

Autonomous Mobility

Autonomous Vehicles Are Likely
to Cut the Cost of Transporting
Everything

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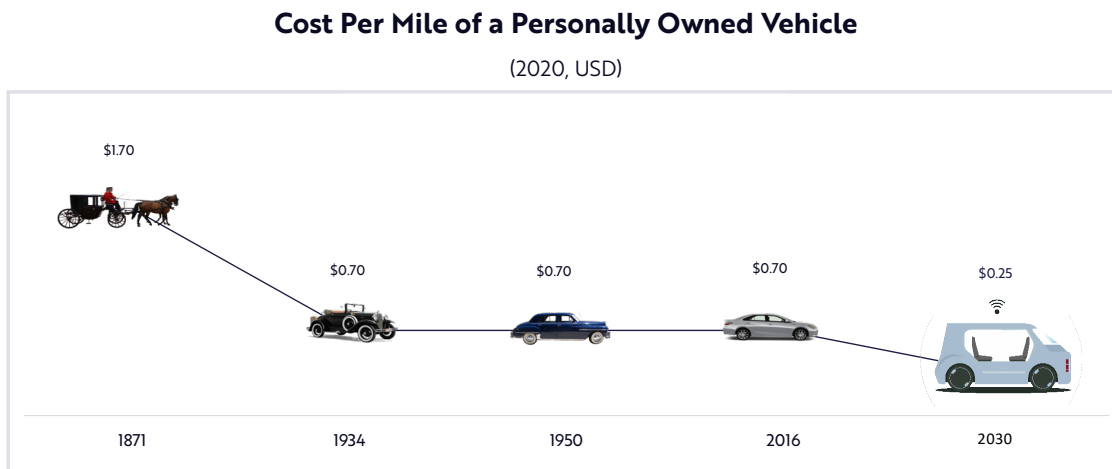
CONTENTS

I.	Introduction	3
II.	Autonomous Human Transport	6
	I. Ride-Hailing	6
	II. Air Taxis	12
III.	Autonomous Freight Transport	15
	I. Trucks	15
	II. Rolling Robots	17
	III. Delivery Drones	19
IV.	Conclusion	25



Introduction

Adjusted for inflation, the cost of owning and operating a new vehicle hasn't budged since the Model T rolled off the first assembly line in 1934: \$0.70 per mile, as shown below. That cost has been anchored in the 19th century transportation technology upon which humans still rely today. We believe the convergence between artificial intelligence and battery technology has created unprecedented autonomous electric transportation possibilities, including vehicles that fly and roll in ways that will alter the movement of people and goods radically. This paper examines the economics of those shifts.



Forecasts are inherently limited and cannot be relied upon.

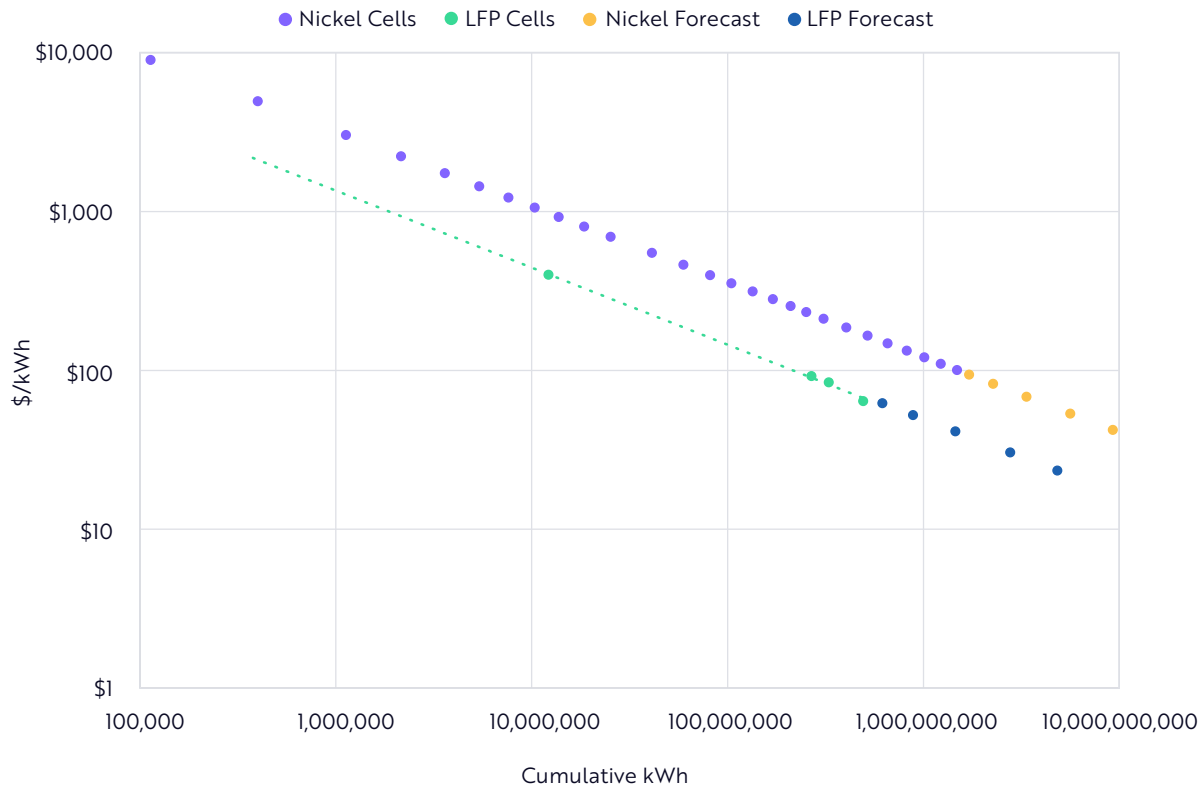
Source: ARK Investment Management LLC, 2022

The success of autonomous electric vehicles will depend on lower battery costs that will make them competitive with gas-powered vehicles. Those costs are falling in line with Wright's Law,¹ as shown below. According to ARK's research, a 350-mile range EV will be competitive on a sticker price basis with a comparable gas-powered car in 2023.

¹ Source: <https://ark-invest.com/wrights-law/>



Battery Cost Decline Estimates



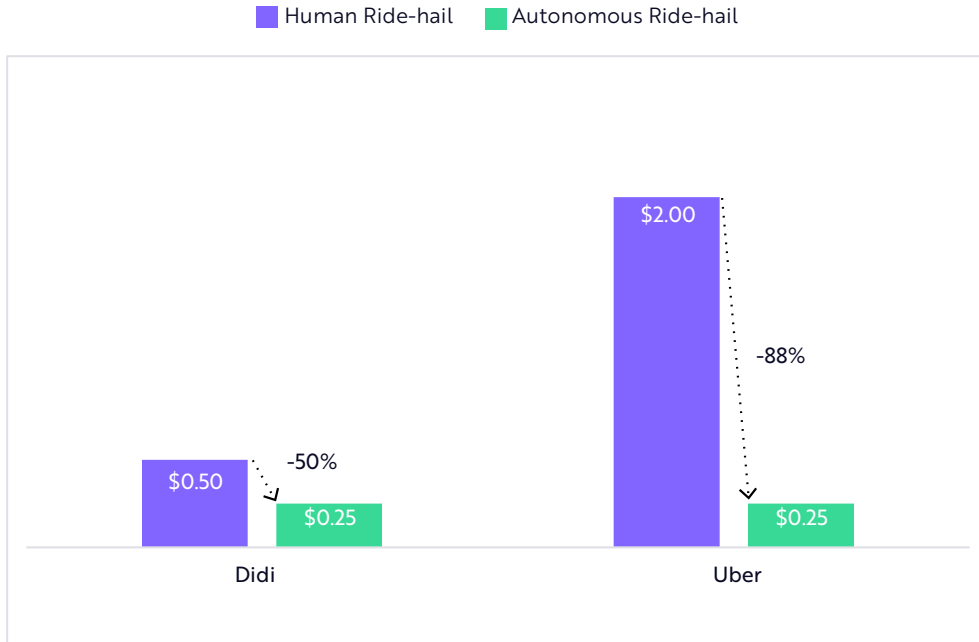
Note: "LFP" ("lithium iron phosphate").
Forecasts are inherently limited and cannot be relied upon.
Source: ARK Investment Management LLC, 2022

At the same time, battery technology itself is improving. According to ARK's research, flight energy reserves now can meet FAA regulations, enabling air taxis and air ambulances to fly safely, and electric propulsion can be customized to form factors smaller than those associated with internal combustion engines. Improvements increasing the energy and power density of batteries should enable many other forms of autonomous transport.

