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Driving the Future

A Scenario for the Rapid Growth
of Electric Vehicles

Authored by the Gutierrez Energy Management Institute in collaboration with UH Energy

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EXECUTIVE SUMMARY

Several major technical and social trends are converging to improve the prospects for rapid penetration of electric vehicles in the light duty vehicle market, displacing internal combustion vehicles. Over the last year, significant technology advances have occurred in four areas – vehicle electrification, widespread charging networks and fast charging technology, renewable electric power generation, and autonomous vehicle technology. While the impact of each of these individually is significant, collectively they now appear to create a plausible scenario for a very different transportation future.

In addition to technology advances, several trends in government policy and regulations around greenhouse gases and other polluting emissions, as well as societal concerns around urban congestion and increased interest in shared mobility, support the growth of electric vehicles, or EVs.

The benefits of widespread adoption of EVs are also becoming clearer. These include lower cost and safer travel. EVs can also provide an improved travel experience and better access for mobility-challenged populations. Beyond these direct benefits, widespread use of EVs will reduce road construction expenditures by increasing road capacity and lead to more efficient land use due to the need for fewer parking spaces.

These advances and trends support the rapid penetration of EVs into the market for light duty vehicles (LDVs), and there are many potential benefits from the transition. Significant additional progress is required in many areas, however, and the likely pace of change in those areas is uncertain.

Invited leaders from the energy, finance and other fields recently met to consider these challenges at a symposium and workshop hosted by the Gutierrez Energy Management Institute at the University of Houston, C.T. Bauer College of Business. The group included about 40 high-level executives and thought leaders from the oil, gas, power and renewable energy sectors, as well as investment banks, think tanks and nonprofits. UH was represented by faculty from the business, engineering and law schools, as well as business school students. The event was held under Chatham House rules.

Participants worked in small groups to identify the key drivers of EV penetration, producing a high level of agreement on the nature and breadth of the important drivers of growth of battery electric vehicles. The five most important identified drivers include continued vehicle technology advances, increased availability of clean electricity and infrastructure, growth in consumer preferences for EVs, continued government policies supporting EVs, and government policies to deal with negative indirect consequences of rapid EV penetration.

Symposium participants were then presented with a rapid-penetration scenario where, by 2040, electric vehicles would represent 100% of new vehicle sales and comprise over 50% of the global light duty vehicle fleet. Each of the five groups created a potential path to that outcome. There were four main conclusions:

- The probability of a rapid penetration outcome has increased.
- There are multiple paths to that outcome.
- The paths to the rapid penetration outcome are likely to be different for the key regions (U.S., Europe, China, India).
- The full benefits of electrification of the transportation sector will come with a complete revolution in the way people move from one place to another, which may not occur quickly unless the benefits are evident and compelling.





Almost all global automakers are launching a large number of new electric models in 2019 and 2020. While the first wave of EV models were mostly small cars, the next wave will be focused on larger cars, including sport utility vehicles.



CONVERGING TRENDS

Several major technical and social trends are converging to improve the prospects for rapid penetration of electric vehicles in the light duty vehicle market, displacing internal combustion vehicles (ICVs).

Technology Trends

Over the last year, significant technology advances have occurred in four areas – vehicle electrification, widespread charging networks and fast charging technology, renewable electric power generation, and autonomous vehicle technology. While the impact of each of these individually is significant, collectively they now appear to create the possibility of a very different transportation future. Electric vehicles costs will soon be competitive with comparable ICVs. Extended EV range and widespread fast-charging networks will make EVs as convenient to operate as ICVs. Competitive costs for renewable electricity generation will allow electric vehicles to contribute to reducing polluting emissions and greenhouse gases (GHG). Finally, vehicle automation technology will provide the opportunity to reduce congestion and travel times, even as passenger-miles increase due to population growth and greater travel convenience.

