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URBAN ELECTRIC VEHICLES: A CONTEMPORARY BUSINESS CASE

Summary. In a world where energy supply security and environmental protection are major concerns, the development of green vehicles is becoming a necessity. The Electric vehicle (EV) is one of the most promising technologies that will make the "green dream" come true. This paper is a contemporary business case that encourages the immediate deployment of urban EVs. It proposes a model in which we can profit from the benefits of urban EVs namely, high energy efficiency, emissions reduction, small size and noise reduction. The model mitigates the EV potential limitations such as energy source, charging infrastructure, impact on electrical power system and cost issues. It also provides ideas to overcome the barriers of the technology application in order to speed up their commercialization. This study reveals that having an environmentally friendly vehicle can soon become a reality if our collaborative efforts are properly directed.

MIEJSKIE POJAZDY ELEKTRYCZNE: WSPÓŁCZESNY PRZYPADEK BIZNESOWY

Streszczenie. W świecie, w którym zabezpieczenie dostaw energii oraz ochrona środowiska to nasze główne problemy rozwój ekologicznych samochodów staje się koniecznością. Elektryczny Pojazd (EV) jest jedną z najbardziej obiecujących technologii, który sprawi, że „ekologiczny sen" się spełni. Niniejsza praca to współczesne studium przypadku biznesowego, który zachęca do natychmiastowego rozwijania miejskich samochodów elektrycznych EV. Oferuje on model, w którym można w pełni czerpać z korzyści miejskich samochodów elektrycznych EV a mianowicie z ich wydajności elektrycznej, redukcji emisji zanieczyszczeń, małych rozmiarów pojazdu oraz redukcji hałasu. Model ten łagodzi potencjalne ograniczenia dla EV, takie jak: źródła energii, zmiany infrastruktury, wpływ na system energii elektrycznej oraz kwestie finansowe. Dostarcza także pomysłów jak pokonać bariery technologicznych zastosowań celem przyspieszenia jego komercjalizacji. Badania dowodzą, że posiadanie pojazdu przyjaznego środowisku może wkrótce stać się rzeczywistością, jeśli nasze wspólne wysiłki zostaną prawidłowo ukierunkowane.

1. INTRODUCTION

High gasoline prices, global warming, pollution and dependence on foreign sources of oil are four major issues the world is facing today. In 2004, the transport sector consumed 30% of the total final energy consumption and it was responsible for 25% of CO_2 emissions [1]. Today, approximately 900 million vehicles worldwide are on the roads and there are estimates for the year 2020 that this number will increase to 1.1 billion [2], which will inevitably have consequences on oil demand and CO_2

emissions. Since this will have a negative impact economically, ecologically and politically, a strategy to replace fossil fuels as a source of energy for vehicles is urgently required. In this direction, the Electric vehicle (EV) is the natural vehicle evolution since, in addition to having very high energy efficiency it does not produce any harmful emissions. On the other hand, having alternative energy sources will reduce the nearly total dependency on oil.

This paper presents a contemporary business case for the electric vehicle; it proposes a business model for urban EVs intended for near-term deployment. Subsequently, their main advantages, namely, high efficiency, reduction of emissions, energy security, small weight and size, and noise reduction are discussed in detail. For a complete analysis, EV limitations and potential challenges like energy source concerns, charging infrastructure issues, impact on electrical power system and cost issues are analyzed. To support the case of urban EVs, a mitigation technique is proposed for each limitation and the commercialization aspects are evaluated. Finally, the current case of EVs is summarized and a recommendation is provided for the next step that should be followed to achieve the intended evolution in the current transportation system.

2. PROPOSED MODEL

A lot of literature is concerned with how EVs can compete with other vehicles (gasoline and other alternative vehicles) [3-5]. The author, however, believes that a competition with Internal Combustion Engine Vehicles (ICEVs) should not be the target at the current stage since; the ICEVs of today are the result of decades of high budget research and development. At the beginning, competition of EVs with conventional vehicles in all applications will not be possible so, at this stage we must define the niche markets that are feasible.