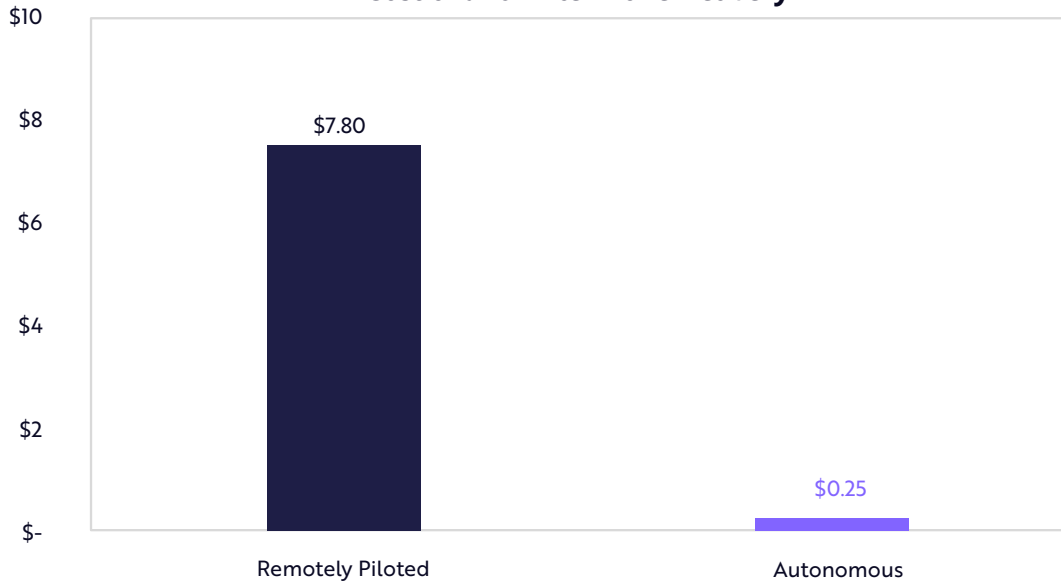
Artificial intelligence (AI) is central to the cost declines we expect in transportation—a prime example of the convergences occurring between and among ARK's five innovation platforms. Optimizing path planning, reducing accidents, and increasing auto utilization rates, AI should eliminate many of the inefficiencies associated with human drivers and remote pilots today. Those improvements, in turn, could result in a near order-of-magnitude improvement in costs across multiple domains, as shown below.



Human Ride-Hailing vs. Autonomous Ride-Hailing Average Price Per-Mile in China vs. The US



Cost of a 10-Mile Drone Delivery



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Source: ARK Investment Management LLC, 2021



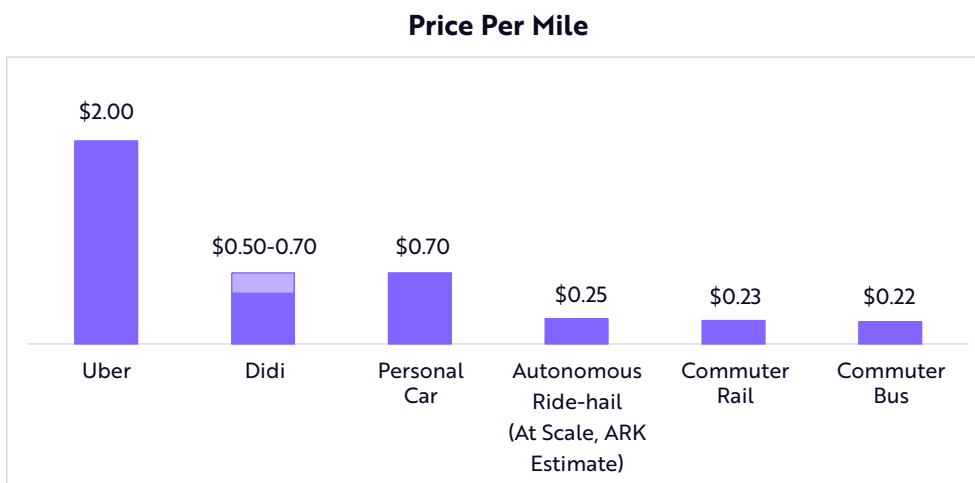
AI-powered automation and electric vehicle technologies are likely to work in mutually supporting ways. Their convergence in autonomous electric vehicles should enable a proliferation of form factors, each tailored to individual applications. Despite higher upfront costs, we believe electric drivetrains are more cost-effective on a total cost of ownership (TCO) basis than are internal combustion drivetrains today. Vehicle automation maximizes drivetrain utilization, more than offsetting the higher upfront costs of today's electric vehicles. The efficiencies multiply when the automation system is powered by the same source moving the vehicle.

The following pages detail the economics of human and freight transport, both of which are facing profound changes.

Autonomous Human Transport

Ride-Hailing

Autonomous electric ride-hail vehicles should benefit from much higher utilization rates than human-driven cars, not to mention lower labor and insurance costs. ARK estimates that, at scale, an autonomous electric taxi platform could price rides profitably at \$0.25 per mile. As a result, autonomous rides could cost less than personal car transportation and could approach public transit pricing, as shown below, potentially spurring widespread adoption.



Note: Shown here is the cost per mile of a new personal car.

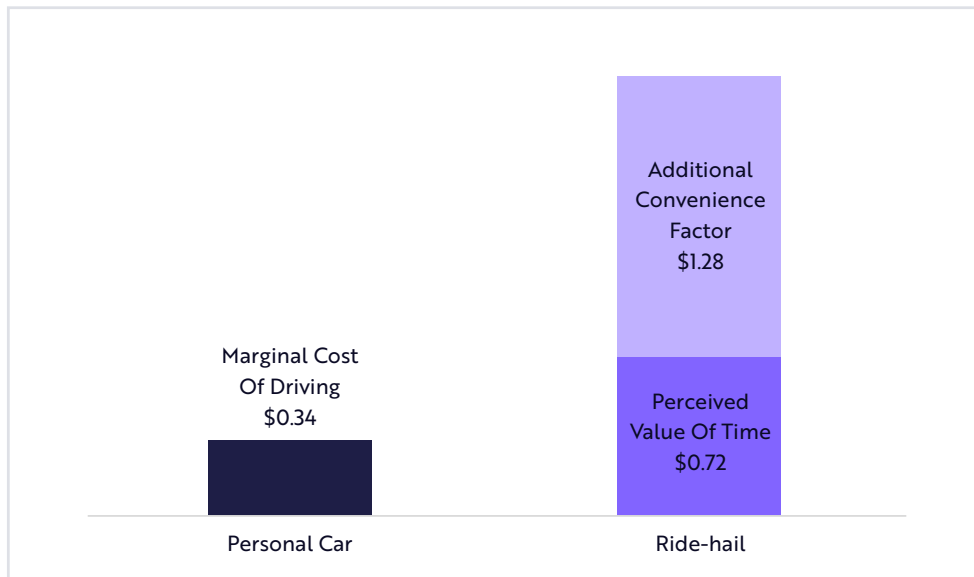
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Source: ARK Investment Management LLC, 2021 data sourced from Didi S-1; US Department of Transportation



While services at scale could be priced as low as \$0.25 cents per mile, ARK’s research suggests that substantial demand could support higher price points. Two-car households are likely to become one-car households and, as more people gain access to relatively inexpensive and convenient travel solutions, traffic could triple relative to today’s levels. More traffic, in turn, should increase the burden of driving, making ride-hail services an even more attractive option. Taking into consideration the perceived value of time otherwise spent driving, we would expect a significant increase in the demand for ride-hail services priced between \$0.60 and \$1.10 per mile in western markets.² Today, ride-hail prices in the US average \$2, roughly six times the \$0.34 marginal cost of personal car transportation, which excludes the fixed costs of driving, as shown below. In other words, consumers seem to be placing a high value, much more than \$0.25, on the time they spend driving, also shown below.

Estimated Per Mile Cost of Ride Choices



Note: The marginal cost of driving includes insurance, fuel, maintenance, tires, and excludes all other fixed costs, which we believe may be closer to consumer’s perception of driving costs. Our \$0.70 per mile estimate includes fixed costs.

Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2021 data sourced from American Automobile Association; U.S. Department of Transportation; <https://econpapers.repec.org/paper/feb/natura/00720.htm>

² Source: ARK Investment Management LLC, 2021 data sourced from: <https://www.transportation.gov/sites/dot.gov/files/docs/2016%20Revised%20Value%20of%20Travel%20Time%20Guidance.pdf>, https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf, <http://s3.amazonaws.com/fieldexperiments-papers2/papers/00720.pdf>, <https://www.bls.gov/opub/ted/2020/average-hourly-earnings-for-private-payrolls-increased-3-point-1-percent-for-year-ended-january-2020.html>, <https://ideas.repec.org/p/feb/natura/00720.html>



Expanding consideration to non-western markets, we note that Chinese autonomous services probably will be priced lower, say \$0.50 per mile, given the inexpensive human-driven ride-hail options available there today.³ Accordingly, we estimate that tiered pricing could stimulate autonomous vehicle miles driven, as shown below:

Ride-Hail ASP Table

Price Per Mile	Total Possible Miles (Billions)	Cumulative Miles (Billions)	Price At Breakpoints	Notes
\$4.00	1	1	\$4.00	Premium to Uber
\$3.00	10	11	\$3.08	Premium to Uber
\$2.00	50	61	\$2.18	Rough estimate for Uber + Lyft addressable
\$1.10	900	96	\$1.18	Assuming 15% of time is spent commuting and using DOT study for time value (commute time is valued at 100% of hourly wage). This is an estimate for Europe and North America urban miles
\$0.60	4,000	4,961	\$0.70	Using personal time estimate values at 50% hourly wage. This is an estimate for Europe and North America urban miles Using personal time estimate values at 50% hourly wage. This is an estimate for Europe and North America urban miles
\$0.50	5,500	10,461	\$0.57	APAC + Rest of World Miles
\$0.25	20,000	30,461	\$0.36	ARK estimates autonomous driving could triple miles travelled

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Source: ARK Investment Management LLC, 2021

Given the demand for transportation at each of these price points, ARK estimates that the total addressable market for autonomous ride-hail services could reach \$11-12 trillion.⁴ Illustrated in the estimates chart below, the width of each rectangle represents the demand for a specific number of miles while its height captures the price point. The thin teal box on the far left represents our estimate of the addressable markets for Uber/Lyft and other conventional ride-hail companies charging between \$2 and \$4 per mile. At a price point just above \$1, the addressable ridership, mostly in heavy commuter western markets, could approach \$1 trillion. The blue rectangle depicts the demand associated with light commuting regions in higher income countries that, according to our estimates, will approach \$2.4 trillion. The green rectangle depicts a long tail of demand in lower income countries that, according to our estimates, will total \$2.75 trillion. Finally, the \$0.25 per mile price point, in combination with lower upfront costs and increased accessibility, could unlock additional demand worth \$5 trillion, as shown in the purple rectangle.