LDV electrification

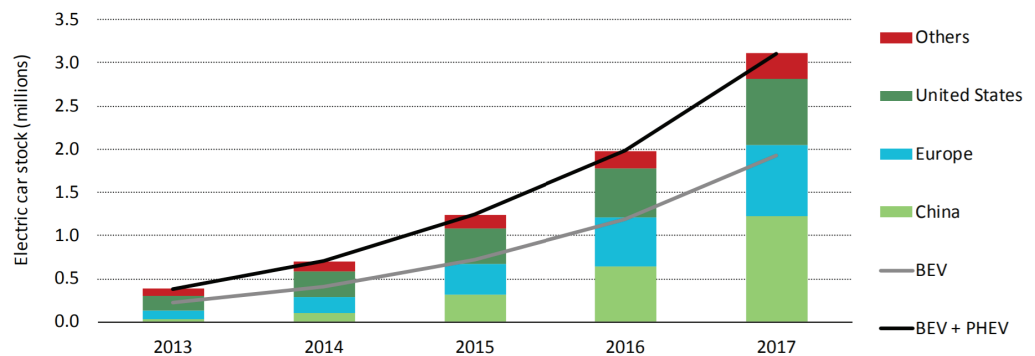
The initial electrification focus was on hybrid vehicles, which is now a mature segment.

Next were plug-in hybrids, which introduced externally-generated electricity to vehicles but kept internal combustion capabilities to reduce range anxiety. Finally, the focus has shifted to fully electric vehicles.

There have been significant advances in LDV electrification in the last few years. Lithium-ion batteries are at the center of these advances. Since 2010, prices have dropped 79% and battery energy density has improved by 5%-7% per year. The price of the average lithium-ion battery pack has fallen from \$1,000 to \$209 per kilowatt hour (kWh) from 2010 to 2017.¹

In response, automakers have dramatically increased their commitments to electrification over the last 18 months. Almost all global automakers are launching a large number of new electric models in 2019 and 2020. While the first wave of EV models were mostly small cars, the next wave will be focused on larger cars, including sport utility vehicles. This segment has grown quickly over the last few years and generally has higher margins, providing automakers more cushion until battery prices fall further. There are about 180 EV models on the market today. By 2021 this is set to rise to over 250 and based on automakers' statements, 47% of the new models will be in the SUV segment.² Several models with a range of 200+ miles have been introduced, ushering in a new era of higher-range EVs and

Figure ES 1 • Evolution of the global electric car stock, 2013-17



Notes: The electric car stock shown is primarily estimated on the basis of cumulative sales since 2005. Where available, stock numbers from official national statistics have been used (provided that the data can be shown to be consistent with sales evolutions).

Sources: IEA analysis based on country submissions, complemented by ACEA (2018); EAFO (2018a).



reducing what has been a major barrier to widespread adoption.³

Electric vehicle charging networks and fast charging technology

The lack of infrastructure to charge these electric vehicles has been another barrier, but EV infrastructure is emerging in many countries. Tesla's Supercharger network consists of more than 9,000 fast-charging points at over 1,200 locations, mainly in the U.S.⁴ BMW, Daimler, Ford and Volkswagen are developing the Ionity network of 400 charging sites along major highways in Europe by 2020.

Utilities are also establishing charging networks in the U.S., Europe and China.⁵ Fast-charging technology has also advanced. ABB is involved in several major electric vehicle charging networks. The company has recently unveiled a 350 kW electric vehicle charging technology, which it claims can add 200 km of range, or about 124 miles, in eight minutes.⁶

Renewable electric power generation

To realize the full environmental benefits of electric vehicles requires charging with electricity generated from low- or no-emission sources. That's been helped by significant cost reductions in wind and solar power generation due to 1) technology improvements; 2) competitive procurement processes; and 3) a large base of experienced, internationally active project developers.

Global wind capacity reached approximately 540 GW in 2017⁷, and solar reached 405 GW last year. On a global basis, the fall in electricity costs from utility-scale solar photovoltaic (PV) projects since 2010 has been especially remarkable. Driven by an 80% decrease in solar PV module prices since 2009 and reductions in other costs, the global weighted average levelized cost of electricity (LCOE) of utility-scale solar PV fell over 70% between 2010 and 2017, to USD 0.10/kWh.