The proposed model is thus based on the main concept of using the right tool for the right distance rather than using ICEVs for all applications. Accordingly, the EV is believed to be mainly suitable for short-range low-speed transportation which includes urban automobiles, electric bikes and golf cars. The model will focus on urban electric vehicles used in large cities and urban centers where low-speed traffic is a typical characteristic. The scenario also matches with the motorists' driving habits especially the average distance traveled every day. Data collected by the National Personal Transportation Survey (NPTS) in 1995 indicates that the majority of US daily mileages are relatively short, with 50% of days being less than 30 miles (48 km) [6]. More optimistic results are reached in Germany where 90% of daily driving is in the range of 100 km [2]. Accordingly, the proposed model of an urban EV with 100 km (60 miles) range, 90 km/hr top speed and Lithium-ion battery will be the focus of this study. The following analysis investigates the various benefits and costs of the proposed urban EV and shows that it is a compelling business case that deserves to be examined and nurtured.

3. WHY ELECTRIC VEHICLES?

The EV is not just a car; it is rather a new sustainable system for our lives that will create a clean, efficient and cost-effective road transportation system. The advantages of EVs, with a focus on our proposed urban EV, will be presented as follows:

3.1. Gasoline Savings and Energy Security

The deployment of electric vehicles will lead to significant fuel savings and will diminish the problems associated with oil dependency. A complete dependence on oil, especially foreign oil, is a risk in case of a gasoline shutdown or political problems leading to oil supply interruption or in case of an extreme gasoline price spike. Since 95% of the energy used to recharge EVs comes from domestic sources [7], EVs reduce substantially dependence on foreign oil limiting the possible economic damages resulting from the above events. A big benefit obtained from using electric vehicles is, thus, the security in case of a gasoline shortage.

On the other hand, the continuous increase in gasoline consumption combined with high gasoline prices represents a threat to the world economy. Currently, the United States uses more than 20 million barrels of oil per day, two thirds of which is used for transportation. Petroleum imports cost about $5.7 billion a week [8]. Depending on its price, oil has accounted for between 30% and 59% of the U.S. trade deficit over the last decade [9]. Additionally, forecasts by the Energy Information Agency (EIA) anticipate a rise in oil prices over the next two decades where the U.S. gasoline price is predicted to rise to $4 per gallon by 2030 in the baseline scenario and to over $5.5 per gallon in the high price scenario [9]. The main reasons behind future inflation in oil prices are the rising oil extraction costs, as well as, the increasing energy demand from developing countries, especially China and India. China has been experiencing very rapid growth in vehicle population where it was about 63 million in 2008, and it is projected to be 550-730 million by 2050, 38-83% higher than that of the U.S. in 2050 [10].

Electric vehicles depend solely on electricity and consume no gasoline; hence considerable gasoline savings can be achieved. To get a clear idea about these savings, we will start by calculating the gasoline consumption in conventional vehicles based on EPA (Environmental Protection Agency) data [11]. The average fuel consumption of conventional vehicles ranges from 18 mpg to 25 mpg. For easy comparison with the urban vehicle model proposed above, we can safely assume that vehicles drive on average 20,000 miles per year (given the 60 mile daily mileage). The gasoline consumption thus, ranges from 800 to 1100 gallons per year. For an average gasoline price of $3/gallon, fuel savings range from $2400 to $3300 per year. Of course, these gasoline savings imply an increase in electricity consumption for charging the batteries of electric vehicles. Field tests indicate that the energy consumption of modern urban EVs varies from 0.2 to 0.3 kWh/mile [5, 12, 13] so, the total electricity consumption is calculated to be from 4000 to 6000 kWh per year. Therefore, for average electricity US price of 10 cents per kWh [14], EV electricity consumption per year ranges from $400 to $600. It is obvious that the annual fuel cost of an urban electric vehicle is about 6 times less than a gasoline one.

3.2. High Energy Efficiency

Another advantage of EVs is their high energy efficiency when compared with conventional vehicles. For a fair comparison of EV efficiency with that of ICEVs, well-to-wheel rather than tank-to-wheel efficiency factors are considered. The well-to-wheel analysis considers the whole energy lifecycle; starting from the extraction of energy from natural resources through transportation and distribution, and ending with transformation into kinetic energy to the wheels. Calculations of energy efficiency and consumption are given by the following equations.

$$E_{W2W} = E_{W2T} \times E_{T2W} \tag{1}$$

where: E_{W2W} is the Well-to-Wheel energy efficiency, E_{W2T} is the Well-to-Tank energy efficiency and E_{T2W} is the Tank-to-Wheel energy efficiency

$$C_{T2W} = C_{W2W} \times E_{W2T} \tag{2}$$

where: C_{T2W} is the Tank-to-Wheel energy consumption, C_{W2W} is the Well-to-Wheel energy consumption and E_{W2T} is the Well-to-Tank energy efficiency.

