TRANSPORTATION2050

The Future of Personal Mobility | May 2018

A Delphi White Paper in collaboration with Ideafarms



Evolution of Personal Mobility

The din and speculation surrounding the future of transportation has reached a deafening pitch. Rarely does a day go by without some major news story about the driverless future. We are clearly at an inflection point between the old and well-established notion of transportation, along with all of its incumbent industrial era risks and costs, and a future that promises safe autonomous vehicles, while it also threatens a deeply entrenched set of players, economics, and social attitudes.

This white paper provides a radical view into how that future will change. Not only is it a glimpse into what personal mobility will look like in the near future, but also a prediction of the ultimate demise of an era that has been defined by personal vehicle ownership. Owning an automobile has been a part of every aspect of modern life, from a rite of passage into adulthood to a means of retaining independence into old age.

The projections and conclusions drawn in this white paper are based on a detailed analysis of current trends and expected advances in transportation. While the focus is on what would today be considered owner-driven automobiles, rather than public transportation, taxis, livery services, and commercial transport, we expect that the distinction between many of these forms of personal transportation will merge into a single market, which is often referred to as TaaS (Transportation-as-a-Service). This white paper focuses primarily on personal mobility, which we will refer to as MaaS (Mobility-as-a-Service).

Envision cars that own themselves, whose utility is closer to 90% rather than today's 10%, and picture a future where the total number of cars on the road drops to less than 1/5 of what it is today.

MaaS differs from TaaS since it focuses specifically on what will replace single-owner private vehicles as opposed to commercial vehicles and public transportation. MaaS may be a much harder transition since one of the greatest obstacles to the adoption of both Electric Vehicles (EVs) and Autonomous Vehicles (AVs) will be individual drivers who have developed a deep cultural attachment to the traditional automobile.

We are also already accustomed to having public transportation that is driven by autonomous or semi-autonomous systems.

Autonomous car's interior concept (top right image) | Photo cheskyw / 123RF Stock Photo

From trains to planes, we accept that highly automated systems are already responsible for driving or piloting. These systems have also had a measurable and significant impact on increased safety. For example, in the case of air travel, the introduction of autopilot, Flight Management Systems, and advanced computer controlled Fly by Wire have reduced fatalities per million flights to just 1% of what they were 60 years ago[1].

Lastly, due to the ability to scale public transport by using technology to require fewer human operators for more passengers, we can realize radically different and far more attractive economies of scale in a TaaS Model that are not initially true of a MaaS model.

Although the evolution of EVs is a cornerstone of MaaS, implicit in that is the concurrent shift to AVs. Without the AV, a changeover in just the power source that fuels an automobile would drive costs down, but it would not solve either the last-mile problem or the issue of utilization. The last-mile problem, which deals with the personalized transport of an individual to his or her final destination, cannot be solved with present public transport and TaaS models, which focus on multi-passenger solutions. As we'll show, *it is the uniquely powerful combination of the EV and the AV, with a MaaS model of transportation, that creates the disruption which displaces both the Internal Combustion Engine (ICE) and the individual ownership model.*

The most radical conclusion of this report is that there will be a *long-term shift in the ownership, economics, and experience of an automobile.* For example, envision cars that own themselves, whose utility is closer to 90% rather than today's 10%, and which are used as platforms for entertainment and socialization. Even more disruptive is our projection that the trajectory for the total number of cars registered will rise in the short term but then dramatically fall from a peak of 550 million vehicles in 2034 to less than 50 million by 2050—creating a socioeconomic roller coaster that will displace workers, disrupt industries, and force a wholescale reinvention of transportation's role in our lives.

As difficult as the future of MaaS is to envision, the trajectory of trend lines that are driving it—a pun we will try to avoid as much as possible—appears to be nearly immutable. While the timing we present may be subject to some debate, we are certain of the direction and overall conclusions.

It is also important to note that the data presented in this report (unless otherwise stated) reflects USA statistics and projections. We believe these to be the most accurate and, due to the fact that the USA has the highest ratio of licensed drivers to registered vehicles (222M Drivers to 269M vehicles[2]), also the best indicators of long-term trends in the evolution of MaaS.

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1 "A Statistical Analysis of Commercial Aviation Accidents 1958-2016," *Airbus*, June 2017, http://www.airbus.com/content/dam/corporate-topics/publications/safety-first/Airbus-Commercial-Aviation-Accidents-1958-2016-14Jun17.pdf

2 *Statista https://www.statista.com/topics/1197/car-drivers/*

Personal Mobility and the end of Automobile Ownership

For most people, a car is the first or second largest purchase they will procure during their lives. Yet, it is not utilized for 90% of its useful life

The 150-year reign of the Internal Combustion Engine (ICE) Vehicle is fast approaching its end and with it the near-sacred model of automobile ownership. Although conventional wisdom for the past forty years has been that the downfall of ICEVs would be entirely due to the depletion of fossil fuels, it has become clear that there are many more factors at play. The most significant are the recent and anticipated advances in the affordability of electric vehicles, the ability to easily recharge battery-powered vehicles, advances in autonomous vehicles which are better suited to electric power, favorable effects of Moore's Law on battery technology, exponential technologies accelerating the advances of artificial intelligence (AI), and the need to deploy transportation to a global population that is expected to reach 10 billion by 2050. And, not to be discounted, our round-the-clock connectivity has created a nearly untenable level of distraction when we are driving, which by some estimates accounts for close to 500,000 incidents yearly.

According to the NHTSA[3]:

"In 2016 alone, 3,450 people were killed. 391,000 were injured in motor vehicle crashes involving distracted drivers in 2015.

During daylight hours, approximately 481,000 drivers are using cell phones while driving. That creates enormous potential for deaths and injuries on U.S. roads. Teens were the largest age group reported as distracted at the time of fatal crashes"

What's surprising about each of these dynamics is that they collectively paint a very different future for transportation than would have been anticipated given the last 150 years of growth in the single-owner-driven vehicle. Rather than just changing the way vehicles are powered, EVs change the most fundamental utilization models for transportation. EVs last longer, require far less maintenance, can achieve higher sustained utilization rates, and fundamentally alter the economics of transportation.

In its most extreme form, MaaS will utilize fleets of fully autonomous vehicles, which will be available on-demand where and when needed. These vehicles will operate at nearly full utilization (90%) with down time only for maintenance and recharging. Individual ownership of vehicles will become a novelty for collectors and for sport. In countries like India, where a feudal mindset persists, car ownership might even accord pseudo-status in the short term.

The inevitable result of MaaS will be something that is anathema to anyone who has owned or aspired to own an automobile—the end of the single owner automobile. With that will come what is arguably the most controversial finding of our research: that the number of automobiles will drop precipitously to a mere 15% of what it is today in the USA,

3 *National Highway Traffic Safety Administration*, https://www.nhtsa.gov/risky-driving/distracted-driving

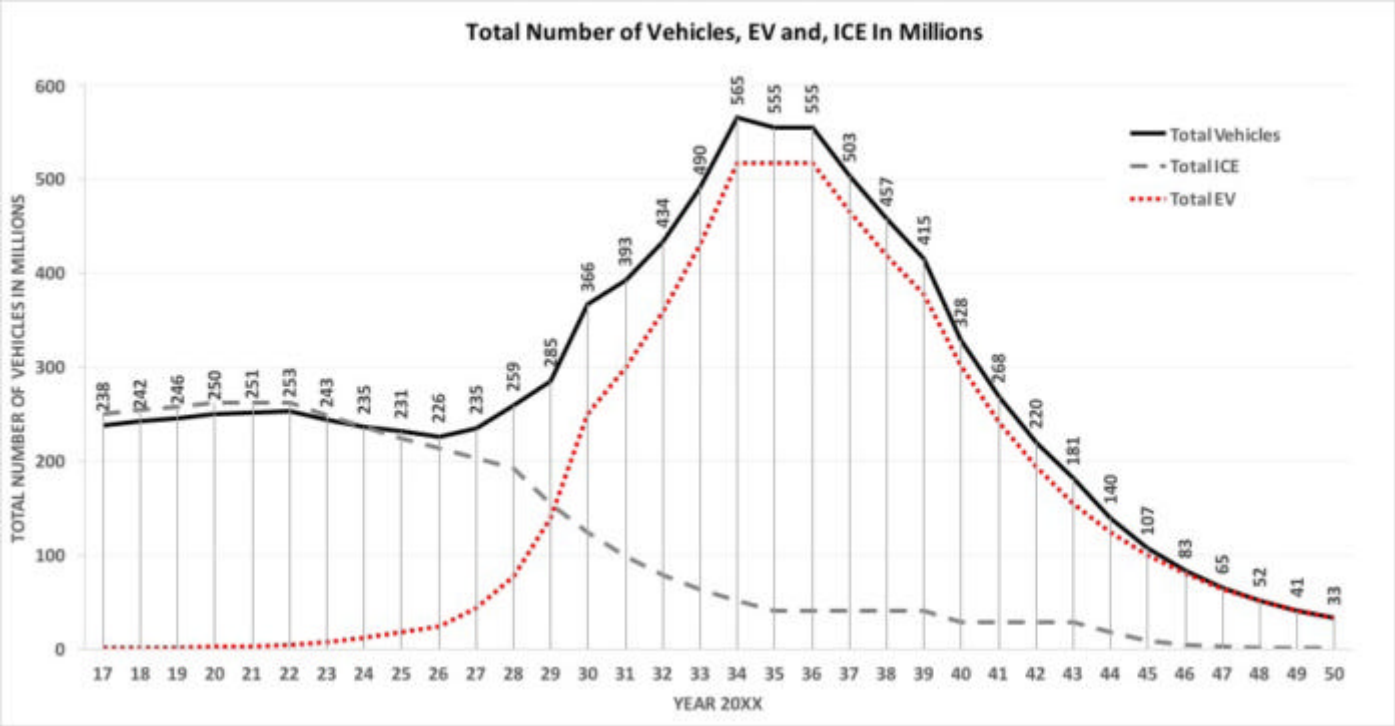


Figure 1: *Total Number of Vehicles. One of the most remarkable findings of this research is that total vehicles on the road will drop to less than 15% of it current volume. Why? In a word, utilization.*