By 2020, based on the latest auction and project-level cost data, the global average costs of the most cost-effective technologies could

decline to about USD 0.05/kWh for onshore wind and USD 0.06/kWh for solar PV, with solar overtaking wind in terms of installed capacity in 2019. Within the next year or two, the best onshore wind and solar PV projects will be delivering electricity for an LCOE equivalent of USD 0.03/kWh.⁸

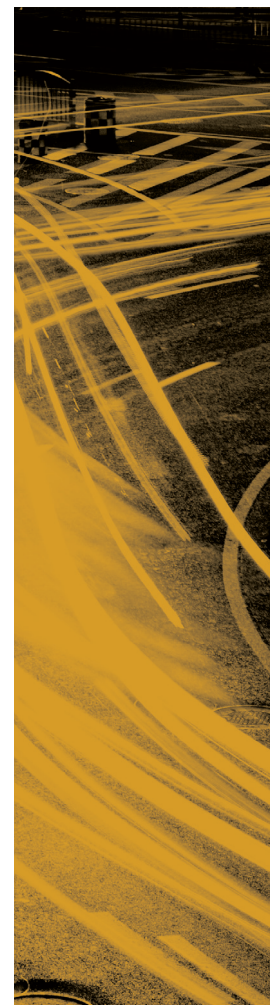
Autonomous vehicle technology

At the same time, autonomous vehicle technology is advancing. Today, the field for autonomous vehicles is diverse, from incumbent car manufacturers to electronic mapping companies to entrepreneurs—in total, 44 different corporations and over 250 startups are currently working on the technology.⁹

The U.S. Society of Automotive Engineers defines a full range of automation levels from Level 0 to Level 5. Level 0 consists of traditional vehicles without advanced driver-assistance systems to support a human driver. Levels 1-3 provide features to support the driver (steering, acceleration/braking) but require the driver to remain in control of the vehicle. Autonomous vehicles fall into Levels 4 and 5. Many automakers are developing Level 4 (Highly Automated) vehicles, whose driving is highly automated without human intervention in many, though not all, conditions. Other automakers are focused on developing Level 5 (Fully Automated) vehicles that can be highly automated in all conditions and may not even allow for human driver control.¹⁰ Several car companies, including GM, Volvo, Nissan and Ford, have announced that autonomous vehicles will begin appearing on highways as soon as 2021.¹¹

Government and Social Trends

In addition to technology advances, several trends in government policy objectives and regulations around GHG and polluting emissions, as well as societal concerns around urban congestion and increased interest in shared mobility, are supporting EV penetration.



Pressures to reduce GHG and polluting emissions

The Paris climate accord is an international agreement reached in 2015 aimed at reducing carbon emissions, slowing the rise in global temperatures and helping countries deal with the effects of climate change. Under the terms of the agreement, signatories committed to “holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.”¹² Accounting for population growth and increasing consumption as standards of living increase in developing countries, global greenhouse gas emissions would have to be reduced by 60%-80% versus a business-as-usual scenario.¹³