3.2.1. EV Energy Efficiency

The Well-to-Tank efficiency takes into account the energy lost during production and distribution of the electricity. Energy efficiency of electricity production varies widely depending on the type of power plant (coal-based, natural-gas based; conventional or combined cycle power plants). An average figure of 40% has been reported [12]. The average energy efficiency of electricity distribution is around 92.5% [12]. The Well-to-Tank energy efficiency can be thus calculated to be around 37% (40%*92.5%).

The Tank-to-Wheel energy efficiency depends on battery charging/ discharging, charger, electric motor efficiency and electronic engine management whose average Tank-to-Wheel efficiency values are as follows: 90%, 89%, 92.5% and 97% respectively in our proposed urban lithium-ion EV. The Tank-to-Wheel energy efficiency for Lithium-ion battery is around 72% [12].

Using equation (1), the Well-to-Wheel energy efficiency of EVs is around 27%.

3.2.2. ICEV Energy Efficiency

While the Well-to-Tank energy efficiency is around 83% taking into account the production, refining and transportation of fuel, the Tank-to-Wheel energy efficiency of ICEVs is quite low: around 18% [12]. In addition to the heat energy lost during the combustion process, additional energy is lost due to the friction of moving parts between the engine and the wheels.

Using equation (1), the Well-to-Wheel energy efficiency of ICEVs is around 15%.

Table 1

Comparison of EVs and ICEVs Energy Efficiencies

	ICEV	**EV**
Well-to-Tank	83%	37%
Tank-to-Wheel	18%	72%
Well-to-Wheel	15%	27%

Table 1 illustrates that EVs are almost twice as efficient as ICEVs, from a Well-to-Wheel perspective.

The above data will be used to calculate the energy consumption of our proposed urban EV relative to a sample ICEV. Considering the current EV market figures, it is reasonable to assume that our proposed urban EV has a Tank-to-Wheel energy consumption of 0.2 kWh per mile [12, 13]. Using equation (2), the Well-to-Wheel consumption of the 60-mile urban EV is 0.5 kWh per mile.

To compare with ICEVs, the 2008 Toyota Prius will be taken as a reference since it is one of the most efficient ICEVs on the market. Considering our urban driving model, the fuel consumption city estimate of the Prius is 48 MPG [11]. With a gasoline energy density of 33.7 kWh per gallon [15], the Tank-to-Wheel energy is 0.7 kWh per mile. Again using equation (2), the Well-to-Wheel consumption of the Prius is 0.8 kWh per mile.

It can thus, be concluded that our proposed urban EV model can offer higher energy efficiency than that offered by a conventional ICEV. Moreover, it is important to note that the EV Well-to-Tank energy efficiency can be further improved if electricity production process is optimized, as will be discussed later.

3.3. Emissions Reduction

Climate change is currently the most significant long-term threat to the global environment and man-made emissions of greenhouse gases are the main cause of the observed global warming over the last 50 years. Fossil fuels, such as gasoline, are considered the major contributor to global climate change since burning them releases greenhouse gases (CO_2, NO_x, SO_2) into the atmosphere. Additional runoff pollutants, such as heavy metals, oils and grease, are also produced. In addition to global warming, these pollutants are known to cause respiratory and heart diseases, and are well-known carcinogens. They are also the leading causes of smog and acid rain. Carbon Dioxide (CO_2) is the most important human made greenhouse gas, and highway vehicles account for 26% of U.S. CO_2 emissions each year [11].