from 250 million in 2018 to 33 million in 2050 (see Figure 1). We see the same approximate effect across the globe.

MaaS will develop on an evolutionary path with many stages of incremental—and disruptive—advances in both the supply (manufacturing) and demand sides (consumers) of the market. The challenges to both will be without precedent given the industrial behemoth that has been built to supply automobiles, the number of jobs associated with traditional car manufacturing (3% of all employment in the USA), and the cultural attachment we have as a society to vehicle ownership.

MaaS is so far removed from the traditional model of car ownership that the forecasts in this report will likely appear outlandish as they tread on some culturally and economically sacred turf. Cars are far more than a mode of transportation. The automobile has become synonymous with personal identity in the developed world. For most people it is the first or second largest purchase and ongoing expense they will incur during their lives. Yet, unlike a home, the typical car is idle and has no utility for 90% of its useful life. When weighted based on total cost of ownership over actual hours used it becomes *the single largest life expense for 99.9% of the world's population.*

However, the transportation infrastructure of the developed world makes MaaS an absolute necessity. Nine in ten employees in the USA need a car to commute to work. Even when public transportation is involved, the challenge remains: the last-mile problem—getting to and from public transportation still requires an automobile on one or both ends of the commute. Ride-sharing services are starting to change that, but their economics are still tied to models that rely on private ownership. They are an interim step in the right direction but, as we'll see, not sustainable in their current mode. In countries like Singapore the last-mile problem is better mitigated through a combination of seamless connections and, starting in 2022, even doorstep services using AVs[4].

4 Adrian Lim, "Driverless vehicle rides in three new towns from 2022," *The Straits Times*, November 23, 2017, http://www.straitstimes.com/singapore/transport/driverless-vehicle-rides-in-three-new-towns-from-2022

One of Nanyang Technological University (NTU), Singapore's, Group Rapid Transit (GRT) autonomous vehicles on the NTU Smart campus
Photo: NTU Singapore

In August 2016, Singapore introduced its AV taxi service, "starting small—six cars now, growing to a dozen by the end of the year. The ultimate goal is to have a fully self-driving taxi fleet in Singapore by 2018, which will help sharply cut the number of cars on Singapore's congested roads. Eventually, the model could be adopted in cities around the world," according to nuTonomy, a Boston-based startup that is testing autonomous vehicles in Boston and Singapore.[5]

We see significant differences between the adoption of many prior technologies and MaaS. Although technology convergence can experience exponential growth in developing countries, MaaS requires the creation of significant infrastructure, such as roads that are suitable to an AV. One need only watch any YouTube video of traffic in a country such as India to appreciate the challenges of navigating streets that are crowded with all types of vehicles, animals, people, and an apparently total lack of adherence to any consistent set of rules for drivers.

Vehicle fatalities in India are five times those in the USA even though India has approximately 50 million fewer vehicles!

What is often missed in discussions about AVs in developing countries is that the current state of affairs creates devastatingly higher rates of injuries and fatalities. For instance, vehicle fatalities in India are five times those in the USA even though India has approximately 50 million fewer vehicles![6] When you consider

5 Annabelle Liang and Dee-Ann Durbin, "World's First Self-Driving Taxis Debut in Singapore," *Bloomberg Technology*, August 25, 2016, https://www.bloomberg.com/news/articles/2016-08-25/world-s-first-self-driving-taxis-debut-in-singapore

6 "Road accidents in India, 2016: 17 deaths on roads every hour, Chennai and Delhi most dangerous", *The Indian Express*, September 11, 2017, http://indianexpress.com/article/india/road-accidents-in-india-2016-17-deaths-on-roads-every-hour-chennai-and-delhi-most-dangerous-4837832/

that steep human cost, along with the relatively undeveloped rules of the road in a developing country, it is easier to make the case that a country such as India could lead the revolution to MaaS before a country that has a well-developed, significantly safer personal transportation model, and a well-entrenched and broadly accepted cultural framework for individual ownership.

India's current mobility scenario differs from the West in that it still has non-motorized, animal-driven (and human-propelled!) transportation, even in metropolitan cities. Compared to the developed world, personal vehicle ownership isn't a strong driver.

India's potential to create a shared system based on usership—as opposed to ownership of the means of transport—can decrease congestion: shared and connected systems can help provide more viable mobility alternatives while simultaneously improving air quality, especially as EVs become the default transportation option. In the chaotic and disorganized environment that characterizes the country, AVs will provide a much higher level of safety for people and property.

According to Kurt Lehmann, Global Corporate Technology Officer, Continental AG, which is focused on developing safety systems for implementation,

"Early tests are being done to validate our own knowledge of systems of how they would or could perform in automated circumstances. We believe automated driving is going to improve safety and will be adopted in developed markets soon.

And, yeah, there will be problems along the way but it already shows that it is far safer than a human driving the vehicle."[7]

We also think India's evolved IT ecosystem can add value at the intersections of sensor technology, vehicle-to-vehicle communications, response times and the interplay between AI, analytics and decision systems.

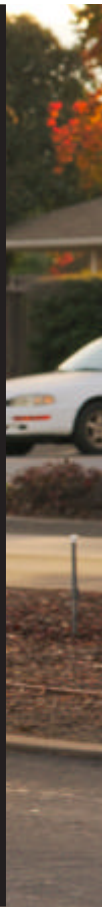
7 Vishal Krishna, "Technology for disruption: How the connected world will drive Continental's future," *YourStory*, April 19, 2018, https://yourstory.com/2018/04/technology-disruption-connected-world-will-drive-continentals-future/

The Waymo autonomous car. The California government has given clearance for fully autonomous cars to hit the roads in April 2018[8]. At the time that this report was published over 20 states had legislation relating to AVs.[9] However, recent incidents, including the first pedestrian fatality from an autonomous Uber in Tempe Arizona during March of 2018, has caused renewed debate and discussion about the use of AVs and their safety.

Photo: Dllu / Wikimedia Commons / CC-BY-SA 4.0

8 Daisuke Wakabayashi, "California Scraps Safety Driver Rules for Self-Driving Cars," The New York Times, February 26, 2018, https://www.nytimes.com/2018/02/26/technology/driverless-cars-california-rules.html

9 "Autonomous Vehicles State Bill Tracking Database," National Conference of State Legislatures, http://www.ncsl.org/research/transportation/autonomous-vehicles-legislative-database.aspx



Factors driving the shift to MaaS

Higher Asset Utilization

One of the primary economic forces that will drive the shift towards MaaS is higher vehicle utilization. The relationship between utilization and the number of vehicles on the road is a simple one. As with any machine, the effective cost of ownership decreases as the use of that machine increases. If I pay $100 for a shovel to dig just one hole then the cost of the hole is $100. Dig two holes and the cost per hole is now $50. Using that same reasoning, at 5% average utilization, individually owned automobiles represent one of the most underutilized assets in a modern society. The relationship between utilization (as hours driven per day) and the number of vehicles needed (based on current demand) is shown in Figure 2.