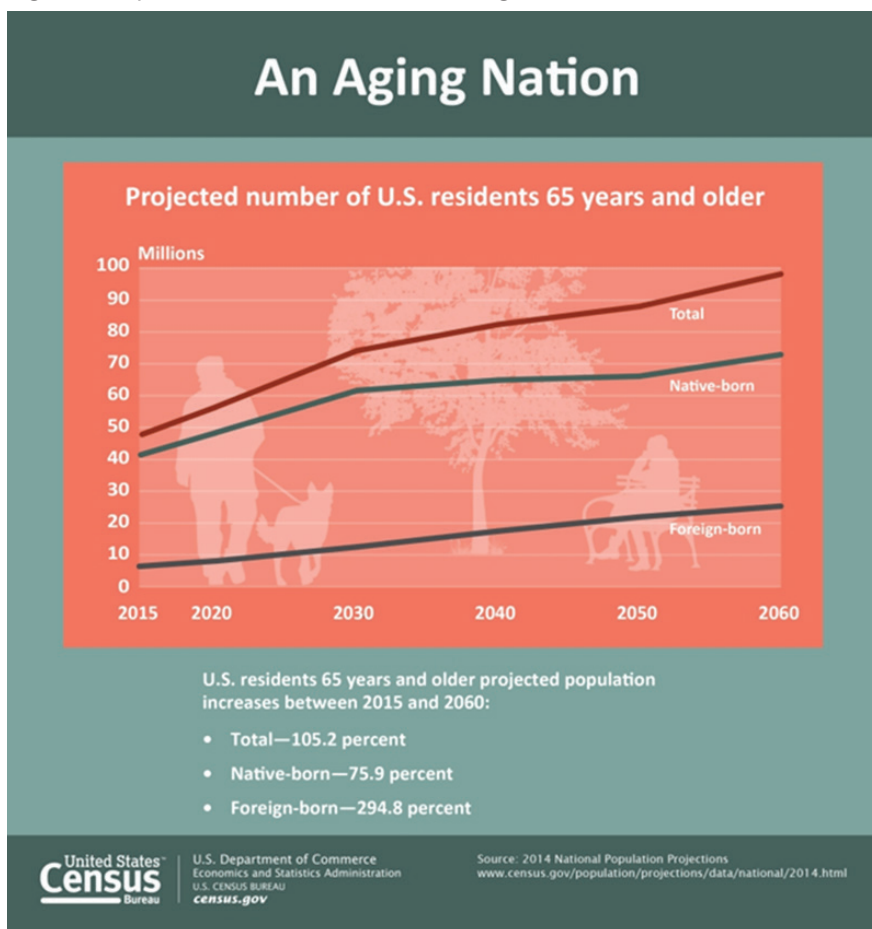
The transportation sector is a significant source of greenhouse gas emissions, ac-

counting for a quarter of U.S. greenhouse gas emissions.¹⁴ Despite the high energy intensity of battery materials mining and assembly, EVs today produce lower GHG emissions on a life cycle basis compared to internal combustion vehicles, unless the EVs use electricity produced exclusively from coal-fired power plants. Using the average U.S. electricity fuel mix, EVs produce 25%-30% lower GHG emissions per mile.¹⁵

With electricity generation emissions about two-thirds of the total EV life-cycle emission, the further potential reductions are large due to the de-carbonization of electricity generation with renewables.

EV penetration will also help reduce polluting emissions, including particulate matter, nitrogen oxides, carbon monoxide and unburned hydrocarbons, which will have significant benefits for public health and reducing air pollution.

Figure 1: A potential market for self-driving cars



Need to reduce urban area congestion

Congestion costs the U.S. about \$300 billion per year.¹⁶ With about 220 million drivers¹⁷, this cost is about \$1,400 per driver per year. Urbanization is expected to increase average city density by 30% over the next 15 years, stretching existing systems as demand rises.

Autonomous vehicles allow much higher speeds (up to 80 mph) with much lower spacing (two feet apart on dedicated lanes) and improved safety.¹⁸ Combined with shared mobility (specifically car sharing, ride hailing and ride sharing), a study showed that an autonomous taxi with dynamic ride sharing could replace 10 private vehicles.¹⁹

A study by the University of Texas estimates that if self-driving cars made up 90% of vehicles in the U.S., traffic delays would decrease by 60% on highways and 15% on suburban roads.²⁰

Increased interest in shared mobility

Shared mobility is a term used to describe transportation services that are shared among users.²¹ Examples include traditional services

such as public transit, taxis/limos and car-pooling, as well as new services including ride hailing, car sharing and bike sharing. Shared transportation has grown rapidly in recent years as a renewed interest in urbanism and growing environmental, energy and economic concerns have intensified the need for sustainable alternatives. Simultaneously, advances in electronic and wireless technologies have made sharing assets easier and more efficient. Shared mobility benefits include:

- More mobility choices, especially for those who cannot drive or afford to buy a vehicle
- Last-mile and first-mile solutions
- Reduced traffic congestion
- Reduced pollution
- Reduced transportation costs
- Improved efficiency

POTENTIAL BENEFITS

Advocates maintain that a major penetration of the LDV market by battery electric vehicles (BEVs) with autonomous capabilities powered by renewable energy would have significant benefits for consumers.