Since EVs use electricity as a fuel, substantial reductions in greenhouse gas emissions are expected. In fact, the magnitude of reduction depends on the source used to generate the electricity. Electricity generated from non-carbon sources (renewables, nuclear, or hydroelectric) produce much less gas emissions than that generated from carbon sources. According to the Center for Entrepreneurship and Technology (CET) of University of California, if the electricity to power electric cars is produced by non-carbon sources the range of expected greenhouse gas reductions in 2030 is between 25% and 62% [9]. On the other hand, EVs do not promise much benefit in reducing emissions in countries such as China where electricity is primarily generated from coal. Contrarily, they could increase emissions of criteria pollutants like SO_2 and NO_x because power plants are believed to be the largest contributor to China's SO_2 and NO_x emissions [10].

It is important to examine the CO_2 emissions of urban EVs versus those of ICEVs. 20 pounds of CO_2 are generated for every gallon of gasoline burnt in ICEVs [11]. Using the fuel consumption range (800-1100 gallons per year) calculated above, a typical ICEV releases around 7 to 10 tons of CO_2 each year.

On the other hand, EVs emit nothing during their operation; so, their tank-to-wheel CO_2 emissions are zero. It is however more practical to know the Well-to-Wheel CO_2 emissions generated not only by the vehicle, but also by the power plant and by the distribution of the electricity. EVs generate around 616 g of CO_2 for each kWh of transmitted energy with lithium batteries [12]. For an urban EV yearly consumption of 4000 to 6000 kWh, 2.5 to 3.7 tons of CO_2 are emitted per year. That means that with the average European Union electricity mix, Well-to-Wheel CO_2 emissions of an electric vehicle are about 2.5 times less than those of a gasoline vehicle. If electricity is generated from solar energy, an average of 130 grams is emitted for every kWh of generated electricity so, the annual CO_2 emissions range from 0.5 to 0.8 tons. The annual emissions may be further reduced to 0.07 to 0.1 tons, if wind energy is used. This is the case in countries such as Norway, Sweden and France [12]. Furthermore, the EV Well-to-Wheel emissions can even reach zero if nuclear energy is used in electricity generation.

In view of the above, using urban EVs can substantially reduce CO_2 emissions. They become even more attractive in countries where renewable sources are used in electricity generation.

3.4. Small Size and Light Weight

Many people think that EVs are bigger and heavier than conventional ones because of their use of large batteries. This might be true for long range vehicles that require big heavy batteries. However, with our proposed model (short-range urban vehicles), EVs are smaller and lighter than conventional ones.

The battery is usually considered the main component in the EV weight. So, it is important to examine the battery weight in the urban EV model. As will be explained later, the proposed urban EV will use a Lithium-ion battery with average specific energy 0.13 kWh/Kg. For a 60-mile - 0.2 kWh/mile urban vehicle, the total needed battery capacity would be 12 kWh. Therefore, the expected battery weight is about 90 kg which is quite satisfactory for an urban EV. Market data in Table (2) shows that commercial urban EVs are lighter and smaller than comparable ICEVs (like the Honda Civic coupe). For long-range EVs however, the weight/ size is equal to, or even higher, than ICEVs. This is due to the heavy and large batteries used for long EV ranges.

It can be noted that the EV is lighter than the ICEV due to several reasons; the heavy acoustic insulation and steel body, necessary in ICEVs to damp the sound of the engine, are not required in EVs so, they can have a light plastic body rather than the heavy steel body in ICEVs. Moreover, the electric motor of an EV is much lighter than the internal combustion engine of a conventional vehicle delivering the same power. In addition to the fact that the EV does not need manual or automatic gearbox, it is also possible to eliminate every mechanical transmission using wheel-drive motors. Furthermore, future advancements in battery technology will make batteries smaller and lighter which will in turn lead to further reductions in weight and size of the EV.

The data in Table (2) also shows that the EV dimensions are generally less than the ICEV ones. The small size of EVs is useful in short trips which are often made in intense traffic conditions and with a single person or a couple persons on board. A small car is better because it can be easily manipulated in high traffic and can be parked easily and consequently, reducing the parking congestion problem.

