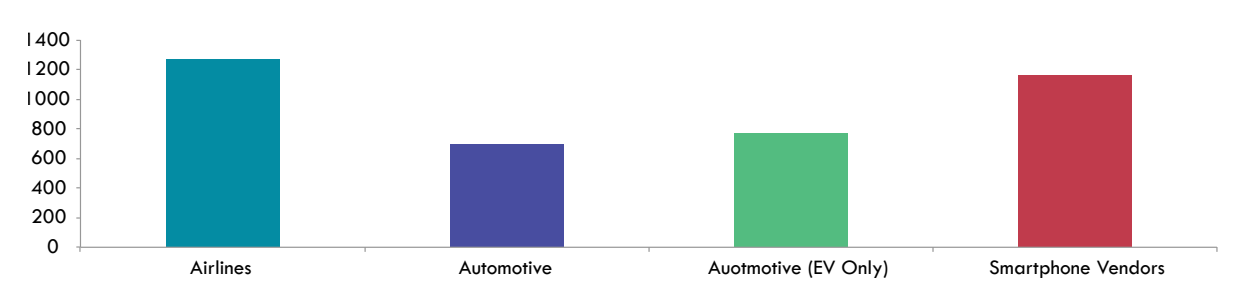
Source: ARK Investment Management LLC, History.com

According to ARK's research, just the transition to EVs could cause modest consolidation among auto manufacturers. To put the automotive industry into perspective, the Herfindahl-Hirschman Index (HHI), a measure of market concentration,[51] suggests that the EV industry is somewhat more concentrated than the overall auto industry, as shown below. Just as the moving assembly line transformed auto manufacturing roughly 100 years ago, EVs have the potential to do the same today. EV manufacturing is much simpler and faster than traditional auto manufacturing, primarily because

51 "The Herfindahl-Hirschman index (HHI) is a commonly accepted measure of market concentration. It is calculated by squaring the market share of each firm competing in a market, and then summing the resulting numbers. The U.S. Department of Justice uses the HHI for evaluating mergers. The U.S. Department of Justice considers a market with a result of less than 1,000 to be a competitive marketplace; a result of 1,000-1,800 to be a moderately concentrated marketplace; and a result of 1,800 or greater to be a highly concentrated marketplace." http://www.investopedia.com/terms/h/hhi.asp

EV's have a fraction of the number of parts.[52] In a conference call held on June 22, 2016, Elon Musk channeled his inner Henry Ford saying, "The fastest car plants in the world, the car exit velocity is basically grandma with a walker. It's real slow, it's 0.2 meters per second… We can do way better than that."[53]

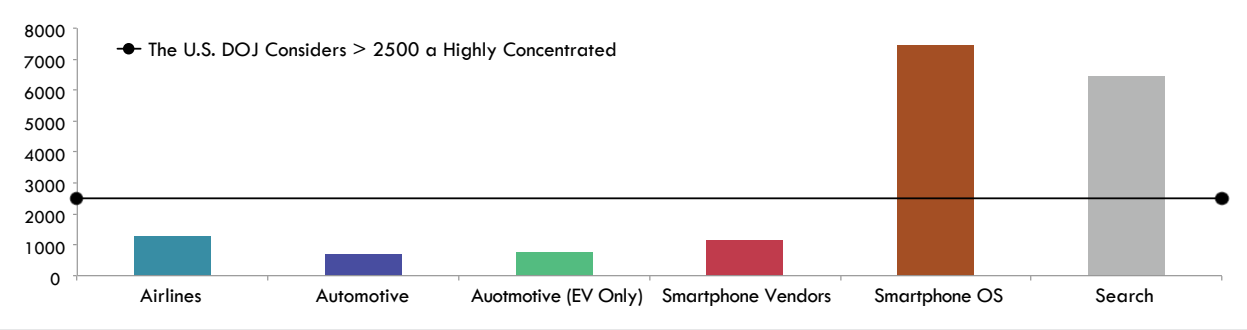
FIGURE 28
Herfindahl-Hirschman Index by Industry



Source: ARK Investment Management LLC, Bloomberg Intelligence, EV-Volumes.com, IDC

Adding autonomous capability is likely to accelerate consolidation of the auto sector. In ARK's view, autonomous vehicles will benefit from network effects: a company with higher market share will collect more detailed and accurate real-world data, enabling enhanced autonomous performance, further boosting its market share, triggering a virtuous cycle. Industries that are data-centric and benefit from the network effect are five to seven times more concentrated than those that are not, as shown below. ARK believes that comparing the concentration of smartphone vendors to that of smartphone operating systems (OS) is particularly instructive. While the auto industry is similar to the smartphone space today, autonomous technology will move it up the value chain to a position much like that in the smartphone OS space.

FIGURE 29
Herfindahl-Hirschman Index by Industry



Source: ARK Investment Management LLC, Bureau of Transportation Statistics, Bloomberg Intelligence, EV-Volumes.com, IDC

52 http://www.businessinsider.com/credit-suisse-on-tesla-2014-8
53 http://electrek.co/2016/06/22/elon-musk-tesla-solarcity-tsla-scty-merger-amazing-quotes/

Manufacturing EVs requires expertise different from that for ICE vehicle production. As detailed earlier in this paper, EVs could be lower in price than ICE vehicles on a like-to-like basis by 2022. By that time, the impact of mapping data on autonomous performance, the network effect, and market share gains should be obvious as the market begins to consolidate at a rapid rate.

While the CEO of Fiat Chrysler already is calling for consolidation to combat rising development costs from stricter emissions standards,[54] ARK anticipates concentration on a completely different and more profound scale.

CONCLUSION

Relatively unchanged for the past century, the auto industry could be dramatically different in the coming decade. Demand for EVs could exceed expectations by more than an order of magnitude. In the supply constrained market environment that ARK expects, the beneficiaries should include auto manufacturers with EV manufacturing and design expertise, battery manufacturers able to capitalize on the opportunity, mining companies with easy access to lithium reserves, companies that control the data enabling autonomous vehicles, countries desparate for cleaner air, and of course consumers who benefit from better performing cars at lower price points.

The simultaneous evolution of electric and autonomous technology in the auto industry is unprecedented. The software and data requirements of future autonomous electric vehicles are likely to create new business models for OEMs and new travel habits for consumers.

Potential bottlenecks or obstacles to this outlook include consumer anxieties and behavior, as well as big budgets for infrastructure spending. Range anxiety, though irrational given the extended ranges of new models, continues to impact consumer psychology. Charging infrastructure is rolling out, but as with smart phones, owners will have to adapt to charging their EVs. Utilities will have to cope with a massive increase in electricity consumption and adapt to grid-connected energy storage.

Perhaps most meaningful, however, will be the day-to-day impact on the public. Just as the ongoing Internet revolution fundamentally transformed the price of information-access and broadcast, the autonomous electric revolution will transform the price of mobility - moving people and things from place to place - changing how we shop, what services we buy, where we live and work, how cities evolve, how much energy we consume, how big our houses are, and how long we live.

The auto industry has been status quo for so long that we seem to have normalized its shortcomings. While few people alive today witnessed the transition from horse and buggies, we all will have front row seats for the autonomous electric revolution…so hold on and buckle up!

54 http://www.bloomberg.com/news/articles/2015-10-21/fiat-ceo-sees-even-more-need-for-consolidation-after-vw-scandal

ARK Invest
155 West 19th, 5th Floor
New York, NY 10011
info@ark-invest.com | www.ark-invest.com

JOIN THE CONVERSATION
@ARKinvest
@skorusARK