³ Source: ARK Investment Management LLC, <https://www.scmp.com/tech/start-ups/article/2181542/didi-numbers-ride-hailing-firm-covered-more-miles-2018-5-earth>, <https://equalocean.com/auto/20190703-didi-posts-21-million-rides-per-day-in-q1>

⁴ Note: \$11-12 trillion is the total addressable market, as opposed to an estimate for the market size in a given year.



Addressable Market at Each Price Point

4.00 3.00 2.00 1.10 0.60 0.50 0.25

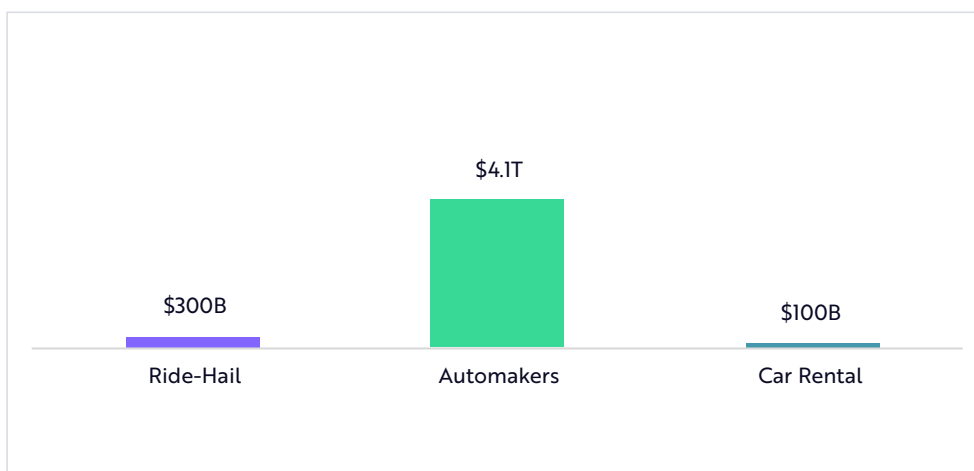


Forecasts are inherently limited and cannot be relied upon.
Source: ARK Investment Management LLC, 2022

Based on lower costs and higher convenience, ARK expects the penetration of autonomous vehicle platforms to increase dramatically by 2030. If so, the ride-hail market could expand from roughly \$300 billion in enterprise value today to over \$11 trillion, as shown in the graphs below.⁵

Current Enterprise Value Estimate

As of November 2021



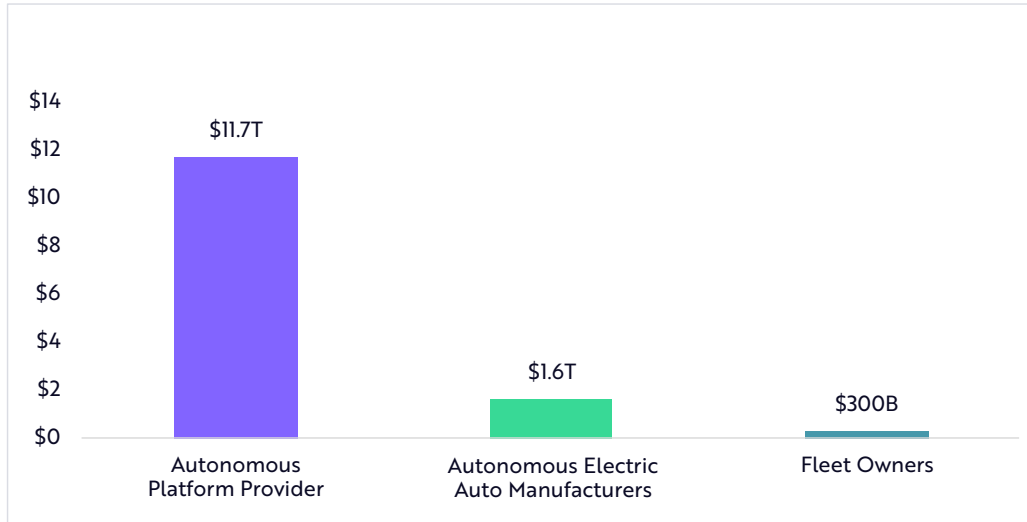
Source: ARK Investment Management LLC, 2022 data sourced from CAPIQ Data

⁵ Note: ARK estimates a market size of \$11 trillion in 2030, which applies an adoption rate to our total addressable market estimate.



2026 Enterprise Value Estimate

(Trillions, USD)



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2020; Data Sourced from bitmain.com

In each of the markets examined in this paper, ARK believes that the companies owning the autonomous technology stack and successful electric vehicle platforms will capitalize disproportionately on the economic benefits. Like Uber, Postmates, Meituan, and other delivery services operating today, autonomous electric network operators with fleets of cars, trucks, robots, and drones should be able to offer services priced on a per mile or a per trip basis, taking a platform fee or a share of gross revenues. Ride-hail and delivery take rates today range from 10-30%.⁶ ARK estimates that take rates on autonomous platforms could be even higher, perhaps up to 60%, as autonomous vehicle networks deliver better value and convenience to customers. Meanwhile, today's ride-hail companies could face lower take rates in the future if they have to partner with outside technology providers for autonomous driving.

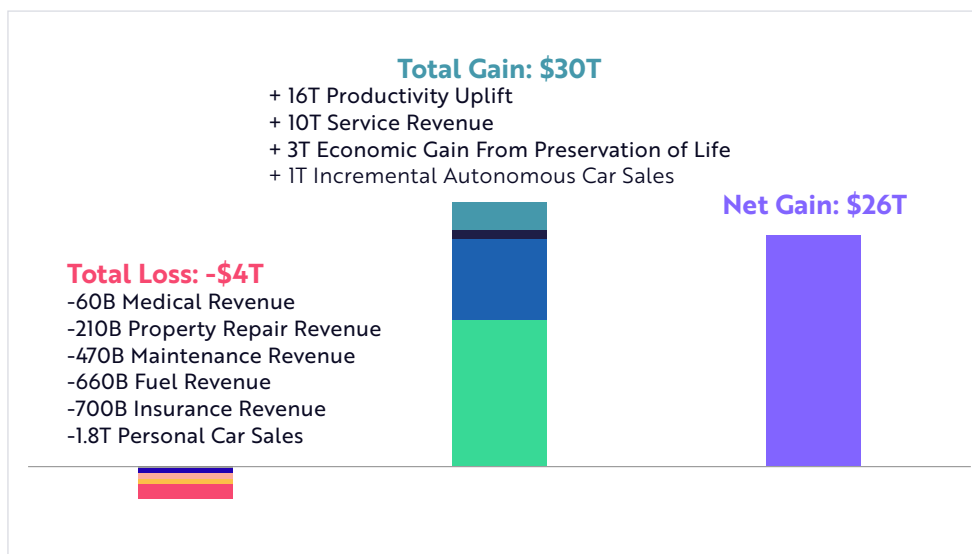
According to our analysis, not all auto manufacturers will survive the transition to the autonomous electric transportation future. ARK anticipates that both electric and autonomous technology will force consolidation among them. As a result, most of the \$4.1 trillion in public gas-powered car manufacturer enterprise value could disappear, as successful electric automakers that partner with autonomous technology providers create \$1.6 trillion in enterprise value. Lastly, other areas of the auto ecosystem, such as car rental providers, also will have to adapt. Perhaps they will partner with autonomous ride-hail providers and will own, house, and maintain the vehicles. ARK estimates that such autonomous electric fleet owners could reach \$300 billion in enterprise value by 2026.

⁶ Source: <https://thelowdown.momentum.asia/why-did-didi-publish-its-unit-economics/>, https://s23.q4cdn.com/407969754/files/doc_financials/2021/q4/Q4-2021-Supplemental-Slides.pdf



Importantly, autonomous transport should save consumers both time and costs. The average car owner in the US spends more than 420 hours per year driving—more than 10 work weeks.⁷ From that standpoint, autonomous vehicles could transform unpaid driving labor into measured economic activity. In addition, ARK believes that autonomous electric passenger cars will lead to fewer accidents.⁸ Taken together, those factors could add roughly \$30 trillion to global GDP from autonomous ride-hail service revenues and freed time that could increase productivity. Those GDP gains, in turn, could offset the \$4 trillion in revenue loss that we expect with falling sales and maintenance of gas-powered vehicles. Net gains could approach \$20 trillion of additional GDP, roughly the size of the US economy, by 2030, as shown below.