Lower travel cost

Higher vehicle utilization and ride sharing

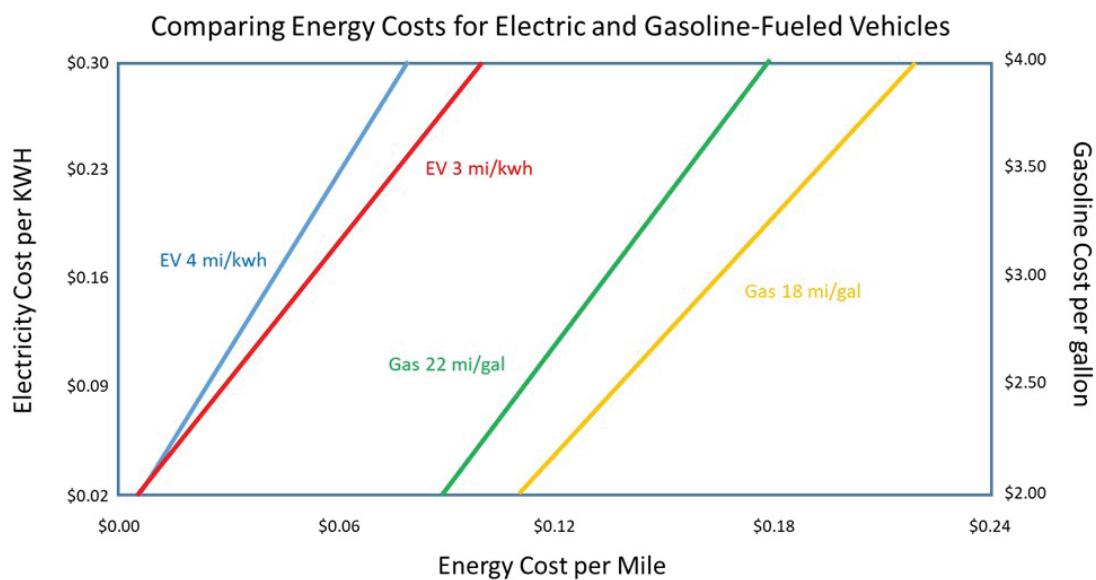
could significantly reduce capital cost per person per mile. Private cars sit idle, on average, 95% of the time.²² Google believes that shared, self-driving taxis could have utilization rates of more than 75%.²³ In terms of operating costs, energy costs given U.S. average gasoline and electricity prices are estimated to be about 50% less for EVs compared to internal combustion vehicles. In fact, with new EV models approaching four miles per kWh, an electricity price over \$0.30/kWh (nearly three times the current U.S. average retail price) combined with gasoline at \$2.00 per gallon, would be required for gasoline vehicles to be competitive at the current light duty vehicle fleet average of 22 MPG. Maintenance costs are also lower, due to the fact that EVs have about 40% fewer parts.²⁴ Even including battery replacement, maintenance costs for EVs are about 25% less than their internal combustion counterparts.²⁵

Safer Travel

A study by the nonprofit Eno Centre for Transportation estimates that if 90% of cars on American roads were autonomous, the number of accidents would fall from 5.5 million a year to 1.3 million, and road deaths from 32,400 to 11,300.²⁶ This would generate a substantial financial benefit in the form of reduced insurance costs. Drivers in the U.S.



A study by the University of Texas estimates that if self-driving cars made up 90% of vehicles in the U.S., traffic delays would decrease by 60% on highways and 15% on suburban roads.



Source: Idaho National Laboratory



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In most cities, curbside parking is considerably cheaper than off-street parking. As a result, an estimated 30% of the cars in central urban traffic flows are cruising for parking. This time cost could be essentially eliminated by autonomous, shared vehicles.

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spend over \$200 billion per year on automotive insurance,²⁷ an average of \$900 per driver per year. Assuming that insurance rates drop proportional to the reduction in automobile accidents, insurance costs would be reduced by 75%, or nearly \$700 per driver per year.

