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Titel der Masterarbeit

„DECARBONISING PRIVATE TRANSPORTATION:
CHALLENGES AND PROSPECTS FOR
ELECTRIC VEHICLES“

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i. LIST OF ABBREVIATIONS

GHG – greenhouse gasses

GWP – global warming potential

EVs – electric vehicle powered by external power station

EPA – U.S Environmental Protection Agency

E2W – electric two-wheelers

ICE – internal combustion engine

ICEV/CV – internal combustion engined vehicle/conventional vehicle

IPCC – Intergovernmental Panel on Climate Change

IEA – International Energy Agency

Mpg – miles per gallon

kWh – kilowatt-hour

Li-ion – lithium ion

LiBs – lithium-ion battery

LCA – life cycle assessment

R&D – research and development

Wh – watt-hours

ZEV – Zero Emissions Vehicle

ii. LIST OF FIGURES

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“Ere many generations pass, our machinery will be driven by power obtainable at any point in the universe. It is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature.”

Nikola Tesla, Inventor. 1892

“God doesn’t want us to have full-function electric vehicles. The laws of nature don't allow this.”

John Wallace, Ford Think group. 2000

Abstract

It is estimated that more than a billion cars, mainly working on conventional fuels, are circulating on the roads worldwide and in the next 50 years the number is expected to double. The time when oil was abundant is unlikely to come ever again, while its price is constantly triggered by military conflicts and political tensions in oil-exporting countries. These issues have long been raising concerns about the reasonability of using internal combustion powered vehicles and urged governments and scientists to look for more environmentally friendly alternatives. Although a century ago electric car was highly favoured by engineers and manufacturers and was seen as a prospective technology, the efficiency and inexpensiveness of gasoline-engined vehicle took over the mass market and the former remained in very limited quantity.

The aim of this thesis is to present an analysis of economical, political, social and technological challenges for the electric car in historical and contemporary perspectives and ways of resolving such challenges.

The research is mostly limited to passenger electric vehicles which use an external source of power and to conventional gasoline or diesel-powered vehicles, with some inputs into electric trucks and electric two wheelers. Other alternative technologies, such as Hybrid Electric, Hydrogen or Biodiesel vehicles are not included in the research.

Abstract (German)

Es wird geschätzt, dass mehr als eine Milliarde Autos, die Mehrheit davon wird mit konventionellen Treibstoffen betrieben, weltweit auf den Straßen zirkulieren und in den kommenden 50 Jahren wird erwartet, dass sich diese Zahl verdoppelt. Die Zeit, als Öl unbegrenzt verfügbar war, wird wahrscheinlich nie wieder kommen, während der Ölpreis durch militärische Konflikte und politische Spannungen in den ölexportierenden Ländern angeheizt wird. Diese Aspekte haben schon lange Bedenken über die Sinnhaftigkeit der Verwendung von fossilen Verbrennungsmotoren in Autos ausgelöst, und Politiker und Wissenschaftler dazu gedrängt nach mehr umweltfreundlicheren Alternativen zu suchen. Obwohl das Elektroauto vor mehr als hundert Jahren von Ingenieuren und Erbauern favorisiert wurden und als aussichtsreiche Technologie angesehen wurde, gelang es den auf fossilen Brennstoffen basierenden Autos den Massenmarkt zu übernehmen, und erstere waren nur eingeschränkt verfügbar.

Das Ziel dieser Arbeit ist es, eine Analyse von ökonomischen, politischen, sozialen und technologischen Herausforderungen für das Elektroauto in historischer und zeitgenössischer Perspektive zu präsentieren und Wege aufzuzeigen, wie diese Herausforderungen gemeistert werden können.

Die Forschung ist weitgehend auf PKW, die externe Energiequellen verwenden und auf traditionelle Benzin- und Dieselfahrzeuge limitiert, mit einigen Aspekten zu Elektro-LKWs und elektrische Zweiräder. Andere alternative Technologien, wie Elektrohybrid, Wasserstoff- und Biodieselfahrzeuge, sind in dieser Arbeit nicht inkludiert.

Structure and Methodology

The research begins with the comparative analysis of benefits and limitations of gasoline and electric vehicles as a primary mode of transportation. Two types of vehicles are compared in terms of their impact on air pollution, climate change, noise pollution, human health, economic costs and fuel efficiency. Alternative sources of energy are also analysed in terms of energy security, as an integral part of the use of electric cars.