The perversity in personal vehicle use is that utilization rates are among the lowest of virtually any significant asset that most people own. Ride-sharing services (Uber),

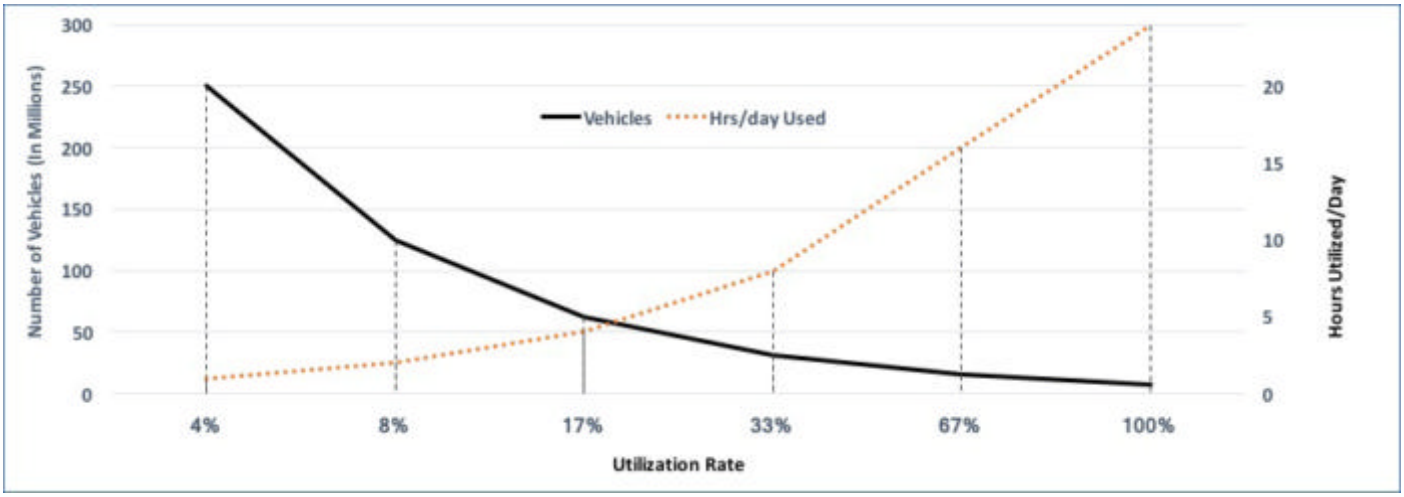


Figure 2: *Vehicle utilization rate (in hours/day) – majority of vehicles are used for less than 4 hours a day. However, as utilization rates increase, the effective number of vehicles needed decreases. At 17% utilization the number of vehicles needed to provide the same level of transportation as 250,000,000 vehicles drops to roughly 60,000,000 vehicles.*

ownership sharing (ZipCar), and owner rentals (SnappCar) are all helping to improve utilization rates. However, as we show, the current model of ride-sharing is unlikely to account for a significant jump in utilization.

We expect that ride-sharing will increase utilization from the current 5-10% to 20-25%. However, we see a hard stop at between 20-25% utilization due to the inherent limits of ride-sharing drivers. In other words, each percentage point of increased utilization is equal to about 14.5 minutes of increased usage per day for each registered car. However, given that at this time there are approximately 1,000,000 active ride-sharing drivers in the US, even if all of these cars were used 100% of the time the increased utilization would amount to less than 10% of all automobile hours driven (currently at between 0.05% and 1.3%).

As a result, we don't expect a significant uptake in utilization from the current model of ride-sharing in the developed world. We're also suspect of the long-term economics of ride-sharing that relies on underutilized owner vehicles, given the current cost of ownership and maintenance for ICE cars.When all costs are accounted for, Uber drivers make less than or very close to minimum wage[10]. The EV will lessen this burden on drivers and enhance the economics of owning a ride-share vehicle, but, again, even if this doubles the net effect will still be an incremental change in the overall number of vehicles due to the inherent limitation of the driver over the car. The owner of a ride share car cannot operate the vehicle more than a reasonable number of hours during the day, resulting in a car that is still underutilized 50-60% of the time.

10 Jacob Bogage, "How much Uber drivers actually make per hour," *The Washington Post*, June 27, 2016, https://www.washingtonpost.com/news/the-switch/wp/2016/06/27/how-much-uber-drivers-actually-make-per-hour/?utm_term=.18039c2b59aa

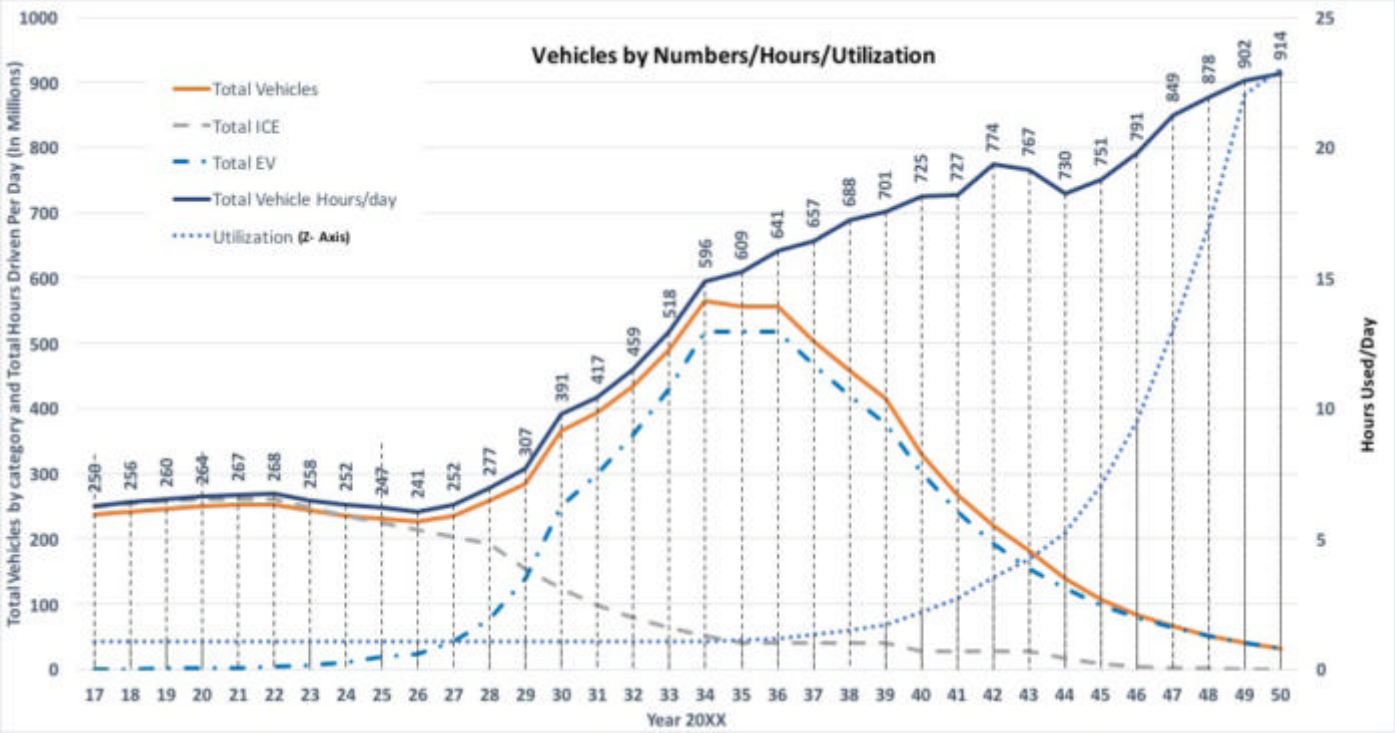


Figure 3: *Vehicles by numbers/hours/utilization. The long-term trend towards increased hourly automobile usage. Through the early and mid 2020s we expect to see little change in the overall number of vehicles on the road. In large part that is due to a swapping of existing ICEVs with EVs during that same time period. However, this will be followed by a steady projected decrease in ICEVs and a concurrent rise in EVs with the number of EVs on the road surpassing the number of ICEVs by 2030. We project that EVs will then rise steadily and peak at just over 500 million EVs in 2034. A plateau for EVs and total vehicles is then expected to last for the following two years. This is the result of a sudden spike in utilization starting in 2034. After 2036 we expect to see a steady decline in total vehicles as utilization steadily rises and the economics of individual ownership diminish rapidly.*

Currently, Uber's business model for India has more to do with affordable taxis over ride-sharing by car owners. Again, cultural context dictates the attitudes towards new transportation models, such as ride-sharing. Few car owners in India, who are generally affluent, want to be Uber drivers. Both because it does not provide an attractive enough economic proposition, but also because it has a cultural implication of being a driver rather than the one being driven. In India people who would otherwise use Uber can typically afford personal drivers and employ others to drive for them. Uber India, therefore, needs to adopt a business model that caters to drivers, meaning that they have to sell and finance cars for those who wish to be full–time drivers.

In addition, the reason drivers in other parts of the world have been flocking to ride-sharing services over the past several years has to do with a lack of awareness of the total cost of ownership. Over time this will become more apparent. Without a significant reduction in ownership costs, we do not see ride-sharing through privately owned cars (by individuals) as a viable long-term business model for ICE. It remains to be seen if this could be altered significantly through the lower overall maintenance costs of an EV. Our inclination is that it will, but without further evidence and data to support this, we are hesitant to factor it into the projections we are making for EVs at this time.

