

## Autonomous vehicles - the future of electric mobility?

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### Abstract

While there is great interest in predicting market prospects for electric vehicles, most results to date have been notoriously inaccurate. A better approach, set out in the present paper, may be to look at broader social trends and consider a wider range of vehicle systems and personal mobility models. Following clear trends in military vehicle technology, this model may well show an increased shift to autonomous vehicles which offer many advantages of energy efficiency, improved driver and public safety and reduced GHG and other emissions. The rationale for this trend, along with a survey of the technology and some predictions for the future are discussed?

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### 1 Introduction

As author of several reviews[1],[2] on the technology and market prospects for electric vehicles, the author has witnessed the wild swings in the fortunes of the electric vehicle (EV) industry. As luminaries ranging from Neils Bohr to Yogi Berra have noted "Prediction is very difficult, especially if it's about the future". This has especially been the case with electric vehicles where a diverse range of forecasts for EV adoption can be found, depending on the basic assumptions in the model.

Clear demographic trends predict that the bulk of the global population of more than 9 billion by 2050 will be largely city dwellers which will cause serious challenges for traditional vehicle technologies and transportation infrastructure. Already our cities in the industrialised world are experiencing traffic gridlock, with even more serious impacts in cities in the developing world, causing increased accident risk and serious impacts on public health. One obvious solution to this problem is an increased use of public transport, preferably driven by electrification[3]

but the lack of transport infrastructure and a strong personal attachment to the motor vehicle is a major challenge, especially in North America.

Yet with the impending challenge of climate change, the traditional passenger vehicle with one ton of steel carrying a single passenger an average daily commute of less than forty miles makes poor economic sense and even less environmental logic. As we have seen, vehicle forecasts are highly sensitive to unexpected events such as the global financial crisis of 2008 and this may be one cause of the changing public perceptions on personal mobility. By 2050 the global population will have increased by a further 3 billion, almost all located in the developing world and who will be seeking some affordable form of transportation. This may be one of the main factors causing a shift in the public perception of a vehicle. The old adage of "horses for courses" may well, in fact, lead to a different concept of the automobile? There is considerable evidence that this vision may well be the Microcar or its ultimate configuration, the Autonomous Vehicle.

## 2 Catch 22 for EV Industry

Until quite recently, market forecasts for the EV industry were largely focused on two main drivers; increasing oil prices and decreasing costs of lithium batteries. The competitiveness of EVs vs. ICEs (internal combustion engine) was elegantly summarised by McKinsey[4] in their model that relates gasoline prices and lithium battery costs in \$ per kilowatt hour to demonstrate market viability for various classes of EVs. This model reflected the assumption that oil prices would continue to rise, driven by the Peak Oil scenario with its implication of a shift from large quantities of cheap oil to scarce supplies of expensive oil. At the same time, battery prices would continue to fall based on technology advances and economies of scale achieved through volume production.

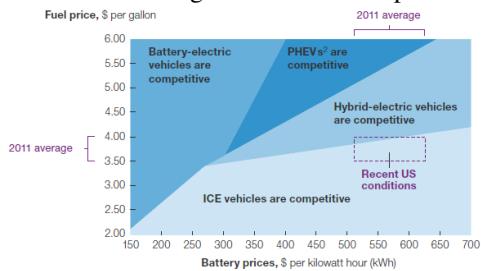


Figure 1: Market viability of EVs as a function of battery and fuel prices

This scenario has failed to materialise since, on the one hand while supplies of conventional, easy oil are still diminishing, there has been the discovery of vast reserves of alternative fossil fuels such as shale gas and tar sands that are keeping oil prices low. In contrast, while lithium battery prices have been predicted to fall to as low as \$200/kW by 2020 this target may also be optimistic. The failure of several lithium battery companies, along with high cost of infrastructure including for many plants the cost of controlling solvent emissions may make this goal difficult to achieve.