The second chapter discusses causes of success and failure of the electric propulsion in the U.S, Europe, the former Soviet Union and China. It is a descriptive analysis in a historical perspective, based on secondary and primary sources, such as historical works and newspapers. A number of profound research works dealing with the causes of failure and success of the electric car has been done by Gijs Mom, Daniel Curtis, Ernest Wakenfield, Andersons and others. In analysing the history of EVs in the U.S and Europe these and other works will be referred to. A great insight into the automobile industry of the Former USSR is given by Shugurov and Stavrov among others.

The third chapter covers current business models and solutions for the electric vehicle industry through a number of case studies, namely companies like the Better Place, Green Way and Tesla Motors. The data regarding case studies is derived mainly from primary sources, such as official web pages, reports, blogs, etc.

1.0 COMPARISON OF ENVIRONMENTAL, SOCIAL AND ECONOMIC EFFECTS OF CONVENTIONAL AND ELECTRIC VEHICLES

1.1 Air Pollution and Global Climate Change

From the beginning of the industrial revolution the planet's temperature has risen for 0,74°C. The CO₂ emissions grew on average 1,1 % annually from 1990 to 2000 and 3,0% during the last decade.¹ The Intergovernmental Panel on Climate Change (IPCC) concluded, that the observed increase in global average temperature over the last century is unlikely to be entirely natural in origin and that the balance of evidence suggests that there is a discernible human influence on global climate.^{ibid} Each year ICE vehicles emit over 900 million metric tons of CO₂ and contribute for more than 15 percent of global fossil fuel CO₂ releases². The greenhouse gases, according to the IPCC, are the cause of the rising earth's temperature, which leads to the rising of the sea level, melting of the Arctic ice, forest degradation, natural disasters and threatens the existence of many biological species. The process is believed to be preventable if necessary measures and policies regarding emissions are undertaken on a worldwide scale.

However most gasses are the result of the generation of so called “black electricity”, which questions the reasonability of using electric vehicles. According to the International Energy Agency, 40% of global CO₂ emissions are constituted by coal, 19% — by gas, 16% — by nuclear and hydro-electric plants, 7% — by oil and 2% by other sources.³ Therefore, nearly a

¹ Intergovernmental Panel on Climate Change, A report of Working Group I of the IPCC, [http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf]

²World Resource Institute, CO₂ emissions from motor vehicles, parag. 3, [http://www.wri.org/publication/content/8468]

³IEA Statistics, CO₂ Emissions from fuel combustion, Highlights, p.9 [http://www.iea.org/publications/freepublications/publication/CO2emissionfromfuelcombustionHIGHLIGHTS.pdf]

half of the world's electricity is now produced with negative consequences for the environment (see figures):

Figure 1.1. World Energy Generation by Source

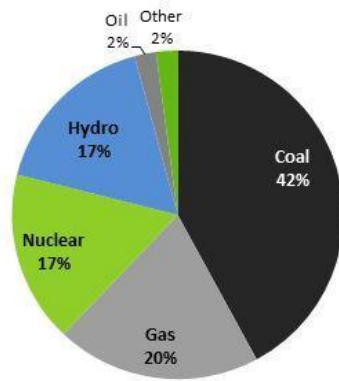
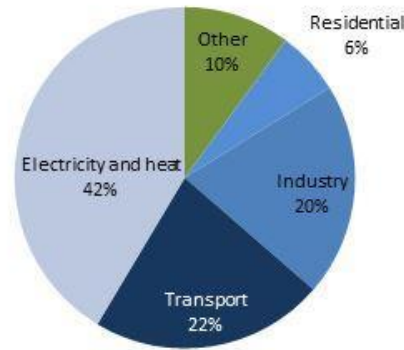


Figure 1.2. World Energy Consumption by source



Source: International Energy Agency

With current figures, electric vehicles in most countries will still consume environmentally unfriendly electricity which will further increase the GHG emission. So the question is whether it makes sense to use them at the moment.