Decreasing Costs Of EVs

One of the greatest factors that will cause EV sales to ramp as quickly as we are projecting for 2026 to 2034 is the anticipated drop in the cost per kilowatt-hour for batteries. The cost of an EV is tied to battery cost with 33% of a vehicle's cost being attributed to the cost of the batteries. For example, we can back into the cost of a Tesla Model 3 by using a formula which first calculates the cost of the batteries and then the total vehicle cost as a multiple of battery cost, which is 3x if batteries make up 33% of the cost.

Vehicle cost = Dollar Cost Per Kilowatt hour x Total Vehicle Kilowatt hours x 3

Since this formula works based on the ratio of battery cost to overall cost today, we expect that it will have to change as battery costs drop and the remaining component costs do not. However, we can still project costs in today's dollars based on a model in which battery costs decline even though components costs may remain static.

Battery costs have fallen precipitously over the last decade. A 2010 Boston Consulting Group report[11] noted that it was unlikely per kWh costs would fall below $250 by 2020. Today they are at between $190 (Tesla) and $260 (GM). Given an average of $225/kWh, the costs for a 60kWh EV would be:

Vehicle Cost = $225 x 60 x 3

= $13,500 x 3

= $40,500

In this example the battery pack cost for a 60kWh vehicle is $13,500 and remaining component costs are $27,000. While we expect battery costs to decrease significantly, the result will unlikely be a significantly lower overall cost for vehicles at the low end of the EV market. In Figure 4 we show the projected decrease in battery costs for a 60kWh battery pack along with the anticipated increase in component costs through 2030. The increase in component costs is anticipated due to both inflationary and demand increases in materials of 3% year over year. This yields a total cost that remains relatively stable (the double top line).

11 Andreas Dinger, Ripley Martin, Xavier Mosquet, Maximilian Rabl, Dimitrios Rizoulis, Massimo Russo and Georg Sticher, "Batteries for Electric Cars," *The Boston Consulting Group*, 2010, https://www.bcg.com/documents/file36615.pdf

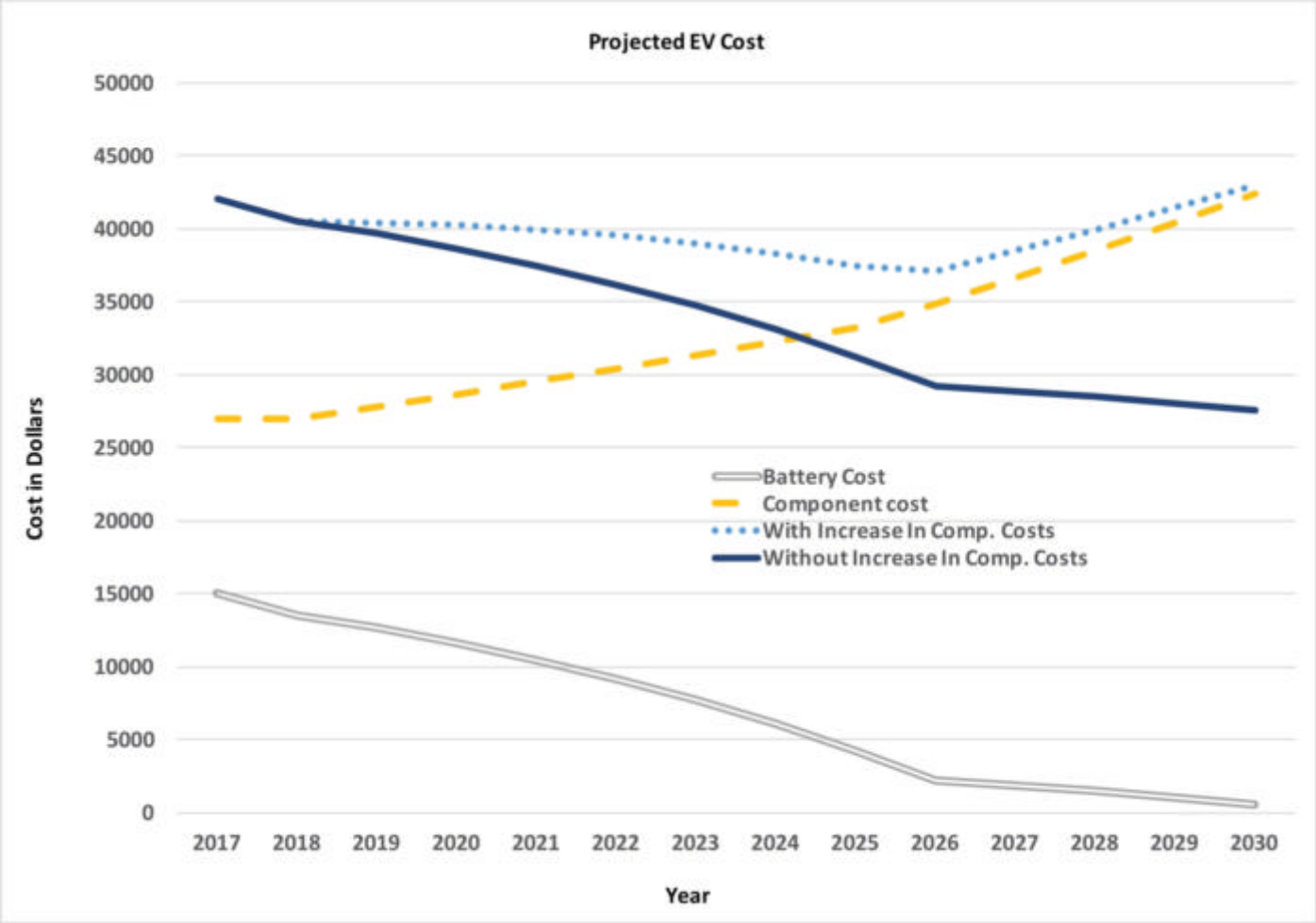


Figure 4: *Projected EV Cost. Projected decrease in battery costs for a 60kWh battery pack along with the anticipated increase in component costs*

Without this increase in component costs, a lower boundary for total vehicle cost is shown in the solid blue line (Figure 4). There is an argument that could be made for total costs of a low-end EV following this lower total cost trajectory due to the ability of manufacturers to better control the component costs and thereby provide greater incentive to spur the appeal of EVs in the short term.

In the final analysis, it seems clear that the impact of EVs will be significant and disruptive from the period starting in 2025 through 2050. We have labeled this the **Transformational Gap,** which represents the wholescale turnover from ICEVs to EVs. This is not just a transition from one era to another, it is a wholescale transformation of transportation's role and place in society. During this period we are in many ways developing an entirely new set of attitudes, norms, cultural adaptations, and even a new vocabulary. There will be three periods of distinct disruption during this Transformational Gap.

The Handoff 2021-2029

The first is the Handoff, from 2021 through 2029 (see Figure 5). During the Handoff it will become increasingly clear that EVs are not only gaining but will eventually be replacing ICEVs. In the early part of the Handoff, traditional legacy ICEV manufacturers will need to already be prepared to compete directly in the EV market. No industrial era industry has ever faced a test on this scale in which a well-established product used this broadly, and requiring this level of consumer investment, has experienced a complete turnover.

This means not only altering the product but the entirety of the business model for car sales, ownership, and disposal. Today that business model is segmented into three distinct markets: new car sales, dealer