Potential Global Economic Impact of Autonomous Ride-Hail, 2030 Forecast



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2020; Data Sourced from: btc.com

ARK expects autonomous ride-hail to contribute roughly two to three percentage points to GDP per year by 2030—an economic impact greater than the boosts delivered by the steam engine, robots, and IT combined, as shown below. In other words, autonomous taxis could be the most impactful innovation in history.

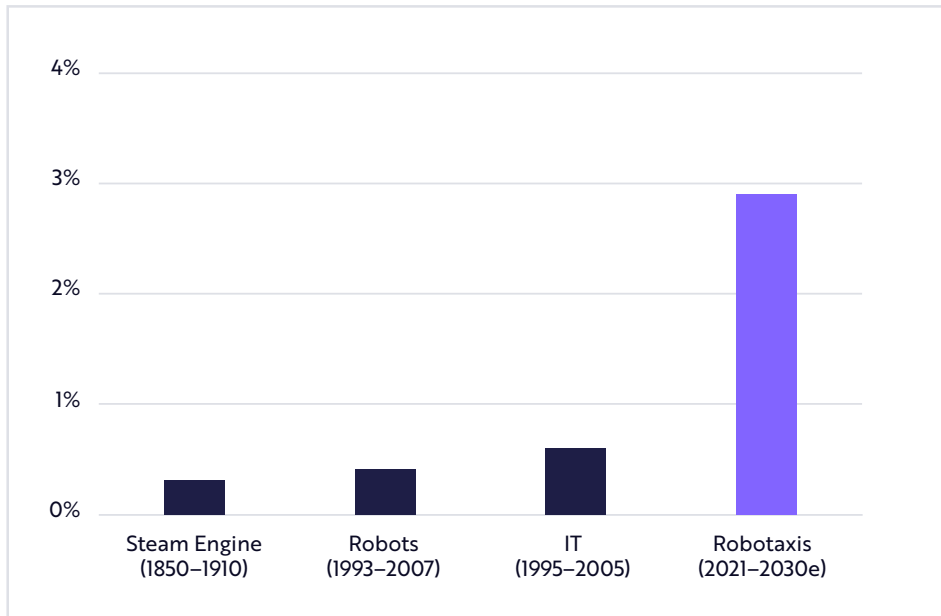
⁷ Source: ARK Investment Management LLC, 2021 based on data sourced from: <https://www.fhwa.dot.gov/ohim/onh00/bar8.htm>, <https://www.bts.gov/statistical-products/surveys/national-household-travel-survey-daily-travel-quick-facts>

⁸ Source: <https://ark-invest.com/articles/analyst-research/autonomous-vehicle-safety/>



Annual GDP Productivity Impact

(Percentage Points)



Source: ARK Investment Management LLC, 2022 data sourced from *Bughin, Jacques, et al. MGI Notes from the AI Frontier Modeling the Impact of AI ... McKinsey, 2018*

Air Taxis

As autonomous ride-hailing increases ground traffic, consumers could choose to travel by air, even for relatively short trips. While the technology for air taxi—or personal drones—is feasible today, regulatory approval remains a barrier to adoption. If batteries continue to improve, as we expect, approved air taxi could fly passengers from cities to airports at price points quite competitive with traditional taxis today.

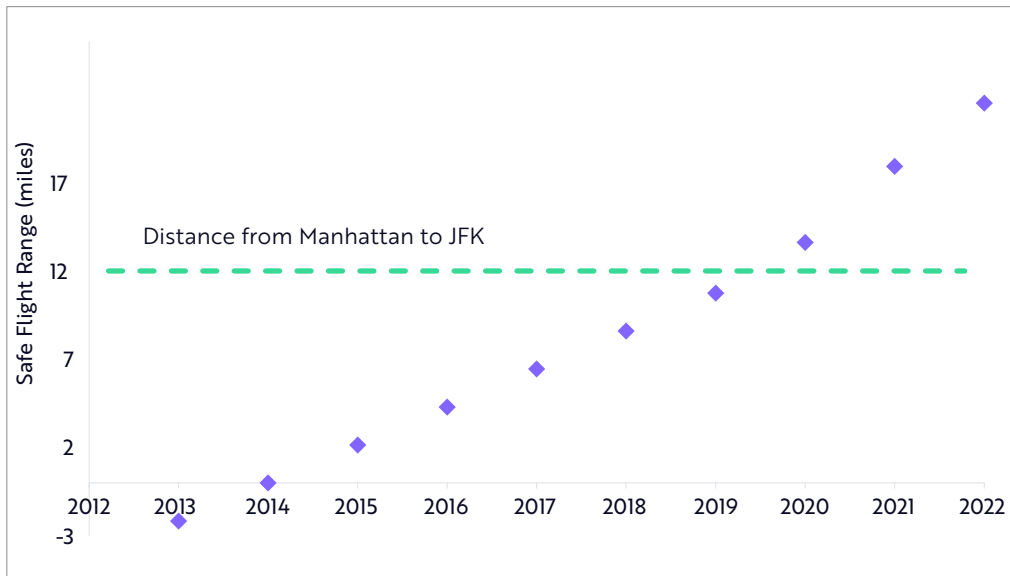
Five years ago, air taxis could not take off because batteries were not powerful enough to support the weight required by the Federal Aviation Administration (FAA). Since then, battery technology has improved dramatically as innovations in chemistry and manufacturing have boosted the specific energy, as measured by watt hours per kilogram, of lithium-ion battery pack systems. Newer generations should deliver even more energy per unit of mass, increasing their range without recharging. ARK estimates that today the battery technology exists for an air taxi to fly the 12 miles from Manhattan to JFK,⁹ as shown below.

⁹ This includes the 20-minute flight reserve the FAA requires for instrument rated helicopter flights.



Safe Passenger Drone Range

(Inclusive of 20 minute flight reserve)



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022

While limited in range, electric Vertical TakeOff and Landing (eVTOL) drones should be able to fly over the traffic jams that are likely to proliferate as autonomous electric vehicles (EVs) begin to dominate urban roads,¹⁰ enabling travelers to save considerable time at a reasonable price. The chart below, for example, compares the cost and time for different vehicles to travel from Midtown Manhattan to John F. Kennedy Airport (JFK). ARK's research suggests that such an air taxi trip will take just 18 minutes, hitting a sweet spot when compared to the alternatives. Today, rides in human driven taxis are four times as long and cost \$65,¹¹ while a traditional helicopter takes 5 minutes but costs \$195,¹² and subways offer low prices are but take much more time.¹³

10 Source: <https://ark-invest.com/articles/analyst-research/traffic-will-increase/>

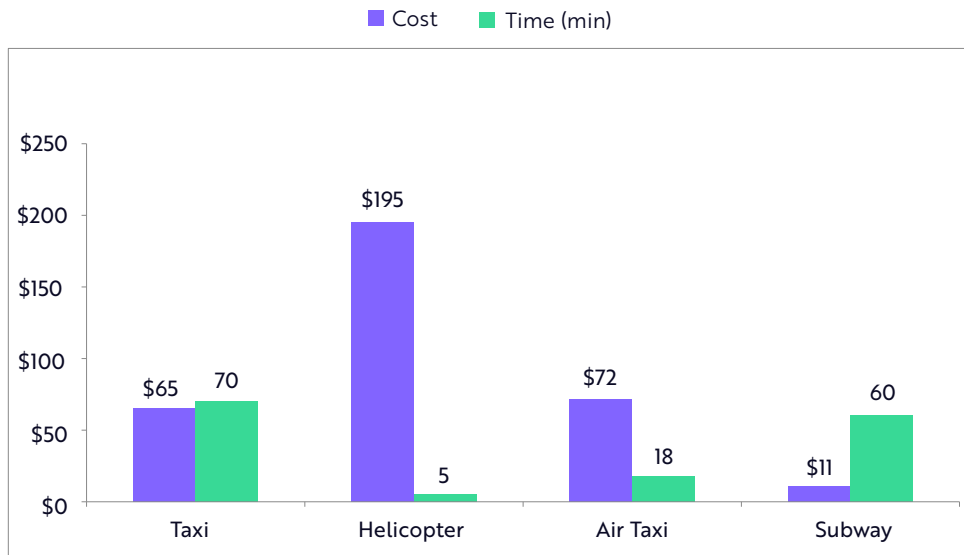
11 Source: <https://www1.nyc.gov/site/tlc/passengers/taxi-fare.page>

12 Source: <https://www.blade.com//p/bounce>

13 Source: <https://new.mta.info/guides/airports>



Cost and Convenience of Travel Options From Manhattan to JFK



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022

ARK's research suggests that lower landing fees, lower operating costs, and autonomous capability will reduce the cost to travel from Manhattan to JFK significantly. An air taxi trip could cost as low as \$74, a \$121 decrease from the \$195 it costs to take a helicopter to JFK today. Based on our modeling, lower landing fees would account for roughly 42% of the savings per drone flight relative to helicopters. Heliports in dense cities, like Manhattan, charge high landing fees because of the scarcity of landing spots. Because passenger drones should be quieter and more maneuverable, landing and takeoff are not likely to require the skills of controllers at most heliports¹⁴ and, as more spots free up for drone helipads, increased competition should drive down landing fees.