By 2050 up to 83% of world's electricity is estimated to be generated from renewable sources of energy, which will make electric cars an environmentally friendly alternative.⁴ Due to improvement in technology, government incentives and rising demand, the price for renewables becomes lower than for conventional energy. Logically, the higher demand for EVs will result in more intensive research and development and the faster transition from conventional vehicles. It is in the interest of electric car manufacturers that their products use clean energy, which enhances the product's appeal. It creates interconnectedness between industries and brings mutual benefits to both.

⁴ Green Peace, Energy Revolution, 2009, p.4 /Энергетическая Революция, Accessed at: [http://www.greenpeace.org/russia/Global/russia/report/2009/11/4129008.pdf]

Some countries already generate most of the electricity from renewable sources. Spain, for instance, produced 54% of the electricity from hydro- and wind power in April 2013.⁵ Norway and Brazil produced 95% and 50% respectfully from hydropower in 2011. There is also Iceland, which produces 100% from geothermal and hydropower and even considers building an interconnector into the UK grid.⁶ But these are seldom examples on a global scale and the world's biggest economies are still the biggest pollutants. In the U.S and China, for instance, coal constitutes 49% and 71% of total national emissions respectfully.⁷

A number of studies shows, that electric vehicles produce less GHG emissions over the course of exploitation and are more efficient than ICE vehicles in terms of energy use. According to the U.S. Department of Energy, an average conventional vehicle in the U.S. produces 87 lb CO₂ during a 100-miles trip, while electric car's emissions are 54 lb CO₂ (35 percent less)⁸. Another study has shown that electric cars produce on average 75 gCO₂/km in comparison to 100-160 gCO₂/km of conventional cars with energy systems of the UK, France, USA and Canada. The opposite result was obtained for China and Greece (see figure):

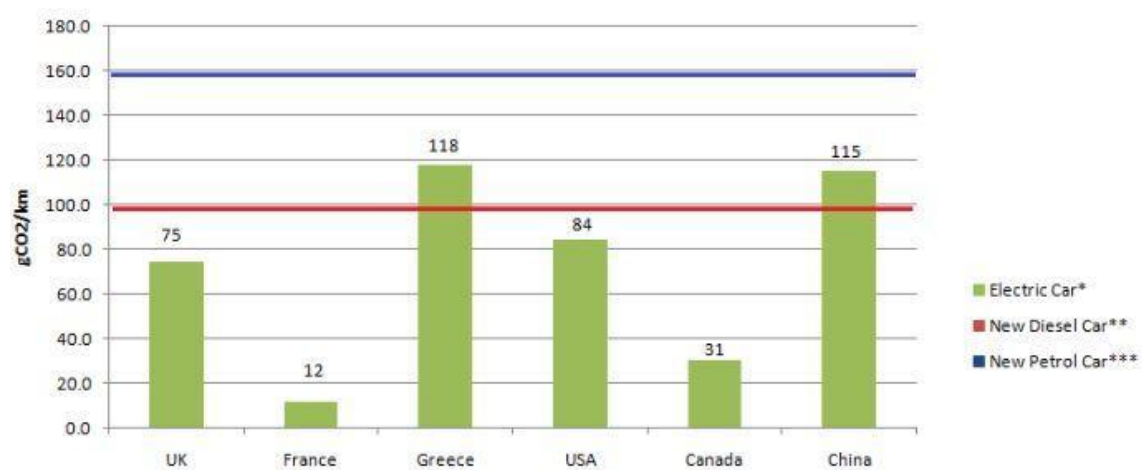
⁵ Red Eléctrica de España (REE). "Renewables account for 54% of Spain's electricity production in April", as cited in PV Magazine, May 2, 2013. [<http://www.pv-magazine.com>]

⁶ Nina Chestney, Henning Gloystein, "UK eyes plugging into Iceland's geothermal power.". Reuters. [<http://uk.reuters.com>]

⁷ EIA, EIA's latest Short-Term Energy Outlook for electricity, [<http://www.eia.gov/electricity/>]

⁸ The US Department of Energy used the GREET model for calculations of conventional vehicle emissions. The specification of Nissan Leaf was used to calculate the emissions of all-electric vehicle with a U.S national grid mix. For details see: U.S Department of Energy official website, [http://www.afdc.energy.gov/vehicles/electric_emissions.php]