There are several approaches to addressing the high cost of batteries; the first is to use a business model where ownership of the car and battery are separated such as the service model introduced by the lately lamented Better Place[5]; another alternative is to downsize the vehicle along with the battery. The latter approach is reflected in the emergence of Microcars[6].

Projections that battery performance will dramatically improve in the near term with new battery chemistries or the emergence of lithium-

air or zinc-air technologies may be optimistic despite BMW's recent forecast that EVs will have batteries with twice the power within 4-5 years. A more reliable strategy may be to reduce the size and weight of the vehicle requires a smaller battery which will also take a correspondingly shorter time to charge.

Additional drivers for the EV industry includes pressures on automakers to reduce CO<sub>2</sub> emissions (Europe and Asia) and increased fuel efficiency in North America.

## 3 The Challenge for the Emerging EV Industry

### 3.1 Gridlock

Even more of a threat than oil or battery prices is the rising incidence of gridlock. Presently, half of the global population live in cities and this is predicted to increase to over 70% by 2050. At the same time the number of vehicles is expected to rise fourfold, from 1 to 4 billion. In an address to the World Mobility Congress in Barcelona[7], Ford Motor Chairman, Bill Ford described the company's "Blueprint for Mobility". Noting the change in the transport landscape Ford warned about the dangers of global gridlock. In several cities including Sao Paolo traffic jams regularly exceed 100 miles and the average commute lasts between 2 and 3 hours a day while in Beijing, in 2010, the world's longest period of gridlock was recorded at 11 days. Ford urged carmakers to work with governments and industries such as telecommunications to find solutions to urban congestion and that failure to do so could risk many of their products becoming obsolete.

On the same theme, Chris Borroni-Bird, General Motors' director of advanced technology vehicle concepts noted that "we know from the US and Europe that vehicle ownership and usage are affected by population density". "As cities become more densely populated, the appeal of owning a car is threatened because of the lack of parking, congestion and viable alternatives such as public transport[6]". The problem is not restricted to the near mega-cities of the developing world. In the UK it is estimated that by 2025 the cost of congestion to the economy through lost time will reach \$35 billion.

However, as this paper sets out, one approach to mitigating the effects of gridlock could be through a shift to smaller, more environmentally sustainable vehicles which includes both Microcars and Autonomous Vehicles.

### 3.2 Achieving GHG Emission Reduction Targets

Various studies[8] have warned that in order to achieve a competitive low carbon economy by 2050 and limiting global warming to 2°C, that transport-related emissions of GHGs should be reduced to around 60% of 1990 levels. Achieving this goal while the number of road vehicles increases fourfold is a daunting task and can only be achieved by a wholesale shift to electric vehicles or some as yet undefined non-fossil fuel technology.

However, given the glacial speed of reaching a global accord on a strategy to address climate change, the time to think seriously about achieving this goal may well have passed. A search for adaptation strategies to manage substantial global warming may be more appropriate.

## 4 The Solutions

Despite this somewhat gloomy outlook, there may be some promising potential solutions for reducing the carbon footprint of the transportation industry.

### 4.1 Microcars

Downsizing vehicles, especially passenger vehicles, is one approach. Microcars, the smallest automobile classification have been around for over half of a century with the earliest examples emerging from the German aero industry after the WWII with models such as the Messerschmitt KR200, the Heinkel Kabine and the BMW Isetta. More recently the brand has undergone a revival caused by changing trends in personal mobility, an increasing shift to urban living along with pressures for reduced emissions and increased fuel efficiency. A recent study by Frost and Sullivan[9] indicates that most of the top 10 automakers have plans to introduce Microcars to the market. Their data shows that some sixty new models will be launched into the European market by 2014. It is also likely that many of these new vehicles will be either hybrid or pure battery-powered.