Better travel experience

Smart highways and connected vehicles with traffic optimization will significantly reduce average trip times due to lower urban congestion. It will also lower travel time “costs” by making travel time more productive. In most cities, curbside parking is considerably cheaper than off-street parking. As a result, an estimated 30% of the cars in central urban traffic flows are cruising for parking.²⁸ This time cost could be essentially eliminated by autonomous, shared vehicles.

Better access for mobility-challenged populations

Autonomous vehicles would significantly improve access to transportation for the elderly and disabled. By 2060, 100 million people in the U.S. will be age 65 and older. More importantly, the population of people aged 85 and over will more than triple to 20 million.²⁹ About 20% of the U.S. population has some form of disability, and 20% report that their disability makes transportation difficult; 45% have no access to a private car. It is estimated that an additional 2 million people with disabilities would be able to work with better access to transportation.³⁰

Lower road construction spending

Higher road utilization leads to less need for new road construction. The previously mentioned University of Texas study estimates that 90% penetration of self-driving cars in America would be equivalent to a doubling of road capacity.

More efficient land use

With cars in constant use, much less parking space would be needed. Parking space accounts for as much as a quarter of the area of American cities.³⁰ In auto-dependent cities like Houston, parking is the single biggest

consumer of land, and there can be 30 parking spots per resident in the city.³¹ Autonomous vehicles combined with shared mobility could conceivably free up substantial amounts of prime real estate for housing, green-space, or commercial uses.

CHALLENGES

Despite the benefits and the many technology advances to support the rapid penetration of EVs into the market, significant additional progress is required in many areas. The likely pace of change in those areas is uncertain.

Leaders from the energy, finance and other fields considered the challenges at the recent Gutierrez Energy Management Institute symposium and workshop.

Participants, working in small groups to identify what are likely to be most important to the growth of EV penetration, agreed on five key drivers:

Vehicle technology advances

Despite the recent rapid progress, further declines in costs will be needed to enable real mass market adoption. These are perhaps best illustrated by the technical targets for the U.S. Department of Energy (DOE) BEV R&D program,³² which fall into three areas with specific goals:

- Battery technology - reduce battery cost to \$125/kWh
- Electric drive system technology - reduce the cost of electric drive systems from \$30/kW to \$8/kW
- Vehicle light-weighting - eliminate 30% of vehicle weight

Meeting these goals would make the levelized cost of an all-electric vehicle with a 280-mile range comparable to that of an internal combustion vehicle of similar size. The DOE has a stretch goal of achieving these targets by 2022. Others believe EVs are on track to be fully price competitive with comparable ICVs beginning around 2024. Different countries



and vehicle segments will hit the crossover point in different years, but by 2030 EVs should be competitive in almost all segments.³³

Availability of clean electricity and infrastructure

While onshore wind and solar are becoming cost competitive with fossil fuels, significant investment in new renewable power generating capacity will be required to replace existing coal capacity and meet growing demand for electricity for EVs. While land access will continue to be challenging for utility scale wind and solar, the biggest challenge is likely to be cost-effective grid-scale electricity storage to manage time of day and weather-induced imbalances. In fact, many new wind and solar projects are now integrating various new large scale storage technologies. Significant investment will also be required in new fast-charging infrastructure. This infrastructure is likely to be distributed broadly with some at residential and commercial sites and some on highways, potentially using current gasoline and diesel fueling locations. There will also need to be significant investment in existing transmission and distribution infrastructure to manage changes in equipment heating and cooling requirements as traditional time of day demand patterns change. Battery recycling systems will need to be developed. Finally, the nature of the electrical grid and its management will fundamentally change. New mechanisms will be needed to manage much more complex electricity flows in a more distributed grid, especially if EVs become a significant part of the storage solution. New pricing mechanisms will be required to help balance grid loads and optimize supply and demand.