Figure 1.3 CO₂ emissions comparison of Electric, Gasoline and Diesel vehicles



* based on average of Nissan Leaf, Mitsubishi i-Miev and Renault Fluencz EV

**based on new Ford Focus 1.6 diesel

***based on new Ford Focus 1.6 petrol

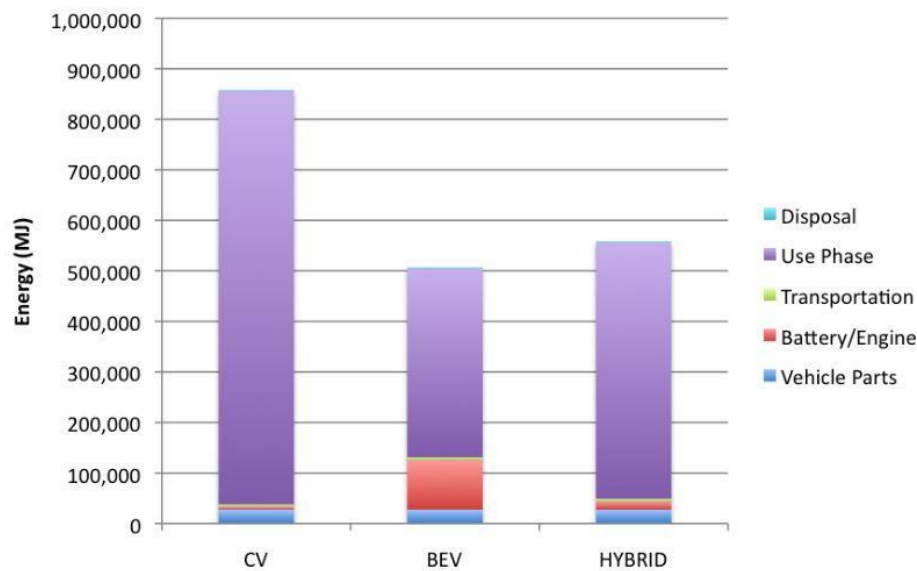
Source: Gary Davis, Ecometrica. Technical Paper| Your new electric car emits 75 gCO₂/km (at the power station), 2011[[http://www.ecometrica.com/assets//electric_car_emits_75_gCO₂_per_km.pdf](http://www.ecometrica.com/assets//electric_car_emits_75_gCO2_per_km.pdf)]

However electricity consumption is not the only factor which is considered in estimating and the overall environmental cost of the vehicle. A number of studies use the Life Cycle Analysis (LCA), which estimates vehicle's overall environmental effects from raw material extraction to manufacture, use and disposal. According to a 2012 study in the Journal of Industrial Ecology, production impacts, given in global warming potential (GWP), are higher of EVs than of CVs, but the operation is the most important phase for all vehicles. Battery production for EVs contributes 35% to 41% while the electric engine contributes only 7% to 8%. Other powertrain components, such as inverters and the passive battery cooling system contributed 16% to 18% of the GWP of the EVs production phase.⁹ The study, assuming a lifetime of 150,000 km showed that EVs operating on European electricity reduce GWP 20% to 24% compared to gasoline and by 10% to 14% relative to diesel vehicles.

⁹Troy R. Hawkins, et al. Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. Journal of Industrial Ecology, Vol.17, Issue 1, p. 57. [<http://onlinelibrary.wiley.com>]

Another study for a California Air Board calculated the total energy input for a number of CV and EVs and found, that over the life cycle EVs are the least energy consuming, although Hybrid vehicles cost less (see figure):

Figure 1.4. Life cycle energy input comparison of Conventional, Battery Electric and Hybrid vehicles



Source: Kimberly Aguirre, et al. Lifecycle Analysis Comparison of a Battery Electric Vehicle and a Conventional Gasoline Vehicle. 2012. [http://www.environment.ucla.edu/media_IOE/files/BatteryElectricVehicleLCA2012-rh-ptd.pdf]

However, many scientists deny the fact that the global warming is actually a result of GHG emissions or human activity at all. A British natural scientist and broadcaster David Bellamy is known for his claims, that man-made global warming is a 'poppycock' and is not sufficiently proven¹⁰. A prominent physicist Freeman Dyson argues that measures proposed to combat global warming have long ceased to belong to the sphere of science and are rather political and speculative business. He was one of the signatories of the letter criticizing the IPCC and said, "to reach reasonable solutions of the problems [of global warming], all opinions must be heard