One of the forerunners of the Microcar revival is the original Smart Car, the brainchild of visionary Swatch founder, Nicholas Hayek. As originally conceived by Hayek the Swatch car was a gasoline-electric hybrid but after the merger with Mercedes, the design was changed to a gasoline ICE. It is interesting to note that the vision has now come full circle to Hayek's

original concept with the launch of the all-electric E-Smart and the Smart Forvision.



Figure 2: The Mercedes Smart Forvision

The emergence of Microcars is also providing an ideal proving ground for testing new materials. Aluminium, steel/aluminium composites, carbon fibre and plastics, will soon transform the mainstream auto industry. Lightweight design requires replacing heavy metal parts with composite materials that can serve the same function while providing equivalent strength and stability. There is a clear trend towards partnerships between auto companies and chemicals companies, such as that between Mercedes and BASF, that has resulted in the development of Ultramid[10], a thermoplastic polymer composite that is used for engine mounts and wheel rims in the Smart forvision

Heating and air-conditioning systems in vehicles are major consumers of energy. However, the amount of energy required can be reduced with the help of a temperature management system that uses polymer films in the windows to reflect thermal radiation and high performance insulating materials in the interior. Other ideas include energy harvesting systems such as flexible solar panel roofing, thermoelectric generation and engine encapsulation.

Microcars are true examples of minimalist engineering and combine many desirable features such as economy, ease of driving and especially parking. Moreover, they bring back real character to the driving experience as can be seen with models such as the SAM EV from the Swiss Group Cree.



Figure 3: The SAM EV ([www.Cree.ch](http://www.Cree.ch))

It is also important to note that many innovative players in the Microcar space have faced problems surviving in the recent challenging economy, including Aptera, Elettrica, Reva, Tzero, Think, Tango and more.

Meanwhile the major players such as BMW are making major investments in the market. Their two new ventures in this space, the hybrid i8 and the all-electric i3 are part of the company's sub-brand that are described as a megacity vehicles. GM, Volkswagen and Honda are developing microvehicles for big cities, including scooters, bicycles and electric cars. In 2012, VW unveiled the NILS, a single-seat electric concept car just 3 m long and 0.39 m wide that it is claimed could meet most German commuters' needs.

## 4.2 Driverless Vehicles

### 4.2.1 Autonomous Road Vehicles (ARVs)

The idea of driverless vehicles has long been a staple of science fiction, but real-world demonstration of the technology dates back to the 1939 New York World Fair where General Motors showed their Futurama exhibit where vehicles interacted with the highway. ARVs have also been a hot topic since the 1980s but were given a huge boost in October 2010 when Google announced that it had built an autonomous vehicle. cars and that these have been safely driven over 700,000km of US roads. They have achieved this target with the help of control and navigation systems that processes almost one gigabyte of data every second. This groundbreaking project was carried out in collaboration with Stanford University Artificial Intelligence Laboratory. A comprehensive survey of the field has been presented by Gilbert[11].



Figure 4: The Google Autonomous Vehicle

In one convincing demonstration, Google posted a video of a legally blind passenger being picked up in its self-driving Toyota Prius, being driven to a drive-through restaurant and finally back home[12]. The feasibility of the technology was dramatically demonstrated when a Google ARV picked up a legally blind passenger, delivered him to a local pizza restaurant and then safely transported him home.

There are clear signs on how the industry will evolve. First, there are ARVs which will be operated in restricted zones such as Eco-cities such as Masdar or Dongtan or in airports like the award-winning Personal Rapid Transit at London Heathrow Airport Terminal 5.



Figure 5: The UltraPod at London's Heathrow Terminal 5

The next stage, which is already well underway, is to deploy ARVs on public roads with a rapid transition from manual to partial automation to fully autonomous operation. In fact many modern vehicles are already partially automated and some of the key elements of the ARV concept have been around for some time. Several companies, Volvo, Mercedes and Lexus all have "driver-alert" systems that can detect when a driver is getting sleepy; automatic parking is now an option on

many production vehicles along alarm features such as blind-spot detection

In one sense ARVs represent the transition from large, spacious, powerful, long range vehicles to compact, lightweight, electric-powered, pollution free transport designed to meet the needs of emerging megacities.