Lower operating costs also should be a significant source of savings, accounting for another 42% of savings per flight. We base this conclusion on two observations. First, electric vehicle maintenance costs are 65% lower than those associated with traditional gas-powered vehicles.¹⁵ We believe air taxis should be no different. Second, electricity is a much cheaper source of energy than aviation fuel.

What about the savings associated with pilots? Because the FAA requires pilots on board in planes and helicopters, drone service providers do face and must overcome that regulatory hurdle. That said, ARK estimates removing the pilot accounts for another 10% of the savings for an air taxi flight.

¹⁴ Risk reduces when liquid fueling is not required. On the other hand, risk comes with the need to swap batteries in and out of drones and into charging racks (or perhaps plugging them in, depending upon the optimization between battery swapping and rapid charging).

¹⁵ Source: <https://cleantechnica.com/2017/09/05/10492-tesla-model-s-maintenance-charging-costs-300000-miles/>



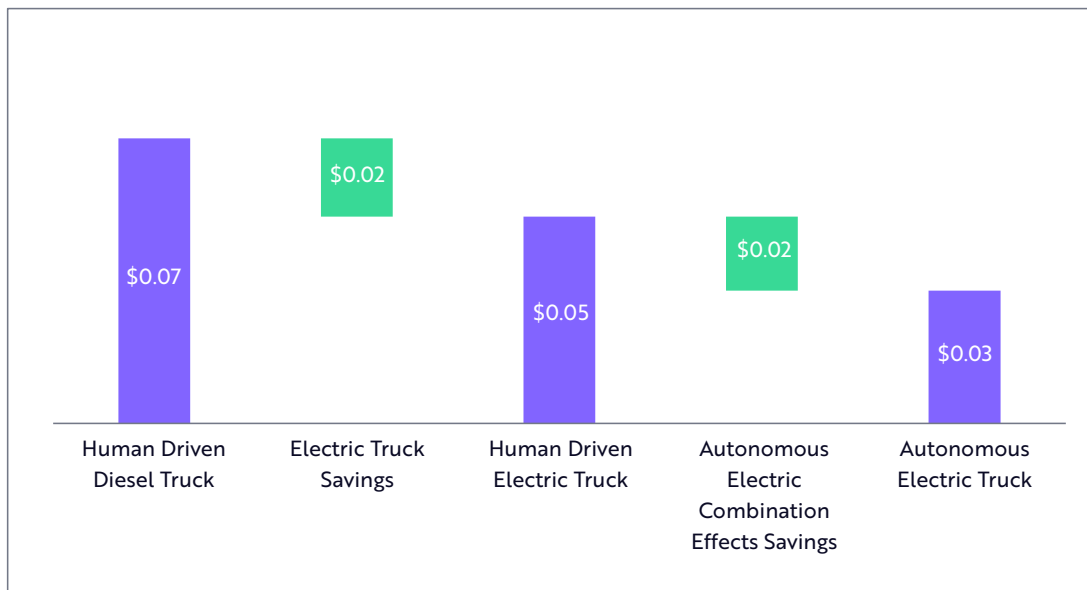
The remaining 6% of savings are attributable to lower upfront costs for the air taxi and lower repair/overhaul costs. While this summarizes the savings, it's worth noting that battery replacement costs and potential downtime for battery charging/swapping are costs that are associated with air taxis, but not helicopters.

Autonomous Freight Transport

Trucks

The integration of electric battery and AI-powered autonomous technologies could increase the productivity and lower the costs of trucking significantly thanks to lower fuel (electricity) and maintenance costs,¹⁶ electric drivetrains will push shipping costs down from \$0.07 to \$0.05 per ton-mile for a full load.¹⁷ With higher utilization rates and reduced labor costs, autonomous trucking technology should cut costs further to \$0.03 per ton-mile, as shown below. Autonomous electric trucks also could become more cost-effective than rail, also shown in the second chart below.

**Human Driven Diesel Truck vs. Autonomous Electric Truck
Cost Saving Per Ton-Mile Estimate**



Forecasts are inherently limited and cannot be relied upon.

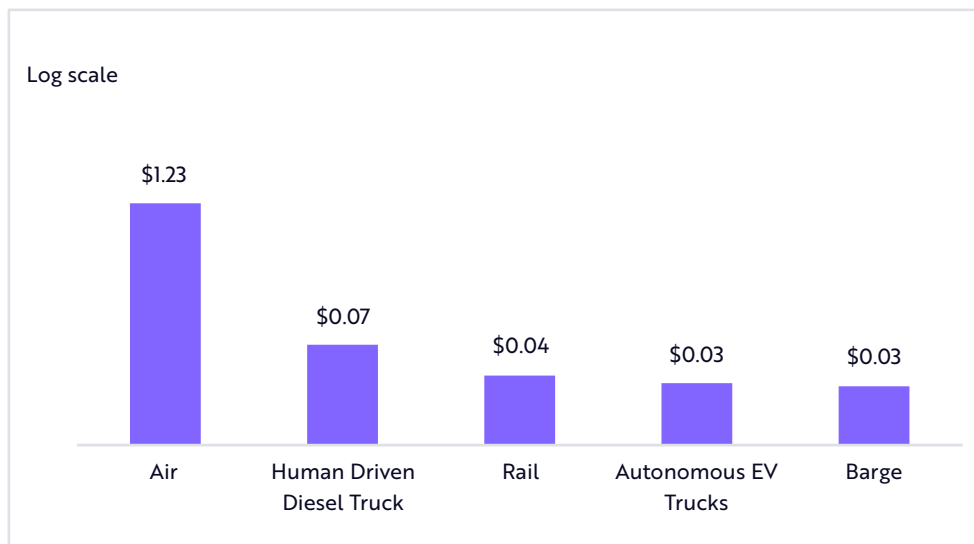
Source: ARK Investment Management LLC, 2021

¹⁶ Note that costs were calculated using pre-2021 cost averages. Shipping prices have increased multiples in 2021 as a result of the global supply chain shortages.

¹⁷ The estimate assumes a dry van with a day cab. ARK previously published an estimate of 12 cents per ton-mile for the cost of human driven diesel truck transport. In our most recent analysis, we examine a full truck load (as opposed to the average truckload) and include an estimate for the resale value of equipment, which was not in our previous model. ARK analysts update models as our research evolves, and our current estimates reflect adjustments to vehicle costs, utilization rates, fuel prices, and other factors.



Estimated Cost Per Ton-Mile by Mode



Note: Cost per ton-mile for air and barge uses the most recent data available—2014 and 2011, respectively. The price estimate assumes a fully loaded human driven diesel truck.

Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investments Management LLC, 2022 data sourced from rita.gov; aar.org; ntl.bts.gov.

ARK estimates that autonomous trucking prices could start at roughly \$0.20 per ton-mile, equivalent to the US trucking average today when accounting for the long-tailed market for goods delivery, before dropping toward \$0.03 at maturity and scale.¹⁸ Door-to-door trucks also will offer a speed advantage over rail, enabling trucks to take share from intermodal transport. If autonomous electric trucks were to absorb the ton-miles shipped over rail in the US,¹⁹ the trucking logistics market could double to roughly 3.1 trillion ton-miles. Globally, combined with ton-miles share gains from rail, the trucking opportunity could increase 60% from 8 to 13.6 trillion ton-miles.

Based on roughly 250,000 unfilled trucking jobs in the US and the demand for an additional 20% globally, ARK estimates that there could be a need for an additional trillion miles of autonomous trucking services.²⁰ Autonomous truck gross service revenues worldwide could total roughly \$700 billion by 2030. Autonomous platform operators could charge a 30% platform fee, half of which could fall to earnings, translating into an enterprise value of roughly \$3 trillion, as shown below.