Table 2

Comparison of Typical Electric and Gasoline Vehicles

Vehicle	Curb Weight (kg)	Battery Weight (kg)	Range (KM)	Battery Type	Car Price (US$)	Dimensions (inch)
Internal Combustion Engine Vehicles						
Honda Civic Si coupe	1310	N/A	N/A	N/A	21,000	176*69*54
Smart for Two 2007	730	N/A	N/A	N/A	21,700	98*60*61
Mazda MX-5 2010	1100	N/A	N/A	N/A	25,000	158*68*50
Toyota Prius 2009	1380	N/A	N/A	N/A	25,000	176*69*58
Honda Accord EX	1535	N/A	N/A	N/A	24,000	194*73*58
Mitsubishi Galant SE	1545	N/A	N/A	N/A	24,800	191*73*58
Electric Vehicles						
Zenn 2009	620	180	80	Lead acid	10,000	122*63*55
Xebra Electric Sedan	655	136	40	Lead acid	11,900	114*56*61
REVAi	665	270	80	Lead acid	12,000	100*51*59
Reva G-Wiz	475	75	112	Li-ion	16,731	102*51*63
Miles ZX40S	1066	300	80	Lead acid	20,800	134*58*67
Wheego 2011	1200	230	160	Li-ion	26,500	119*63*63
Mitsubishi iMieV 2009	1080	130	160	Li-ion	30, 500	134*58*63
Nissan Leaf	1600	300	160	Li-ion	32,800	175*70*61
Nissan Altra	1700	350	190	Li-ion	50,000	184*70*67
Tesla Roadster	1220	410	400	Li-ion	101, 500	155*74*44

3.5. Unique Features

The EV has some unique features which distinguish it from other conventional or alternative vehicles. An electric motor is much simpler than internal combustion engines [3] and because of this simplicity; EVs may be more reliable and can resist very hard work. On the other hand, torque generation of an electric motor is very quick and accurate. Also, a motor which can be attached to each wheel further improves the driving capabilities of EV. Moreover, motor torque can be measured easily; an advantage that allows application of new control strategies based on road condition estimation [16]. Furthermore, energy can be generated onboard through the regenerative braking technique.

Besides, the use of urban EVs can reduce the high levels of city noise. Road traffic, mainly caused by ICEVs, is known to be the cause of the majority of noise in cities. In conventional vehicles, noise is mainly generated from the internal combustion engine (ICE). Since an electric motor rather than an

ICE is used, EVs are very silent. So, their widespread use in cities can significantly reduce urban noise levels.

4. PRESENT MAJOR ISSUES

It is widely believed that EVs are impractical due to their range limitations, high cost, energy storage constraints and missing charging infrastructure. Thus, some people prefer to postpone their use until further advancements in the supporting technologies. This paper, however, proposes the immediate use of urban EVs based on the belief that their limitations are few and can be mitigated using various techniques. Advancements in technology would be a motive to a wider use of EVs rather than a trigger to start their commercialization. The following discussion is concerned with the current EV limitations along with proposed methods to overcome those limitations. Evidence is provided based on the proposed urban EV model.

4.1. Energy Source

The EV energy source has been identified to be the major obstacle of its commercialization [3], [17-20].

The main energy storage requirements for EV applications are summarized as follows:

- Specific energy (kWh/kg) and energy density (kWh/L) high enough to ensure a desired driving range.
- Specific power (kWh/kg) and power density (kW/L) sufficiently high to give good acceleration, allow fast charging and good regenerative braking to achieve high-energy efficiency.
- Fast charging and deep discharging capabilities.
- Long cycle and service lives to meet the general standard of automotive component life.
- Durability against environmental demands (e.g. mechanical or climatic stress) so that EVs can work in harsh environments, if needed.
- Safety under extreme conditions (short-circuits, overcharge,…etc)
- Cost effectiveness for EVs to be able to compete with other conventional or alternative vehicles.
- Environmentally friendly and recyclable
- Easy maintenance

Table 3

Comparison of Different Energy Storage Systems [3]

Energy Source	Specific Energy (Wh/kg)	Specific Power (W/kg)	Cycle Life (cycles)
USABC*	200	400	1000
Lead-acid	35	150	700
Ni-Cd	60	300	1200
Ni-MH	70	220	1500
Li-ion	130	350	1000
Na-NiCl	110	150	1500
Zn-O2	200	100	1(electric fuel)
Flywheels	40	3000	5000
Ultracapacitors	5	2000	500000

* USABC:United States Advanced Battery Consortium

Table 4

Key Features of different Energy Storage Systems [3, 17]