While the technology and market potential of ARVs would seem to have been convincingly demonstrated the industry still faces some major barriers. Foremost is the fact that ARVs have largely been ignored by transport infrastructure planners such as the OECD[13] and the World/Asian Development Banks[14]. However, there is a strong probability that ARVs may well become a major feature of road traffic during the next few decades since they fit neatly into the criteria for transport infrastructure in emerging megaprojects.

ARVs open up opportunities for innovative design with the ability to replace traditional ICE components such as the mechanical steering mechanism, combustion engine, transmission and hydraulics. The inherent safety factors will also reduce the need for vehicles to meet the most stringent crash safety tests. Ultimately, their low cost derived from simple design and construction may allow them to replace a large portion of private passenger and public transport vehicles.

#### 4.2.2 Autonomous Taxicabs

It is a seamless transition from ARVs to Autonomous Taxicabs (ATs) which could easily provide some of the most important benefits of the technology. Having already been demonstrated by Google, a typical customer could order an AT with a Smartphone indicating pick-up and set down points, amount of luggage and willingness to share or require a private journey. After completing the assignment the AT would return to base or continue to its next passenger. Either way the AT approach would eliminate the need for parking

ATs might well offer a superior service to existing taxicabs since their interior space could be matched to the customer rather than the driver's needs. Additional customer-friendly services could include communication and news/entertainment features. The quality of the ride could also be superior since as roads become more populated with autonomous vehicles, traffic could be better managed with fewer stops, speed changes and resulting shorter trips.

The cost of ATs could also be significantly lower than conventional taxis since the cost of the

driver, which accounts for roughly two-thirds of a cab fare, would be eliminated. For fleet operators, ARV/ATs with their lightweight body shells and simple drive train would offer substantial reductions in both capital and maintenance costs.

#### 4.2.3 Personal Rapid Transit (Guideways)

Another option presented by the use of ARVs is Personal Rapid Transit on Guideways. In this approach, if feasible, electric traction should be powered by connection to the grid while in motion. This is standard practice with electric trolley buses and streetcars but now the option of inductive charging via buried cables in the roadway also exists. Electric buses that use opportunity charging wirelessly by induction are presently being tested in the Netherlands[15]. In addition to overnight plug-in charging, this system allows buses to receive a top-up charge by a 120 kW wireless inductive charging system within the space of a few minutes while at a bus stop.

Freight carrying ARVs either guided or autonomous could provide for revolutions in the way goods are moved. Autonomous local delivery vehicles (ALDVs) could carry out many operations currently carried out by mail or courier services provided the destinations were equipped to receive the standard containers. For reasons of energy supply and local and global pollution ALDVs may well move to electric traction. As with ATs, fleet management of ALDVs is ideally suited to electrification.

In 2012 the SARTRE project (Safe Road Trains for the Environment) was launched[16] led by UK engineering group Ricardo, and funded by the European Commission. In this pilot that deploys Volvo commercial vehicles, a lead vehicle with a professional driver is linked to a platoon of four following vehicles all of which are operated in the semi autonomous mode. The system was successfully demonstrated driving at 85 kmh with a 6M separation between vehicles over a route of several hundred kilometres. The estimated fuel savings with this system is approximately 20%.

Another approach for commercial vehicles is based on revival of a 100-year old technology, grid connection via overhead cables. While pure-battery powered commercial vehicles may not be economically viable, conventional traditional grid connection via overhead wires is highly feasible and in fact electric trolley trucks were operating in Germany over a century ago. Nowadays they are finding wide use in mines and other off road applications. Several pilot programs for on-road

trolley truck operation are currently in progress in Sweden and Germany[17].