¹⁰Jane Fryer, "The BBC froze me out because I don't believe in global warming: Outspoken as ever, David Bellamy reveals why you don't see him on TV any more.". 22 January 2013. Daily Mail. [<http://www.dailymail.co.uk>] (accessed July 24, 2013)

and all participants must be treated with respect."¹¹ Danish economist Bjorn Lomborg believes that global warming is “not as threatening as it is depicted by some experts and journalists echoing them”. His views are set out in detail in the book "Cool! The Skeptical Environmentalist's Guide to Global warming"¹² Professor of Moscow State University Andrey Kapitza considers human factor in the issue insignificant in comparison to cosmic and geophysical factors.¹³ An alternative theory to human factor in global warming is the Milankovitch theory, which links changes in the Earth's temperature to various changes in its movement¹⁴. The German Herald, referring to Dr Habibullo Abdussamatov's statement, reported that “mini Ice Age will begin next year (2014) and will last for 200 years”.¹⁵

While general public usually links global warming to CO₂ emissions, fewer people are aware of that rearing cattle actually produces more greenhouse gases than driving cars. According to the UN, livestock generates 65 per cent of human-related nitrous oxide, which has 296 times the Global Warming Potential (GWP) of CO₂. It also accounts for 37 per cent of all human-induced methane, which is has a 23 times more warming effect than the carbon dioxide.¹⁶

Even if conventional transport will be proven not to affect global warming processes, another reason to increase the number of EVs is that they are “clean” locally, meaning that they outsource the pollution to less populated areas outside of the city. The most harmful for health

¹¹William D. Nordhaus, et al. “The Question of Global Warming”: An Exchange. The NY Review of Books. September 25, 2008. [<http://www.nybooks.com>]

¹²Helen Amos, Cool It: The Skeptical Environmentalist's Guide to Global Warming. Summary of the book. 2008. [<http://www.atmos.washington.edu>]

¹³“Andrey Kapiza, Head of Department of Environmental Management at MSU”/”Андрей Капица, заведующий кафедрой рационального природопользования МГУ”. *Lenta.ru*. December 11, 2009. [<http://lenta.ru>]

¹⁴Campisano, C. J. (2012) Milankovitch Cycles, Paleoclimatic Change, and Hominin Evolution. *Nature Education Knowledge* 4(3):5, [<http://www.nature.com>]

¹⁵German Herald. “Prof Warns Mini Ice Age has Started”. March 31, 2013. [<http://germanherald.com>]

¹⁶“Rearing cattle produces more greenhouse gases than driving cars, UN report warns”. *UN News Centre*. November 29, 2006 [<http://www.un.org>] (accessed July 24, 2013)

are GHG particles in high concentration, which mostly occur in urban areas. In 2012, 3.3 million people, mainly living in densely populated places, died because of diseases caused by air pollution.¹⁷ Most common were lung diseases, such as asthma and lung cancer. The number of mortalities has tripled since 1990, although measurements were more crude at that time.

Less significant, but very visible outcome is smog, which harms the visual quality of the landscape. The U.S. Environmental Protection Agency EPA estimated that visibility in national parks and other scenic areas in the United States has been reduced from a 90-mile distance to just 15–25 miles. Even with a naked eye one can see grey landscapes of big cities.

So the answer to the question whether the increase in the number of EVs is rational or not is positive. While fossil fuel is still the world's major source of electricity, the global trend is a shift to the renewable energy in the nearest decades while some countries are already producing most of the electricity from renewables. Such technologies as wind turbines from wood, fat-burning plants, solar windows, thermal solar power plants, etc. are relatively new and are highly potential. Within a lifetime electric vehicle emits less GHG than a conventional vehicle, although there are additional environmental effects from the battery production. The early adoption of EV's will lead to more rapid improvement of the technology and will have a stronger long-term environmental effect.