Energy Source	Key Advantages	Disadvantages	Potentiality
Lead-acid	low cost, simple to use	low specific energy, short cycle life	near-term, Low
Ni-Cd	mature, fast charging, high specific power	high cost, low specific energy	near-term, high
Ni-MH	high specific energy, high specific power, fast rechargeable	high cost	near-term, very high
Li-ion	very high specific energy, very high specific power	high cost	mid-term, very high
Na-NiCl	high specific energy	high cost, need of thermal management	mid-term, high
Zn-O2	low cost, mechanically rechargeable, very high specific energy	low specific power, can not accept regenerative energy	mid-term, very high
Flywheels	very high specific power, pure mechanical with no pollution, no gas emissions or wastes, long cycle life	very high cost	long-term, very high
Ultracapacitors	high specific power, long cycle life	low specific energy, very high cost	long-term, very high

The USABC (United States Advanced Battery Consortium) aims to make EVs compete with ICEVs. So, it has set performance goals of EV batteries. As shown in Table (3), these goals are so demanding that no existing battery is capable of meeting all its criteria.

As mentioned before, today we do not seek competition with long range vehicles (ICEVs or other alternative vehicles). Instead, we aim at a battery technology to satisfy our current needs. The proposed urban EV for short-range low-speed applications requires only a small battery thus; a battery capacity of 20 kWh (90 kg) is enough for such vehicles. As demonstrated in Table (4), Li-ion, Ni-Cd and Ni-MH batteries seem to be viable options for the near-term needs. While Ni-Cd and Ni-MH have demonstrated to be good options for EVs, Lithium-ion batteries have just started to unfold their potential. It is their significantly higher specific energy that makes a high-volume market entry of EVs possible [3]. Their very high specific power is a useful feature for urban EVs; where a good acceleration and regenerative braking are required in high traffic areas. Additionally, their very high specific energy allows the use of a relatively small battery for the 60-mile desired range. The average Li-ion battery cost is $500 per kWh [21, 22]. Although the current cost of the 12 kWh battery is relatively high $6,000 (12 kWh * $500/kWh), it is expected to decrease in the future due to technological advancements [17]. Consequently, the Lithium-ion is a good candidate for our proposed model of urban EVs.

Considering the above scenario, most of the battery issues (heavy weight, range, performance, and charging time) no longer exist. On the other hand, the future of energy storage technologies is very promising; Ultra capacitors have a very high potential as well and recent advances in nano-technology will make the development of a new family of ultra-capacitors possible. In addition, hybridization of energy sources eliminates the compromise between the specific power and specific energy where multiple energy sources can be used in EVs, rather than one energy source. One energy source is selected for its high specific power while, the other for high specific energy. For example, there are the battery and battery hybrid, and battery and ultra-capacitor hybrid.

4.2. Impact on Electrical Power System

Since electricity is the sole power source for EVs, it is important to evaluate the potential impact on the electrical power system. One of the concerns is that EV battery chargers generate harmonic contamination to the power system. This concern has been addressed by scientists and engineers who proposed many possible solutions. On the device level, new topologies of battery chargers are proposed while, on the system level, the adoption of new filters is a possibility for canceling the harmonics. Another possibility is compensating the harmonics generated by EV chargers [23]. Since the phase angles of harmonic currents generated by one charger are different from those generated by another, natural harmonic compensation or even cancellation may occur. Another concern of recharging the battery of EVs is the additional electricity demand especially that EV electricity consumption is relatively high – around 4000-6000 kWh/year for a car (as calculated previously). If vehicles are recharged during normal or peak periods, an additional burden on the power system is created. There are two possible solutions to this issue; the first is charging at night during off-peak hours when electricity consumption is normally low and the other is minimizing the peak current demand which can be achieved through the coordination between charging current and charging time to charge a group of EVs at the same charging station [24].

If users recharge their EVs at night during off-peak hours, they will benefit from cheap tariffs. Considering an off-peak cost of 3 cents per kWh, the annual EV electricity cost is reduced from $400-$600 to $120-$180, hence efficient savings can be made. In this case, electricity should be generated continuously throughout the day to satisfy the above needs. For continuous electricity production, low-emissions high-efficiency power plants are more cost-effective, since their marginal operating cost is lower and their higher investment expenditure can be depreciated over more operating hours [12]. So, in addition to improving the well-to-wheel energy efficiency of EVs, they produce less CO_2 emissions causing less air pollution.