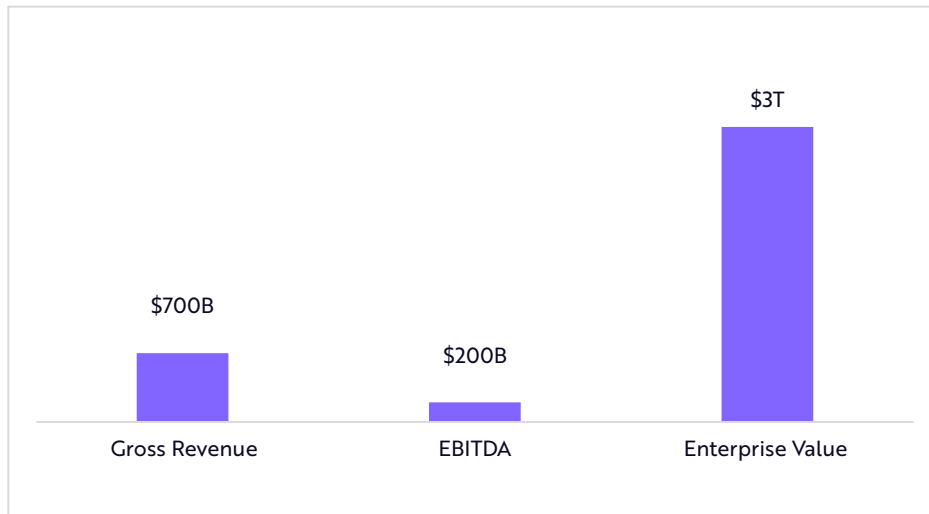
¹⁸ Source: <https://www.bts.gov/content/average-freight-revenue-ton-mile>

¹⁹ Source: https://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national_transportation_statistics/html/table_01_50.html

²⁰ Source: <https://www.americatruckdriving.com/more-trucking-jobs-go-unfilled/>



Global Autonomous Truck Market Estimate



Note: Numbers are rounded. Assumes a 15X EBITDA multiple in 2030. EBITDA: Earnings Before Interest, Taxes, Depreciation, and Amortization

Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022

Rolling Robots

Robot delivery helpers currently work for Dominos, Fedex, Kroger, Walmart, Alibaba, and Meituan, among many other companies.²¹ ARK previously estimated that a sidewalk delivery robot could cost as little as \$0.06 per mile,²² twenty times lower than the cost of human delivery. While local regulations might slow²³ the rollout of sidewalk robot systems, slightly larger robots that integrate into traffic could continue to gain traction. According to ARK's latest research, integrated traffic robots like Nuro²⁴ could cost customers less than \$0.40 per delivery, six times lower than the cost of driving a personal car to the grocery store, as shown below.

21 Source: <https://selfdrivingdelivery.dominos.com/en>, <https://techcrunch.com/2021/05/25/meituan-jd-com-and-neolix-begin-autonomous-deliveries-in-beijing/>, <https://www.autoweek.com/news/technology/a36731148/fedex-testing-delivery-robot/>, <https://www.cnbc.com/2021/11/04/heres-how-kroger-is-using-robots-to-get-groceries-to-customers-doors.html>, <https://corporate.walmart.com/newsroom/2019/12/10/walmart-to-test-drive-autonomous-grocery-deliveries-with-nuro>, <https://www.alizila.com/alibaba-driverless-robots-one-millionth-ecommerce-delivery/>

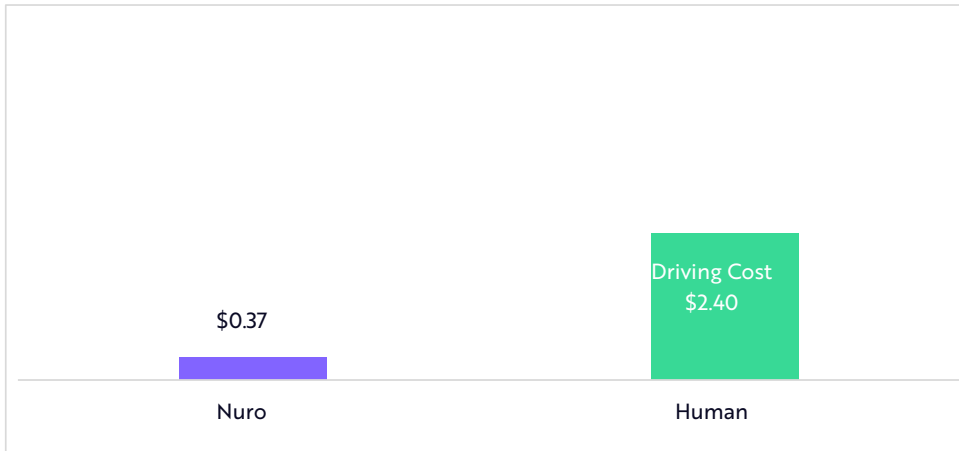
22 Source: <https://ark-invest.com/articles/analyst-research/autonomous-delivery-robots/>

23 Source: <https://fox59.com/news/indiana-law-sets-regulations-for-delivery-robots/>

24 Source: <https://www.nuro.ai/>



Estimated Human vs. Robot Delivery Costs Per Trip For US Grocery Runs



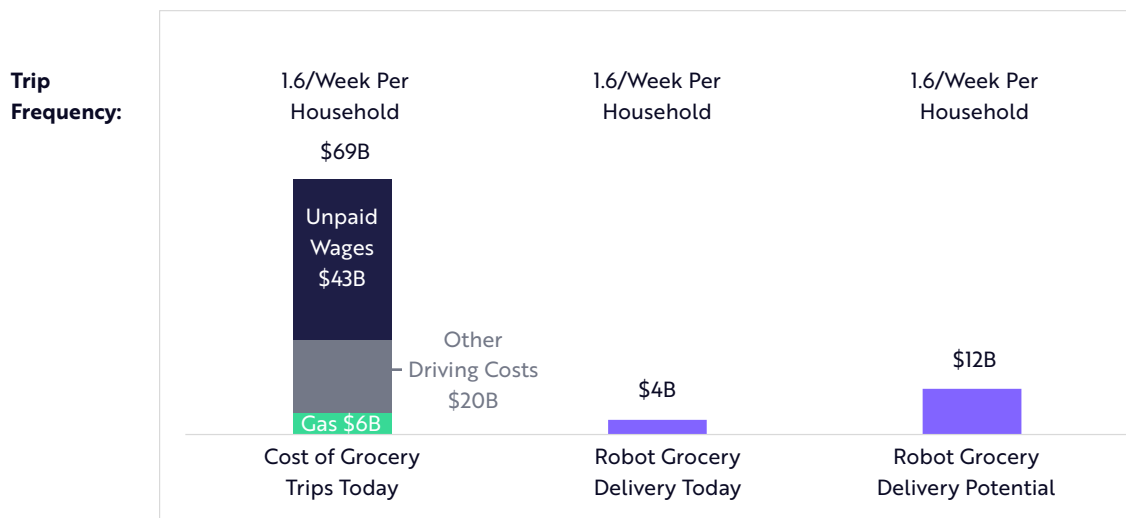
Note: Driving cost does not include consumer's perceived value of time.

Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2021 data sourced from <https://www.irs.gov/newsroom/irs-issues-standard-mileage-rates-for-2022>

If every household in the US were to use the service at the rate of the 1.6 trips that consumers make on average per week, the robot delivery market could scale to \$4 billion per year. If, however, the low cost and convenience were to encourage customers to order grocery supplies in smaller batches and at higher frequencies, the size of the market opportunity could increase materially. If customers were to order fresh groceries five times a week, the robot grocery delivery market could expand to \$12 billion a year, a sizable opportunity that would lower by 20% the \$70 billion in actual costs for grocery delivery today, as shown below.

US Grocery Trip Costs



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2021 data sourced from Internal Revenue Service; Nuro; The Food Industry Association; AAA; and Bureau of Labor Statistics.



ARK estimates that robot grocery delivery will eliminate roughly \$40 billion in “unpaid wages” and convert previously unpaid economic activity into paid services. Replacing gas-powered car grocery trips, electric robots also would eliminate roughly \$6 billion worth of gasoline demand and 18 million metric tons of carbon dioxide emissions, the equivalent of emissions from roughly 4 million cars.²⁵

Use cases for robot delivery are likely to extend beyond groceries. Robotic delivery of all Dominos pizzas alone is a \$500 million opportunity.²⁶ Ground robot delivery networks probably will work alongside delivery drones,²⁷ reshaping consumer behavior by offering an inexpensive and convenient way to receive groceries, prepared food, and other household essentials. As human behavior changes so should home design. Refrigerators could shrink in size and pantries could be repurposed, for example, as consumers order fresh groceries more often. Although some changes will take longer than others to impact society, the collapsing cost of last mile delivery is likely to transform how consumers acquire, store, and consume food, potentially creating \$30+ billion in enterprise value by 2025 in the US.²⁸

Delivery Drones

Major retailers like Walmart, Amazon, Alibaba, and JD.com are experimenting with drones for last-mile delivery.²⁹ ARK estimates that, with regulatory approval, drones could deliver packages profitably for only \$0.25. Given frictionless and inexpensive delivery, consumers probably would buy many more goods online, growing ecommerce’s share of retail sales from 18% in 2020 to 60% in 2030. By that time, drones are likely to deliver more than half of ecommerce volumes, as shown below.

25 Source: ARK Investment Management LLC, 2021; United States Environmental Protection Agency; United States Energy Information Administration; United States Department of Energy Alternative Fuels Data Center

26 Source: ARK Investment Management LLC, 2021; Dominos, <https://www.zdnet.com/article/dominos-dru-pizza-delivery-robot-by-the-numbers/>

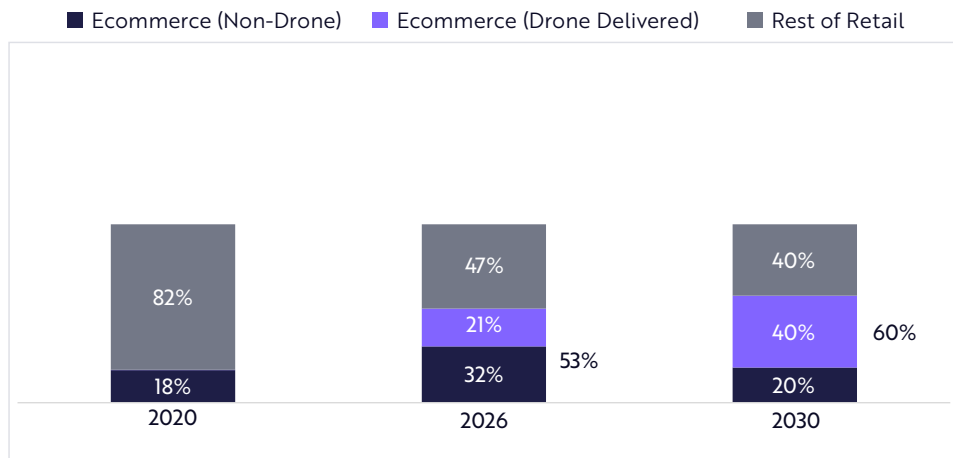
27 Source: <https://ark-invest.com/articles/analyst-research/parcel-drone-delivery/>

28 \$30 billion represents the market for aerial and ground robot delivery combined.