Consumer preferences

EVs are gaining in popularity today due to reduced environmental impact, on-road performance (excluding range) and lower operating costs. However, a rapid penetration scenario probably requires rapid growth in self-driving vehicles which will require the demonstration

of the safety of autonomous vehicles and their benefits in terms of reduced travel time. Broader acceptance of shared mobility systems and reduced private vehicle ownership beyond the millennial generation will also be required. It is easy to imagine conflict among ride sharers with different travel behaviors.

Government policies for EVs

EV penetration so far has been supported by significant government incentives. These vary by country but include mandates (emission targets, vehicle quotas) as well as incentives (purchase subsidies, favorable lane and parking access, free charging, reduced costs for licenses and tolls). Some level of continued government intervention will likely be required to achieve rapid penetration, but this is highly dependent on the pace of progress on the other key drivers.

Indirect consequences that may require government action

A significant energy transition will require government policies to address several categories of indirect consequences:

- Reduced vehicle demand - Ride sharing, ride hailing and car sharing could reduce vehicle demand significantly, although ride-sharing fleets will turn over faster than the general car population. This will significantly impact automobile manufacturing and supply chain employment. Initially this will be most pronounced in developed countries where the peak in total fleets would come earlier while vehicle fleets in developing countries would continue to grow for some time.
- Simpler vehicle design - EVs have far fewer parts than ICVs; one estimate puts these at around 18,000, compared with 30,000 for a conventional vehicle,³⁴ translating into a smaller number of jobs to produce and maintain electric vehicles, compared to those required for a traditional fleet.
- Reduced demand for taxis and traditional mass transit - EV travel will significantly



reduce demand for traditional taxis and mass transit, resulting in lower employment in those sectors.

- Reduced demand for fossil fuels – The substitution of EVs powered by renewable energy will reduce demand for oil and coal, reducing employment and potentially stranding assets in those value chains. In addition, at some point it would become economically prohibitive to keep traditional retail gasoline sites open, which would create fueling challenges for the remaining ICVs.
- Increased demand for batteries and electric motor components – Many components are mined in nations with low levels of environmental and safety standards or extant political conflict (e.g. cobalt mining in the Democratic Republic of Congo). This may prompt calls for increased scrutiny from consumers, boycotts of companies that source materials from these nations, or broader geo-political conflict between EV-producing companies or nations seeking increased access to these minerals.
- Loss of government revenue – The loss of gasoline sales tax revenues will be significant in many countries and will need to be replaced.
- Transition challenges - Managing the transition when autonomous and human-directed vehicles must share the roads will require government policies with respect to liability, insurance and cybersecurity.

RAPID PENETRATION SCENARIOS

Symposium participants were then presented with a rapid-penetration scenario where, by 2040, electric vehicles would make up 100% of new vehicle sales and comprise over 50% of the global light duty vehicle fleet. Each of the five groups created a potential path to that outcome. High level differences in the paths were insightful. In terms of the two most important drivers (those with the most

importance and the highest uncertainty/degree of difficulty), the five paths had the following focus:

Paths	Most Important Drivers
One	Government Policies for EV's Consumer Preferences
Two	Consumer Preferences Government Policies for EV's
Three	Government Policies for EV's Vehicle Technology Advances
Four	Consumer Preferences Availability of Clean Electricity and Infrastructure
Five	Government Policies for EV's Consumer Preferences

CONCLUSIONS

There were four main conclusions from the symposium:

Probability of a rapid penetration outcome has increased - A collective sense emerged that trends in these key drivers seem to be converging to make a Rapid Penetration Outcome more plausible than just a few years ago.

Multiple paths to a rapid penetration outcome – The symposium identified several different paths that could lead to the high penetration outcome. In general, both market/consumer driven and government mandate/incentive driven paths are possible.

Regional differences – The consensus was that the paths to the Rapid Penetration Outcome were likely to be different for the key regions (U.S., Europe, China, India). Consumer and market drivers were expected to be more important in the U.S., while government policies were more likely to dominate in other countries.

Managing the transition – The full benefits of electrification of the transportation sector come with a complete revolution in human mobility practices, which will be difficult to change quickly unless the benefits are evident and compelling.



FOOTNOTES

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