#### 4.2.4 Benefits of ARVs

ARVs offer some real economic and social benefits including improving the quality of transport, reduced wasted labour and reduced need for parking facilities. Increased road safety is also a major potential benefit of ARVs since their wider adoption could dramatically reducing traffic fatalities. ARVs have the potential to virtually eliminate driver fatalities that for developed countries continue to be the leading cause of death for persons in the age group 15 to 25. In the developing countries where vehicle numbers are rising rapidly and where inferior vehicles, infrastructure and driver skills, road deaths are steadily increasing. Reduced operating costs will be another major benefit; since these vehicles will be smaller, much narrower and lighter and use far less fuel, either electricity or fossil fuelled vehicles where consumption could be an order lower than conventional ICEs at approximately 0.25 – 0.5 litres per 100 kM (at 50 kM/hr). Electric powered ARVs, especially fleet operators, would be able to take advantage of battery exchange strategies although fast charging may well be preferable, especially with the smaller battery packs involved.

The widespread adoption of ARVs would offer important benefits for transport infrastructure planning and investment. First, existing road space could be used much more intensively and efficiently, obviating the need for additional roads and road/bridge expansion. However, guideways, often elevated could be constructed to allow for reduced energy consumption and emissions, to separate road traffic from pedestrians and street activity and free urban space. Finally, energy costs of vehicle manufacture and infrastructure maintenance could be significantly lower, due mainly to the smaller size, lightweight construction, and in the case of EVs, the far fewer component parts.

### 5 The Future of ARVs

The development of ARVs has been spurred in a large part from research in the military and the mandate of the US Congress in 2001 that one third of all military aircraft were to be unmanned by 2010 and one third of ground combat vehicles by 2015.

As with any new technology, initial costs can be high. The Google driverless car, for example, includes a laser rangefinder at a cost of \$70,000. Researchers at Oxford University, however, have developed an alternative system that employs a laser scanner on the front of the car, and comparing its surroundings with its stored data[18]. This is different from Google's system which uses a combination of GPS, laser range-finding and mapping to determine its location and route. It is claimed that with volume production, the Oxford system could be retrofitted to existing cars at a cost of under \$150.

The two major barriers at present are first, safety and legislative approval and second insurance and accident liability. The National Highway Traffic Safety Administration (NHTSA) recently noted that ARVs should only be used for testing purposes by U.S. states while they explore safety issues in more detail. The agency has recommended that ARVs include a feature that recognizes when the control systems are failing and alerts the driver to take over.

On the question of insurance there is the debate over who is liable in the event of an accident; the passenger, the technician or the manufacturer. These questions should be resolved in due course without, hopefully, the need for a pedestrian and a red flag!

In summary, the future of ARVs is looking bright. "The future of transport is door-to-door mobility," says Sarwant Singh, a partner with Frost & Sullivan, "This will be led through more connectivity and convergence of the mobile information technology industry with the car industry, but will be largely enabled using the Smartphone." Peter Schwarzenbauer, Audi's head of sales notes that "I honestly believe we need a broader approach than just talking about the car". He adds; "I would call it a mobility system, and the car is just part of the whole issue".

Possibly through exposure to air travel and the aerospace industry reliance of autopilot control, more than half of global consumers appear supportive of the idea of a car controlled entirely by technology that does not require a human driver.



Figure 6: The Toyota concept i-Road

The auto industry is now entering an age where the convergence of electronics, telecommunications and software companies are redefining the traditional relationship of carmaker and supplier and creating the connected vehicle field. Perhaps one of the most serious endorsements of autonomous vehicles is that Elon Musk, CEO of Tesla Motors is considering adding driverless technology to its vehicles and has held discussions with Google[19]. Musk believes technologies that can take over for drivers are a logical step in the evolution of cars although he prefers the term autopilot to self-driving, in line with an airplane's operating system. He notes that "autopilot has proven a good thing to have in planes and we should have it in cars".

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