29 Source: <https://jdcorporateblog.com/jd-coms-drone-delivery-program-takes-flight-in-rural-china/>, <https://corporate.walmart.com/newsroom/2022/05/24/were-bringing-the-convenience-of-drone-delivery-to-4-million-u-s-households-in-partnership-with-droneup>, <https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011>, <https://www.popsci.com/china-drone-deliveries/#:~:text=Alibaba%20is%20using%20drones%20to,fly%20them%20between%20delivery%20points>



Estimated Ecommerce Share of Retail With Drones



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022

ARK expects inexpensive parcel drone delivery to change consumer shopping behavior significantly. Promotions with free shipping tend to increase the size and number of orders.³⁰ Indeed, with free two-day delivery, Prime customers spend twice as much as non-Prime customers.³¹ If drones were to deliver packages in fewer than 30 minutes for less than \$1, as we believe is likely, the shift to online shopping would accelerate.

Given regulatory approval, revenue from parcel drone delivery could scale to \$110+ billion by 2030, as shown below. At roughly \$4 per parcel today, traditional delivery generates roughly \$280 billion in revenue.³² ARK believes that, as drones cut shipping costs, consumers will opt for quick and inexpensive shipping. Heavier packages probably will be split into lighter loads to facilitate drone transport, increasing delivery volumes that much more. While many companies like Alphabet, Rakuten, JD.com, and/or carriers like DHL, FedEx, and UPS should be beneficiaries, we believe Amazon could take disproportionate share with free drone deliveries for both Prime subscribers and customers who subscribe to its home drone surveillance services.³³

30 Source: https://www.researchgate.net/publication/227442405_An_Empirical_Study_of_the_Impact_of_Nonlinear_Shipping_and_Handling_Fees_on_Purchase_Incidence_and_Expenditure_Decisions

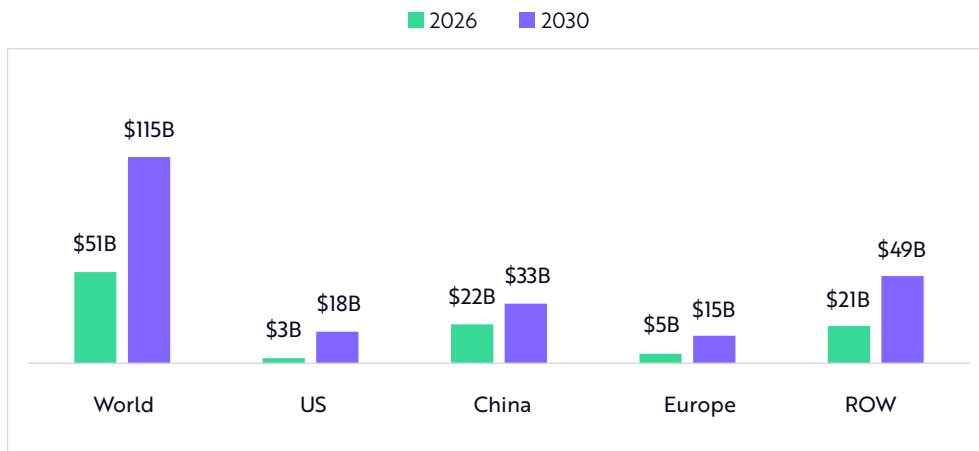
31 <https://www.businessinsider.com/amazon-prime-customers-spend-more-than-others-2018-10>

32 Note Source: <https://www.pitneybowes.com/us/shipping-index.html> Note that last mile is some subset of this market and parcels include packages weighing up to 70 lbs.

33 Source: <https://www.theverge.com/2021/9/28/22692048/ring-always-home-cam-drone-amazon-price-release-date-specs>



Estimated Parcel Drone Delivery Revenue

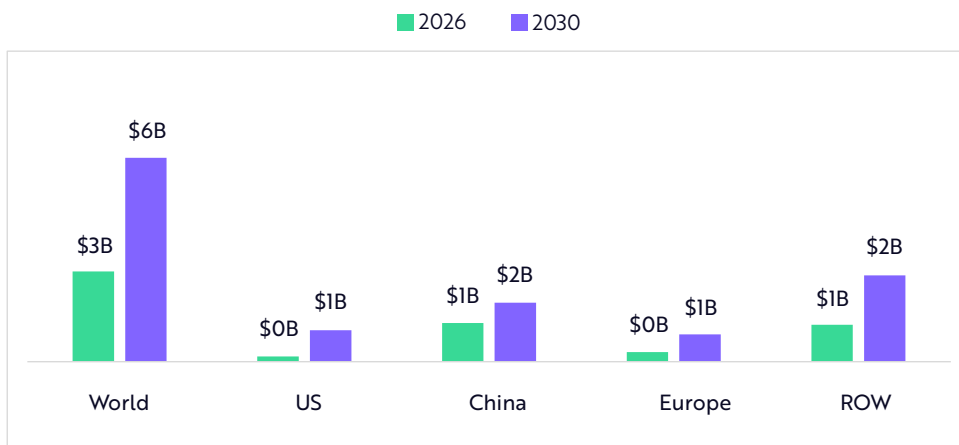


Note: Numbers shown are round. ROW: Rest of the World.

Source: ARK Investment Management LLC, 2021 data sourced from <https://www.pitneybowes.com/us/shipping-index.html>

We believe third-party mapping providers and drone hardware providers also should benefit from the shift to drone delivery services. Mapping providers are partnering with regulatory authorities to offer digital infrastructure and traffic management services to drone delivery service operators.³⁴ Of the \$114 billion that ARK estimates for global drone delivery revenues in 2030, mapping providers could garner 5%,³⁵ or \$6 billion, while the drone hardware market could scale to \$25 billion,³⁶ as shown below.

Estimated Mapping Revenue



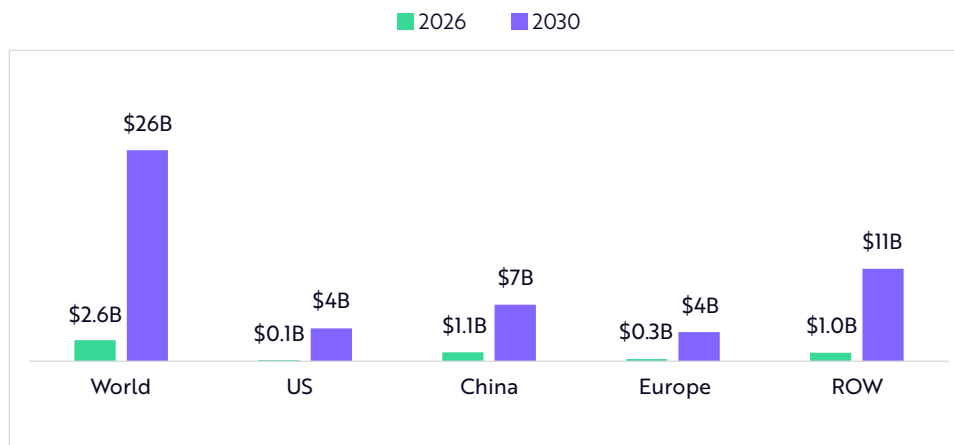
³⁴ Example: <https://www.aviationtoday.com/2021/12/21/droneup-acquires-airmaps-utm-service/>

³⁵ A rough estimate. Note the 7.5% excise tax used to pay for air traffic control in the US today, which suggests a 5% take rate is reasonable. Source: <https://www.vox.com/policy-and-politics/2017/6/5/15740810/trump-air-traffic-control-privatization>

³⁶ Assumes drones have a 3-year life and can deliver 20-30 packages per day.



Estimated Parcel Drone Sale



Note: Numbers shown are rounded. ROW: Rest of world.

Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2020

Finally, thanks to its convenience and cost effectiveness, drone delivery could expand total retail sales. From their homes, consumers might choose to purchase goods online more often, even multiple times a day, especially in rural and suburban neighborhoods. Unlike autonomous taxi services, which ARK expects will be more successful in urban areas, delivery drones could reach and benefit those living beyond the cities.