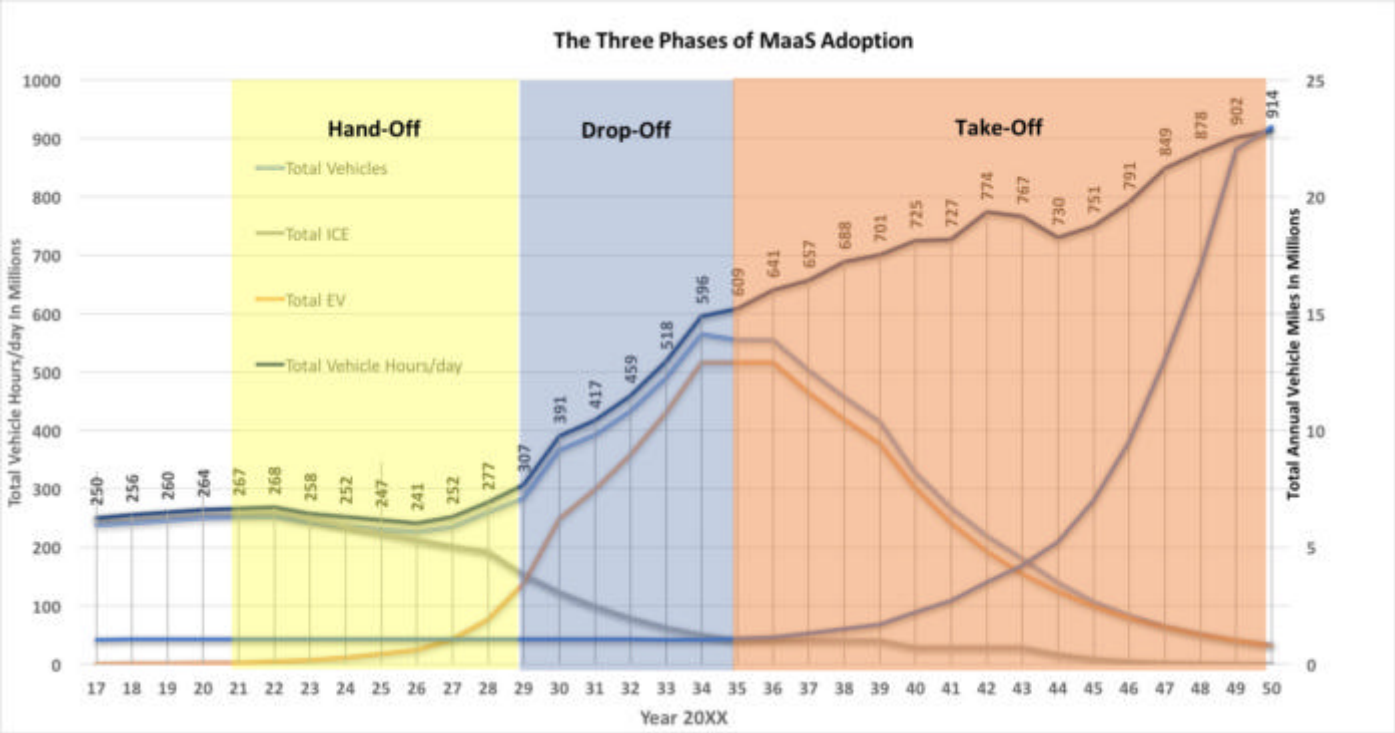


Figure 5: *The three Phases of MaaS. As MaaS trends begin to accelerate, ICEVs will not survive, even though total vehicle hours will increase dramatically. After the Drop-Off period (2029-2035), during which ICE vehicles will steadily decline while EVs rapidly increase in prominence, the total number of overall vehicles will start to decline with rapid increases in utilization. (Global data for total vehicles and vehicle hours is approximately four times that shown for the USA data above. However, timing of the ICE/EV turnover, as well as the corresponding utilization increases do not correlate directly, in terms of timeline, due to the infrastructure, economic, and cultural factors which we've already described.)*

and automotive repair shops, and used car resale. The only significant change in that model over the life of the ICEV has been the introduction of certified pre-owned (CPO) cars. One of the greatest challenges for traditional ICEV manufacturers will be reengineering this business model to a MaaS model. Although the utilization rate for all vehicles does not begin to increase until 2036—well after the Handoff stage—the initial groundwork for a MaaS model will be the use of automobiles as a service, where the owner will pay an agreed upon price to the manufacturer for the use of the automobile, its maintenance, and its disposal.

This radically alters the current infrastructure of dealers as well as the used car market. Reengineering the product will be a relatively simple exercise when compared to reengineering the overall marketplace. While many ICEV manufacturers have committed to EV, for example PSA Group (Peugeot and Citroen) has committed to an 80 percent EV fleet by 2023, not having a solid foundation for a MaaS business strategy will have the same effect on traditional automobile manufacturers as digital photography had on standalone cameras.

Although the camera industry experienced a rapid spike in demand and sales from the early 2000s through 2011, it then fell precipitously as the smartphone evolved. With the exception of professional photography, which may also be in jeopardy as dual lens smartphones evolve, the consumer stand-alone camera market is all but dead. Unlike companies such as Samsung, which had the ability to benefit from smartphone sales while they simultaneously participated in the decimation of their stand-alone digital camera market, automobile manufacturers do not have that option.

The Drop-Off 2030-2035

The second period of disruption, the Drop-off, will last from 2030-2035. During this time those manufacturers which are not prepared to first move to a

life-cycle ownership model and then a full MaaS model will drop off the map as they start to face monumental hurdles when EVs catch up with and eventually overtake ICEVs. These laggards of the industrial-era vehicle manufacturing industry will not survive much beyond 2039 when MaaS utilization trends begin to accelerate rapidly and enter the final period of disruption, the Take-off, during which the EV/AV model has proven its economic and social acceptance and benefits.

The Take-Off

Defining what the period beyond 2035 will look like for MaaS and TaaS is entirely speculative. While we are very confident in the demise of the single-owner model of personal mobility, projecting forward and depicting a credible view of how MaaS will alter the usage model of the automobile borders on science fiction. What's clear is that the automobile will transform into a platform for many other activities well beyond the transportation of people. Among these will be its value for entertainment, on-demand delivery of goods and services, healthcare, hospitality, education, fitness and wellness, and socialization, among others. However, there are certainly applications and use cases that simply do not exist, nor can they be predicted. Because, if they could, we would wonder how we could possibly be living without them.

One additional, and very interesting aspect of the model we've portrayed is its impact on energy use (as shown in Figure 6). While there will be a near-term decline in overall energy usage through the early 2030s, due to the decline of ICE vehicles in favor of EVs, we expect that the longer term increased utilization and growing uses of MaaS for non-traditional vehicle uses will actual increase overall energy demands as measured by kWh (kilowatt hours). However,

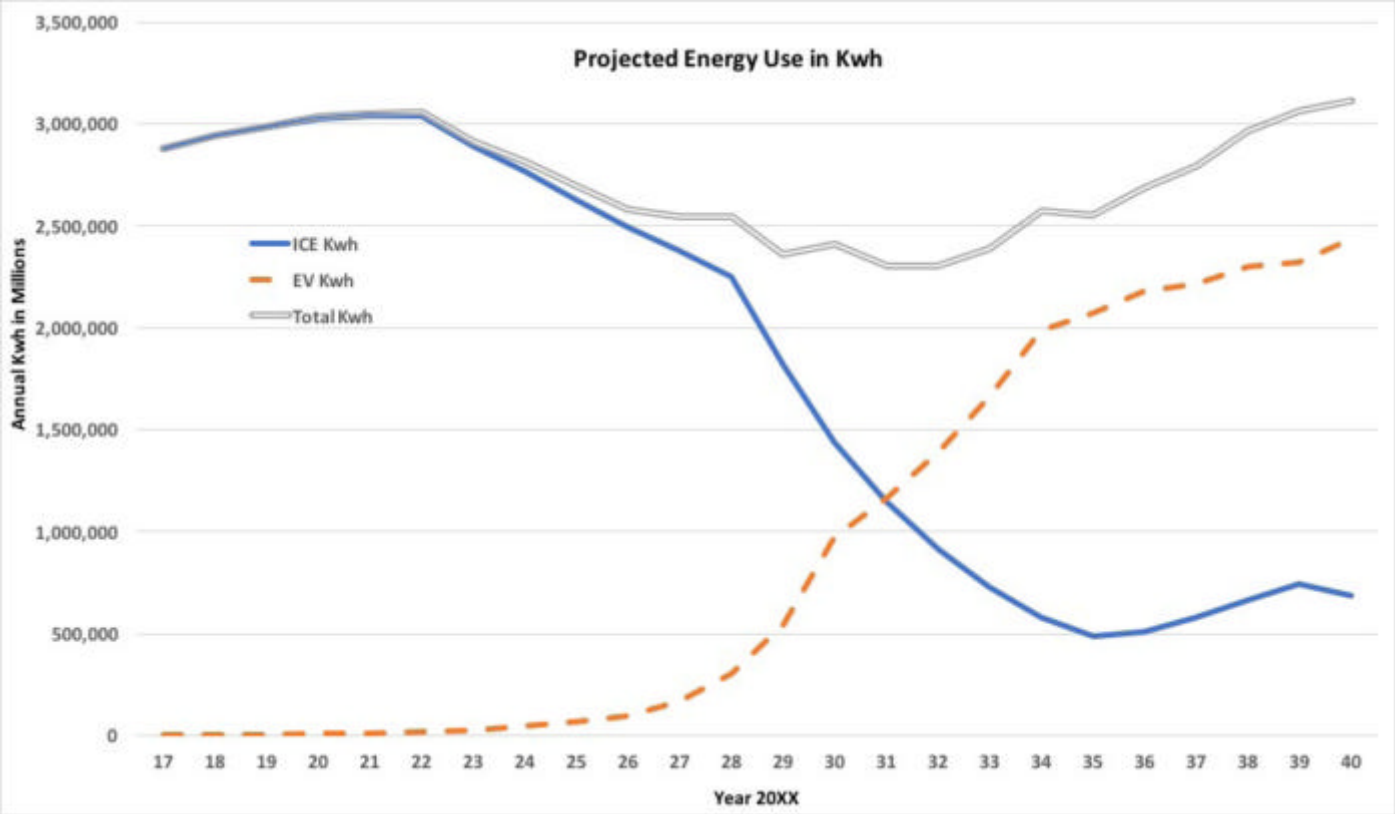
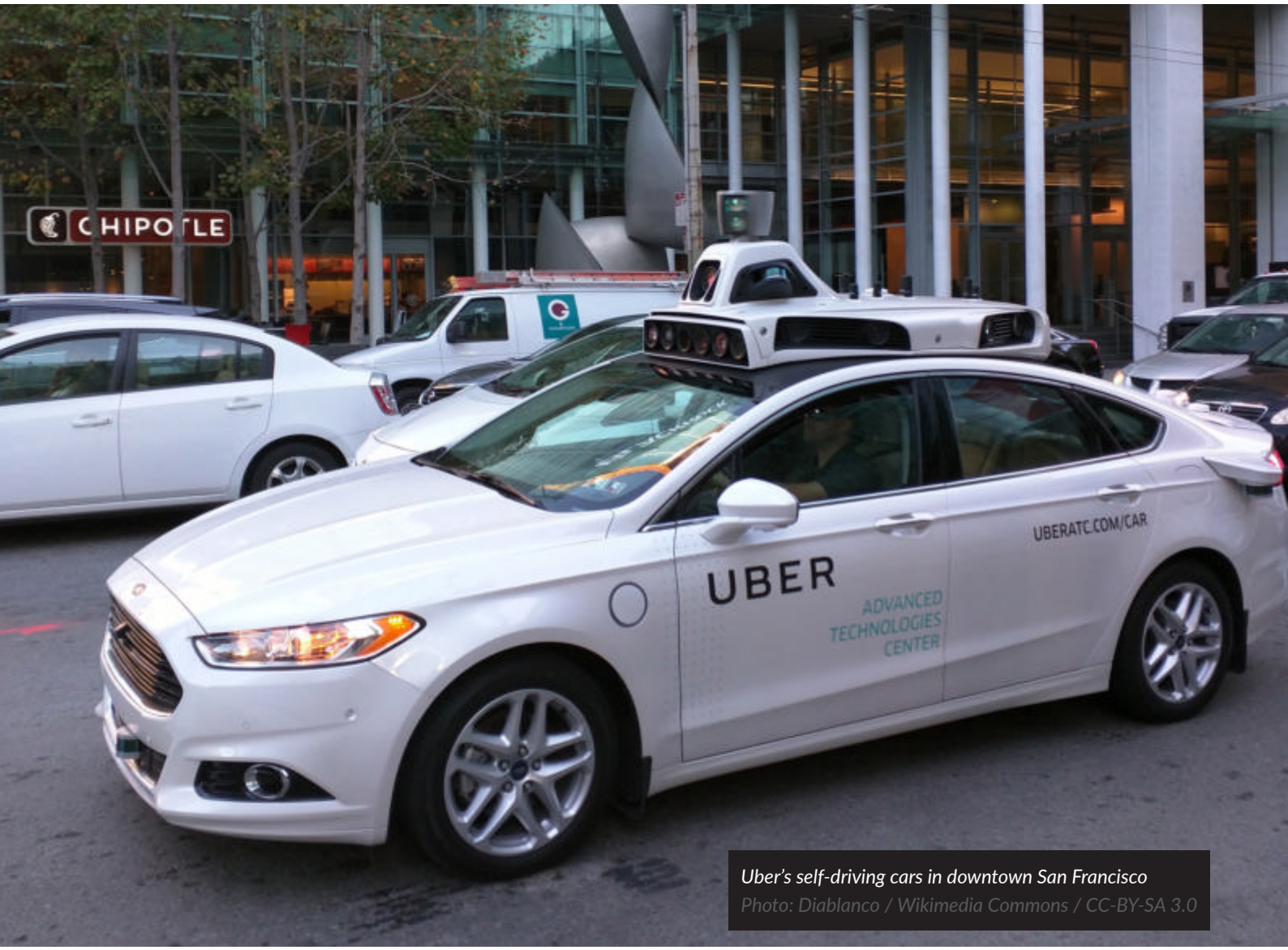