4.3. Charging Infrastructure Issues

Although, large scale charging stations for EVs do not exist today, several charging options are possible. The 2005 American Housing Survey showed that 76% of the occupied housing units were single family structures and 63% of all occupied housing units had access to a garage [25]. For this market segment, it is convenient to charge the vehicle at-home during the night. On the other hand, at-home battery charging may not be practical for apartment inhabitants and those who can not park near their home. In this case, public charging stations are necessary. At the beginning, it will be difficult to establish an extended network of electricity charging stations. It is possible however, to make use of the existing infrastructure of the gasoline charging stations; also, we can take advantage of the public parking areas. If normal charging is used, charging times of one to several hours are required [12]. In this case, a public charging station may become blocked for hours by only one customer. Additionally, the customer does not want to wait for hours until the vehicle is recharged. So, the availability of charging infrastructure in car parkings can solve this issue. In this case, the car could be charged during parking hours which are usually extended hours.

Otherwise, the “battery leasing” business model seems to be an appealing one especially in the initial stages of EV introduction. Depending on the customer’s situation, the battery-leasing company may charge the battery or swap it with another fully charged one. This model has many advantages; it will resolve the range-anxiety issue by installing and maintaining a battery charging and switching infrastructure that will extend the driving range [9]. It will also eliminate the doubts about the durability of the battery and hence, more security to the EV customer. Moreover, it will significantly reduce the EV initial ownership cost, for example, the total price of our proposed urban EV will be reduced by $6,000 which is the Li-ion battery cost.

Contrary to what most people think, EVs will require little initial expenditures on electrical infrastructure in the first stages of EV commercialization. The European Association for Battery EVs indicated that at least 23% of the cars in France can be electric cars without requiring significant increase in the electrical infrastructure, assuming off-peak hours charging. It is also likely that this number can be extrapolated to all Europe [12].

4.4. Cost Issues

Currently, high cost is one of the major obstacles that hinder the commercialization of EVs. In spite of the common belief that all EVs are expensive, urban EVs may have reasonable prices.

The total cost of EVs consists of two parts: initial cost and operating cost. Although the initial cost of long-range EVs is higher than, or equal to, that of ICEVs, Table (2) shows that short-range urban EVs are considerably less expensive than ICEVs. While the average price of ICEVs is $23,000, the projected cost of our proposed urban EV is $15,000, out of which $6,000 is the battery cost. There are basically two cost models for EVs; in the battery ownership model (BOM), the battery cost is included in the vehicle ownership price; whereas in the battery leasing model (BLM), the battery cost is separated from the vehicle ownership cost.

Since the battery cost is considered as the main component in the total EV cost, the ownership cost of EVs can be significantly reduced if battery costs are decreased. The BLM discussed above will relieve the cost burden of the EV customer whereby the battery ownership is separated from the vehicle ownership. On the other side, advances in battery technology and mass production will lead to reductions in battery costs in the future.

The operating cost is the other component of the EV cost which in turn includes maintenance cost, fuel cost, battery rental cost (in case of BLM) and infrastructure cost.

Maintenance cost for ICEV covers oil changes, brake replacement, and transmission maintenance; it costs around 4 cents per mile for a small sedan [26]. The maintenance cost of EVs accounts for only 25% of that of ICEVs [9, 17] so, the maintenance cost of EVs is estimated to be around 1 cent per mile.

The cost of electricity is on the order of 10 cents per kWh in the EV BOM and 6 cents per kWh in the EV BLM [9]. The electricity cost is assumed to be lower in the battery leasing model since the operators can buy electricity directly from the suppliers and thus, lowering the charging costs. For a 0.2 kWh/mile EV, the electricity cost is 2 cents per mile for the BOM versus 1.2 cents per mile for the BLM. The fuel cost of ICEVs calculated above is around 12 cents per mile.

The average battery rental cost is 8 cents per mile [9]. The battery rental cost can be further reduced if the battery-leasing company is a joint-venture between the battery manufacturer, dealer, electric power utility, and Oil Company. The final cost component in the EV deployment is the cost of deploying a charging infrastructure which is projected to be 2 cents per mile in the U.S. University of California model [9].