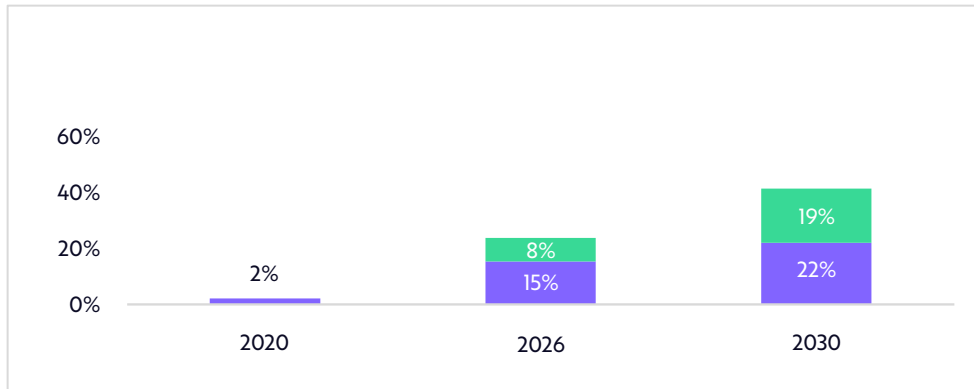
Although this analysis has focused on parcel delivery, take-out food delivery also is likely to be an important use case for aerial drones. Thanks to the convenience of online platforms like Grubhub and DoorDash, ARK previously estimated that the market for food delivery orders is likely to be measured in the trillions.³⁷ Autonomous electric mobility could increase that potential dramatically by enabling more cost effective and convenient services that extend beyond dense urban areas toward suburban and rural areas. According to our research, as a percent of total food spending, delivery could grow from just 2% today to more than 40% by 2030, as shown below.

³⁷ Source: <https://ark-invest.com/articles/analyst-research/food-as-a-service-the-3-trillion-meal-delivery-market/>



Estimated Global Food Delivery as a Percent of Total Food Spend With and Without Drones

■ Additional Share Gain With Drones ■ Food Delivery as a % of Total Food Spend

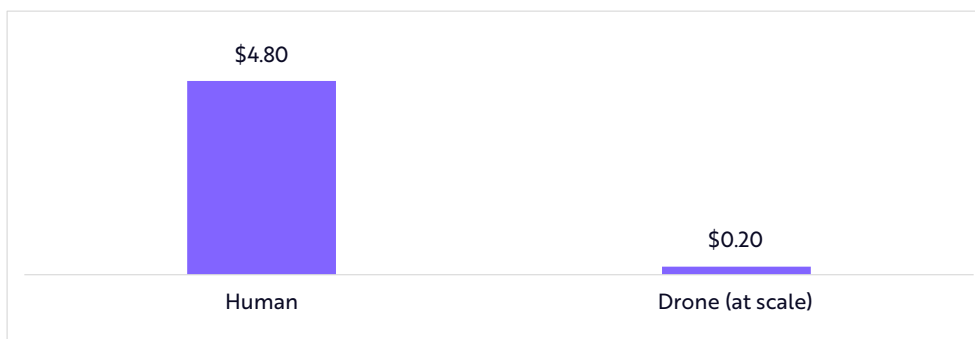


Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022 data sourced from Euromonitor, <https://www.euromonitor.com/>, "Food Expenditure Series." USDA ERS - Food Expenditure Series, <https://www.ers.usda.gov/data-products/food-expenditure-series/>.

Based primarily on advances in battery power, ARK estimates that a drone could deliver the average meal for only \$0.20, or twenty times less than today's human-based food delivery costs, as shown below. Facing fewer regulatory hurdles, drone-based food delivery could debut in less densely populated areas. While most restaurant deliveries span five or fewer miles today, drones could enable longer distances while preserving the temperature of meals.³⁸ Taking share from cyclists, they also should increase the safety of food delivery.³⁹

Estimated Price to Deliver Food Over Three Miles



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022 data sourced from Bridges, Dash. "I Made \$10,378 in 1 Year Working for DoorDash Part Time." The Rideshare Guy Blog and Podcast, 22 Aug. 2019. <https://arkinv.st/37osrPo>.

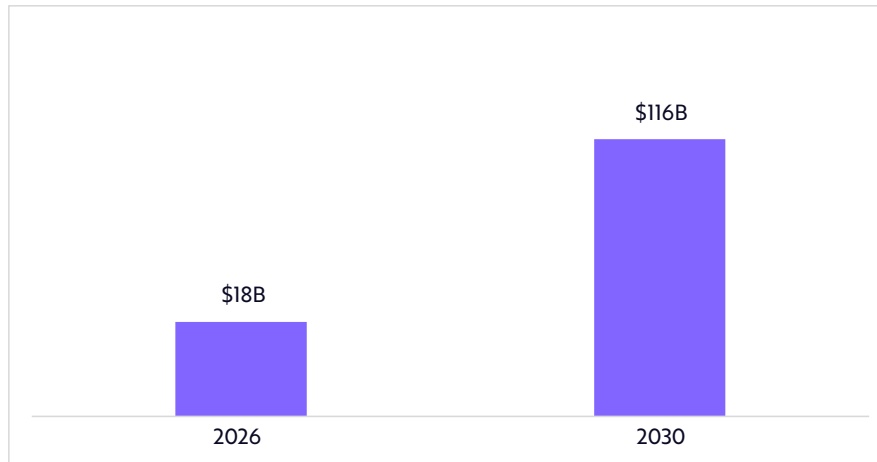
³⁸ Source: <https://www.shopfood.com/online-shopping/whats-the-average-distance-for-food-delivery-services/>

³⁹ Source: <https://nyc.streetsblog.org/2019/06/25/delivery-cyclists-have-one-of-the-most-dangerous-jobs-but-no-one-is-protecting-them/>



If drones eventually deliver 60% of restaurant meals, they could generate roughly \$7 billion in revenues in five years and \$100+ billion in 2030, as shown below.

Estimated Food Delivery Revenue



Forecasts are inherently limited and cannot be relied upon.

Source: ARK Investment Management LLC, 2022 data sourced from "Pitney Bowes Parcel Shipping Index Reports Global Parcel Shipping Reaches \$279 Billion in Revenue." Pitney Bowes, 28 Aug. 2018, <https://arkinv.st/2QjSeSQ>; "Data and Research on Digital for Business Professionals." EMarketer, EMarketer, <https://arkinv.st/2trGQeE>; Total Retail Sales of Consumer Goods in December 2017, National Bureau of Statistics of China, 25 Jan. 2018, <https://arkinv.st/36mBKz6>; "Monthly Sales for Retail and Food Services by Kind of Business: Retail Sales by Kind of Business, Millions of Dollars, Seasonally Adjusted." FRED, Federal Reserve Bank of St. Louis, <https://arkinv.st/2ZJWSN4>

Automation is likely to cut costs across the food industry, from preparation⁴⁰ to delivery, fueling a virtuous cycle that stimulates both restaurant sales and deliveries. Dark kitchens—fully automated food preparation centers—could be optimized for drone deliveries.

In China, an early mover in this space, consumers have responded strongly to low-cost delivery options. Meituan subsidizes restaurant meals that it delivers, in some cases offering 80% discounts⁴¹ and undercutting the cost of meals prepared at home.⁴² As a result, some customers have deserted supermarkets altogether. Even in the absence of such subsidies, continued increases in automation could make food delivery more cost-effective than restaurant meals. Given the unpaid labor associated with shopping, cooking, and cleaning, eventually food delivery could displace home-cooked meals as well.

While ARK's research has focused on some of the largest opportunities for drone delivery, we expect many more drone services, including bridge inspection, mapping, surveying, medical deliveries, and real estate tours. For heavier payloads, including human passengers, large purpose-built drones could take to the skies.

⁴⁰ Source: <https://ark-invest.com/articles/analyst-research/automating-food-services/>

⁴¹ Source: <https://www.bloomberg.com/features/2019-meituan-china-delivery-empire/>

⁴² Note that the current regulatory environment may change this dynamic



Conclusion

The convergence of artificial intelligence and battery technologies within the mobility space could disrupt transportation completely, radically reducing costs and benefiting consumers.

Thanks to lower costs and freeing people from the burdens of driving, autonomous vehicles could increase consumer purchasing power while becoming one of the most impactful innovations in history. More importantly, autonomous vehicles could save lives,⁴³ as human error is responsible for the vast majority of fatal auto accidents every year.⁴⁴

⁴³ Source: <https://ark-invest.com/articles/sustainable-investing/autonomous-cars-will-save-thousands-lives-per-year-us/>

⁴⁴ Source: <https://www.cdc.gov/injury/features/global-road-safety/index.html>



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Tasha joined ARK in January 2014 and is an Analyst for ARK’s Autonomous Technology and Robotics strategy. She covers autonomous cars, additive manufacturing, infrastructure development, and innovative materials.

Previously, Tasha spent almost three years as a management consultant for Applied Value, working primarily with manufacturing and automotive clients. Tasha is a graduate of Boston University’s Collaborative Degree Program with a Bachelor of Science in Business Administration with a Finance concentration, and a Bachelor of Arts in Mathematics and Statistics with a Pure and Applied Mathematics concentration.

Tasha frequently appears on CNBC, CNN, Bloomberg, and Fox Business. She has been quoted and her research has been featured in The Wall Street Journal, Forbes, Wired, the Verge, Bloomberg, CNNMoney, and Marketwatch, among other publications. She has been a featured speaker at the Annual Meeting for the Transportation Research Board, a division of the National Academy of Sciences, Engineering, and Medicine for the United States and at the Port Authority of New York and New Jersey on autonomous driving.



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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.

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