Figure 6: *Projected Energy Use in kWh. Total energy use will initially decline as MaaS relies increasingly on an EV platform with higher energy efficiency, which is at least 3 times that of ICE. However, as utilization and new uses for the EV/AV arise we will see that overall energy use starts to climb once more. While it may be difficult to accurately predict the precise energy uses due to innovations in EV batteries and motors, it is clear that the shift to an EV/AV platform does little in the long term to alleviate increasing global energy consumption, other than on a relative basis when compared to ICEVs.*

the challenge in adequately projecting this model is that current kWh usage (for both EVs and ICE) is based on the current usage models, which account for approximately 1kWh per mile for an ICE vehicle and 0.333 kWh for an EV[12]. Undoubtedly the battery efficiency of EVs will continue to increase. However, we bring this up because it would be foolish and naïve to expect that the shift to EVs alone will somehow alleviate the ever-increasing need to power transportation. Keep in mind that this is also just a USA perspective and does not take into account the rapid and extensive growth of MaaS globally.

12 Assumes a gallon of gas is the equivalent of approx. 33 Kwh.



Uber's self-driving cars in downtown San Francisco
Photo: Diablanco / Wikimedia Commons / CC-BY-SA 3.0

Autonomous car interior concept | Photo: cheskyw / 123RF Stock Photo

A Wildly Distributed Future

One last thing that's worth considering in the context of just how radical the shift to an EV/AV vehicle will be is that of ownership. This is especially critical to understand in the context of scaling MaaS globally to support 10 billion people.

As the MaaS model evolves, so will some of the most basic tenets of ownership through the use of technologies such as Blockchain, which provides for an immutable record of ownership as well as the elimination of the many layers of administration involved in traditional buy/sell business models and bank financing—most of which are not even an option in many developing parts of the world. That may all sound a bit obtuse so let's make it easy to follow using ride-sharing as an example.

Today Uber relies on owners of cars to provide ride-sharing services to clients. What makes this model work is that there are lots of car owners who have cars that are on average used only 5% of the time[13]. That's an enormous waste of value and resources, which is why Uber's model is a great way to leverage latent assets and people while addressing a fundamental need of a modern urban ecosystem—the need for frictionless mobility.

When most people try to

13 David Z. Morris, "Today's Cars Are Parked 95% of the Time," *Fortune*, March 13, 2016, http://fortune.com/2016/03/13/cars-parked-95-percent-of-time/

adapt the Uber model to an autonomous vehicle the natural inclination is to imagine Uber buying fleets of robotic cars. But that just perpetuates an industrial era ownership model. You can picture row upon row of Uber cars that all look the same; we've just gone back to any color as long as it's black. It would certainly be more efficient from the standpoint of resource utilization since the cars wouldn't be sitting in a garage or a parking lot 95% of the time. However, there's still a corporation with employees, management and executives, offices and equipment to factor into the equation. Additionally, the competitive landscape would be limited since enormous initial investment would be required to effectively compete against Uber's scale.

Instead, what if autonomous cars were non-human legal entities in which many people had a stake, not unlike a public corporation, which has many owners? We'd ask that you stop here and think about all of the reasons why that wouldn't work. We're going to guess that your list may include: individual cars would be much more expensive assets since they could not achieve economies of scale; autonomous cars could not maintain themselves; if riders were unhappy there's nobody to complain to; what happens to a car when it's no longer viable; who's to blame if the car is involved in an accident?

Technologies such as Blockchain can address every one of these concerns by allowing cars to collaborate with each other and to form coalitions with buying power, clout, and economies of scale. Blockchain enables transactions for self-service to be conducted with other human or non-human entities, such as an automotive repair shop; the AV can even sell itself off for parts and distribute the proceeds to its owners when demand for its services dips below a profitable threshold; and, just like a human, it can have insurance coverage and funds to pay for damages or liabilities.

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Depending on how profitable any particular AV is, you could move your stake from car to car based on which ones perform best. Pools of cars could join forces to create their own AV corporations and build in redundancy to increase profit margins and return to owners, they could even build a brand image for themselves.

While the notion of cars that own themselves may seem far-fetched, there is no practical reason why this cannot be done. The technologies needed to do this exist today. Refinement will no doubt be needed but there is nothing extraordinary about what we're describing. In fact, in developing parts of the world where individual ownership is economically inconceivable, or where the overhead needed to introduce an industrial era model of corporate ownership is economically unattractive, this may be the only economically viable model to bring the transportation needed to build a thriving economy for ten billion people.

One last point, on the topic of replacing humans. To those who insist that humans must be involved we can only say, "Look at the history of that same sentiment over the past two-hundred years." Not only have we been consistently wrong about the inability of machines to replace humans, but we have also been wring about our inability as humans to find more

valuable and meaningful work to apply ourselves to.

The percentage of unemployment in the developed nations of the world has certainly experienced oscillations throughout the twentieth century, but there is no long-term upward trend. The USA experienced five percent unemployment in 1920 and 6.2 percent in 2014. The UK entered and exited the twentieth century with five percent unemployment.[14]

It seems that we're outstanding at describing how technology will replace humans, but we consistently fail to predict how it will create new jobs. That's because we fail to appreciate the scale of the new prosperity that it will enable. For instance, the tremendous success of the automobile, and the industries it spawned, created far more jobs than it ever eliminated by replacing the carriage and horse.