The Table 5 summarizes the computed values for EV and ICEV costs.

The data in Table 5 shows that for both cost models, an urban EV is less expensive to purchase than a comparable gasoline vehicle. Similarly, the per-mile operating cost of an EV is significantly less than that of a gasoline one, especially in the BOM. It is expected that the per-mile costs of EVs will further decrease due to improvements in battery technology and electric motor efficiency.

Table 5

Comparison of Electric and Gasoline Vehicle Costs

		Urban Electric Vehicle		Gasoline Vehicle
		Battery Ownership Model	Battery Leasing Model	
Initial Cost ($)		15,000	9,000	23,000
Operating Costs ($/ mile)	Maintenance Cost (cents/mile)	1	1	4
	Fuel Cost (cents/mile)	2	1.2	12
	Battery Rental Cost (cents/mile)	N/A	8	N/A
	Infrastructure Cost (cents/mile)	2	2	N/A
	Total (cents/mile)	5	12.2	16

4.5. Range Anxiety

Some users have expressed their concern or fear of becoming stuck with a discharged battery in a limited-range vehicle, away from the electric infrastructure. With the urban short-range vehicle model proposed above, this concern is reduced since the EV will be used primarily for short city distances. That concern can be further reduced if the battery leasing model is applied whereby users will be allowed to exchange their discharged batteries with charged ones.

5. EV COMMERCIALIZATION

There is no doubt that promotion is an important factor in EV commercialization. Proper engineering, commercial and marketing strategies are essential in the development of urban EVs. The overall strategy should take into account how to exploit urban EVs competitive edge, meet market demand and win stakeholders support.

The cooperation, as well as, the commitment of governments and public authorities, manufacturers, electric utilities and users is key to EV success. Government support includes financing, policy legislation and tax incentives. For example, a European Union regulation requires reduction of average fleet emissions; and California's zero emissions vehicle regulation requires explicitly introduction of alternative fuel vehicles.

Technical support from academic institutions and industrial organizations can strongly influence the adoption of EVs. Customer awareness is also crucial for the development of EVs market [4] where people being aware of EV technology become potential customers. Moreover, they talk to other people not knowing the new technology. This way, knowledge about EVs will spread over the whole market via word-of-mouth and turn more people into potential customers. The more EVs are sold the more experience manufacturers get with the technology which in turn leads to decreasing production cost. Eventually, this will lead to price reductions.

6. CONCLUSION

Energy conservation and environmental protection are the main driving forces behind the development of electric vehicles. The business case developed above encourages a fast deployment of urban EVs because of the various benefits they offer such as high efficiency, reductions in petroleum use and greenhouse emissions; national energy security, less noise, reduced maintenance, convenience of home recharging and finally a green image.

Since the 19th century there has been several attempts for EV use however, none of them achieved the required success. Many people believe that a choice has to be made between EVs and other vehicles (conventional vehicles or alternative vehicles). However, this is definitely not the case since each technology serves a different market and address a distinct demand. Thus, it is a question of both/and rather than a question of either/or. In spite of having some limitations, urban EVs seem to be a good choice for cities since their potential drawbacks are few and can be mitigated. The author believes that it is now time to move on so, in this paper some techniques are introduced to mitigate the current limitations of EVs.

A rapid wide deployment of EVs is unlikely due to several issues in commercialization. However, the main idea is to first activate the EV chain reaction. Then, technological advancements will act as a catalyst to speed up this reaction. The chain reaction would start by the introduction of urban EVs then, support and interest in investment would enable mass production. The low initial price, caused by mass production, will lead to a high customer satisfaction and hence, high demand for EVs. High demand will in turn lead to high sales and thus, EV success. Battery technological advancements will be the main catalyst in the above reaction.

Urban EVs just need community support to establish itself as a significant part of the automobile market. We should all strive for such a clean, efficient and sustainable transportation system for the 21st century.

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DEFINITIONS, ACRONYMS AND ABBREVIATIONS:
EV: Electric Vehicle
ICEV: Internal Combustion Engine Vehicles
ICE: Internal Combustion Engine
MpG: Miles per Gallon
BOM: Battery Ownership Model
BLM: Battery Leasing Model

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