There's no doubt that AVs will do the same.

14 US Census Bureau, *20th Century Statistics*, accessed October 2, 2017, https://www.census.gov/prod/99pubs/99statab/sec31.pdf

Interior of the Mercedes Benz autonomous concept car at the 86th International Geneva Motor Show in Palexpo, Geneva, March 1, 2016
Photo: jvdwolf / 123RF Stock Photo

A Radical New Vision of Personal Mobility

While we have no doubt as to the long-term trajectory of MaaS, we are just as sure of the disruptive threat it will pose to a century-old industry that is well-entrenched and ensconced in an employment, business, and cultural model that may seem immovable. However, the economic factors that will drive the changes we have outlined will be impossible to ignore.

1. Insurance companies will adjust models for insuring human-driven vehicles, making car ownership a financially unviable model for individual owners.

2. The transition of the automobile from a form of transportation from point A to point B to a form of entertainment and socialization will create a new platform for the delivery of content and media.

3. Autos will function as vehicles for socialization in which people connect and gather. Some will be mobile conference and meeting rooms, others mobile restaurants and clinics. Commute time will cease to exist and along with it untold hours of lost productivity.

4. The AV will finally allow de-urbanization and decongestion of urban city centers, which are today littered with automobiles that occupy valuable land. For example, in the typical large city 50% of the land area is dedicated to roadways and parking.

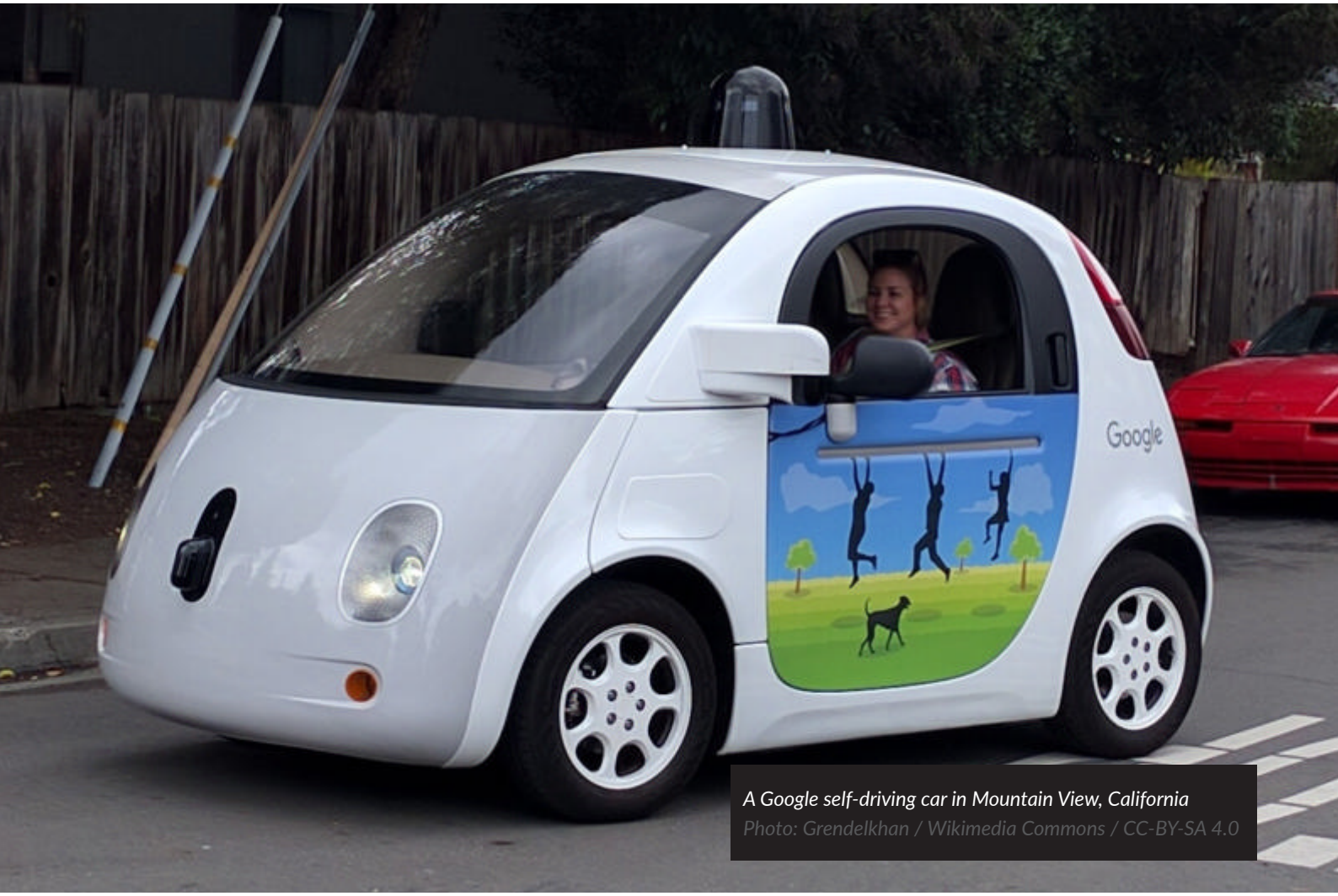
5. According to the National Safety Council the cost of motor-vehicle deaths, injuries, and property damage in 2016 was $432 billion[15] in the USA alone. If AVs do for vehicular transport what Flight Management Systems did for air travel we could reduce that by 99%.

6. The evolution of EVs and AVs will vary significantly from geography to geography and country to country. While commercial TaaS infrastructure will likely develop quickly in developed countries such as the USA, individual non-ownership-based MaaS is likely to take longer. The inverse is true of developing countries, such as India, which will have a higher economic incentive and regulatory latitude to move to MaaS.

7. We expect employment disruption by MaaS within developed countries that rely heavily on both the manufacture of ICEVs and of transportation.

15 Kirsten Korosec, "2016 Was the Deadliest Year on American Roads in Nearly a Decade," *Fortune*, February 15, 2017, http://fortune.com/2017/02/15/traffic-deadliest-year/

8. And lastly, let's not forget the potential impact of vehicles on global pollution and climate change. According to a study by NASA, vehicles are the single largest contributor to climate change.[16] While we've projected in Figure 6 the longer-term increase in overall energy utilization, a 90 percent reduction in the number of vehicles and a shift from fossil fuels to renewable energy sources would have a profound impact since 28 percent of all carbon emissions in the USA are from transportation[17] and the carbon footprint to manufacture an automobile is as great as that of operating it.[18]



A Google self-driving car in Mountain View, California
Photo: Grendelkhan / Wikimedia Commons / CC-BY-SA 4.0

16 Zachary Shahan, "NASA Says: Automobiles Largest Net Climate Change Culprit," *CleanTechnica*, February 23, 2010, https://cleantechnica.com/2010/02/23/nasa-says-automobiles-largest-climate-change-culprit/.

17 "Sources of Greenhouse Gas Emissions," *United States Environmental Protection Agency*, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

18 Mike Berners-Lee and Duncan Clark, "What's the carbon footprint of ... a new car?" *The Guardian*, September 23, 2010, https://www.theguardian.com/environment/green-living-blog/2010/sep/23/carbon-footprint-new-car

As a result of these irreversible economic factors and new market opportunities, we expect a global shift to MaaS during the next 30 years. The timeline will be approximately as follows:

Present to 2020 – Disruption

This period will be characterized by a great deal of legislative and business model disruption. We expect a hybrid market where all types of vehicles (ICE/EV/AV) will compete based on differing value propositions. The economics of EV/AV ownership will still be subject to a great deal of variation as traditional vehicle manufacturers and consumers co-exist. Ride-sharing will continue to expand its footprint and impact and AVs will amplify this. The impact on employment in the transportation industry will begin to raise concerns about displacement of workers within the commercial transportation sector. However, all of these factors will only incrementally impact the overall transportation sector.

2021 to 2029 – The Hand-Off

During this period, the economics of EVs, the acceleration of AI and its use in AVs, the large-scale deployment of AVs in ride-sharing and commercial transport, and the emergence of irrefutable evidence as to the safety of AVs will start to make the insurability of human-driven vehicles more expensive and begin to diminish their attraction to even their most diehard proponents. At the same time the demand for transportation in developing countries will exceed the ability to supply traditional transportation through individually-owned vehicles. EVs battery technology will dramatically improve the business model and affordability of EVs. Most notably, EVs on the road will exceed ICEVs for the first time.

We also see this as the most critical decade for the evolution of MaaS in developing countries, which will need to decide on how to scale their transportation infrastructure to accommodate the needs of a burgeoning and aging workforce. Based on global population pyramids, the largest percentage rate of growth will occur in the over 60-years-old age group. In fact, for the first time in history, the global population of the over-65 age group has exceeded the five-year-old and younger age group. The challenge is that this older age group has historically not been as mobile due to retirement and health. Both factors are changing with retirement being pushed out or eliminated altogether and work-life expectancy approaching a convergence with life expectancy by 2100. Mobility will be critical to keeping this aging population an active part of the workforce and the economy.

This period will also create the final tipping point for acceptance that the safety of an AV far surpasses that of a human-driven vehicle. That will finally start to detach us from the cultural legacy of the automobile. For example, it's easy to imagine scenarios where parents will be glad to have their child in an AV rather than a car driven by a family member, a friend, a third-party transportation service, or, in the extreme, by another 16- or 17-year-old child! Since that will define the cultural framework for this generation of children who have never known a human-driven experience, it is entirely expected that they will see no need to become drivers. In fact, they will come up with myriad reasons why not to.

2030 to 2035 – The Drop-Off

With the number of EVs finally overtaking the number of ICEVs on the road, a shift in greater affordability of an EV over an ICEV, the tipping point for ICEVs and human drivers will have been reached. While at the start of this period the number of vehicles on the road will increase, it will soon peak and then start its decline, slowly at first but then accelerating towards the end of this period. In many ways we regard this period as the most critical global shift in establishing the final move from individually-owned vehicles to MaaS.

2036 to 2050 – The Take-Off

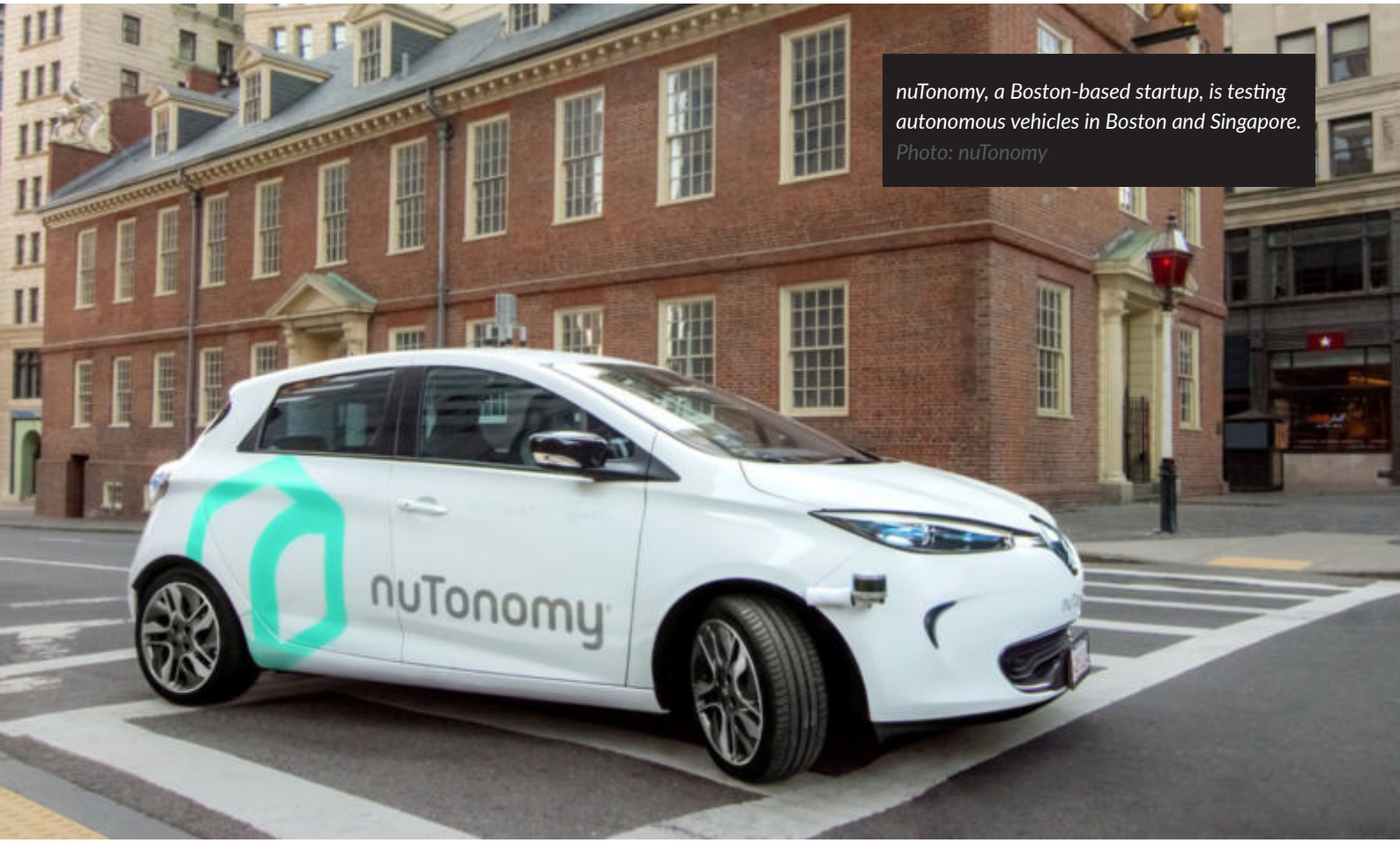
The transition to the EV/AV platform will have reached well beyond an economic and cultural tipping point. At this stage the new cornerstone players will have emerged, fleet turnover from an ICEV to EV/AV will be complete, human-driven will be a novelty, and utilization rates will skyrocket as the number of vehicles declines precipitously.

New Beginnings

The forces we have described are just the foreseeable ones. As with any shift of this magnitude, it is clear that the opportunities of MaaS are far greater than we can currently envision. So too is the disruption that MaaS will bring as we reengineer not only the automobile but also one of the world's largest industries.

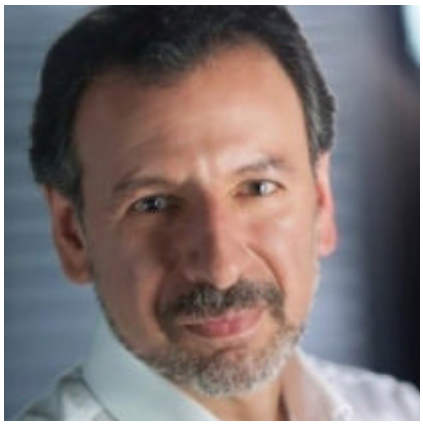
Still, the inevitability of this shift is clear. The human-driven automobile has become an icon of economic progress and a cultural expression of freedom and status. Yet, the price paid for both has been steep when measured in the impact on human lives and the ecosystem.

Continuing to scale the current model of transportation is simply not sustainable. The mandate is irrefutable; MaaS will not only positively alter the economy but will fundamentally enhance our environment and the very human experience of how we live, work and play.



nuTonomy, a Boston-based startup, is testing autonomous vehicles in Boston and Singapore. Photo: nuTonomy

About the Authors



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Meta

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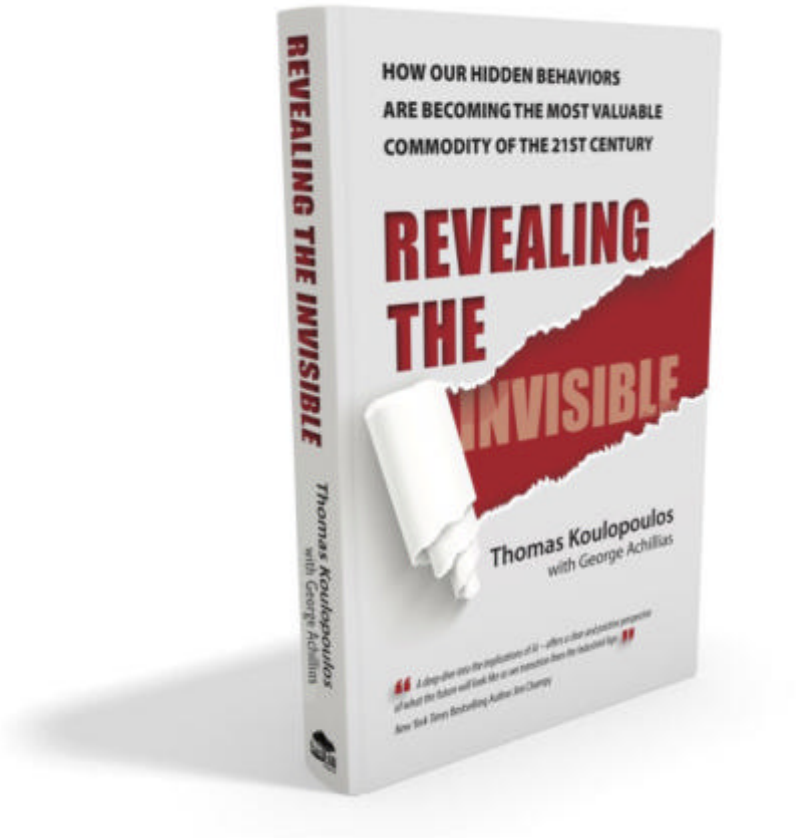

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