1.2 Noise Pollution

According to EPA, noise pollution is “unwanted or disturbing sound,” which “becomes unwanted when it either interferes with normal activities such as sleeping or conversation, or disrupts or diminishes one's quality of life”.¹⁸ The noise annoyance can affect normal functioning of nervous and cardiovascular systems, causing a number of disorders such as

¹⁷World Health Organisation. 66th World Health Assembly Side Event. How reducing short-lived climate pollutants can lower the death toll. May 20, 2013 [<http://www.who.int>]

¹⁸United States Environmental Protection Agency. Noise Pollution. [<http://www.epa.gov/air/noise.htm>] (accessed on June 27, 2013)

hypertension, memory loss, decreased attention and productivity, etc.¹⁹ A number of studies show that noise, mainly produced by various types of motor vehicles, increases stress and reduces the quality of life.²⁰ Noise pollution is estimated to cost around 2.1% of the gross national product in industrialized countries, and causes productivity decrease of 0.2%. It also has a number of effects on daily communication. The sound of diesel engines on streets often causes the inability to understand speech, which results in uncomfortable communication and behavioural changes, especially for people with hearing disabilities, the elderly and the children in the process of language and reading acquisition.²¹ According to a study published in Quality of Life survey, out of 5,021 participants more than a half reported traffic noise annoyance and 13% a high level of noise annoyance.²²

While noise level from 30 to 50 dB(A) is considered comfortable for a human being, an average passenger car with 65 mph speed produces around 70 dB(A).²³ In the European Union, 20% of the population are exposed to levels above 65 dB(A). More than 70% of the population in Moscow live in noise polluted areas, with levels exceeding the norm for 15-35 %.²⁴ At the same time noise pollution affects birds, as the study in Ornithological Monographs suggests. It causes physical damage to their ears, stress responses, fright-flight responses,

¹⁹ Jevgenija Semutnikova, "Noise of Megapolis". ECO-Magazine, May, 2009, p.25. print/Евгения Семутникова. «ЭКО-Журнал», Шум Мегалополиса. Available online at: [<http://www.mosecom.ru>]

²⁰ Branko Jakovljević, et al., Road Traffic Noise and Sleep Disturbances in an Urban Population: Cross-sectional Study, Croat Medical Journal. February, 2006; 47(1): 125–133. Available at: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2080382/>

²¹ Berglund Birgitta, et al.. Guidelines for Community Noise, World Health Organization, p. 10. Available at: [<http://www.bvsde.paho.org/bvsci/i/fulltext/noise/noise.pdf>]

²² Dratva J. et al, Impact of road traffic noise annoyance on health-related quality of life: results from a population-based study. Quality of Life Research 2010 Feb;19(1):37-46. Retrieved from: [<http://www.ncbi.nlm.nih.gov>]

²³ Michael Minor & Associates (MM&A), Traffic Noise Background Information. Available at: [http://www.drnoise.com/PDF_files/Traffic%20Noise%20Primer.pdf]

²⁴ Nearly 70% of Moscow's Territory in sound discomfort zone. / Около 70% территории Москвы находится в зоне шумового дискомфорта. *Ria News*. October 2, 2010. [<http://ria.ru/danger/20101102/291881713.html>]

avoidance responses and changes in other behavioral responses and in reproductive success, etc.²⁵

Electric vehicles, in contrast, produce insignificant noise due to the construction of the engine. There is no combustion process, which is the main source of noise in CV's. However, the quietness of EV's made it "silent killers", as some newspapers call it.²⁶ A study covering more than 8,000 hybrid electric vehicles and nearly 600,000 gasoline-fueled cars showed that electric cars under certain speeds are twice more likely to hit pedestrians than conventional vehicles.^{ibid} Even though the quietness of the electric car is highly favored by drivers, the U.S government urged auto manufacturers to solve the problem until 2017. Similar solutions, such as adding a safe level artificial sound, which will be comfortable for human ear are also considered by EU authorities and the United Nations Economic Commission for Europe.²⁷ As of June 2013 no such technology has been implemented, but even if done, it will produce less disturbing sound than a conventional vehicle's engine.

1.3 Fuel Efficiency and Economic Costs Comparison of EVs and CVs.

Since the first Internal combustion engine was built in 1860 significant technical advances were made. In early years the power of the engine was increased by means of the volume of the cylinder and later by increasing the number of cylinders. By the end of the 19th century two-cylinder engines were in use and just in the beginning of the 20th century the number increased to four. Though even with high energy intensive fuel and progress in engine manufacture, ICEs produces significantly less energy than it consumes.

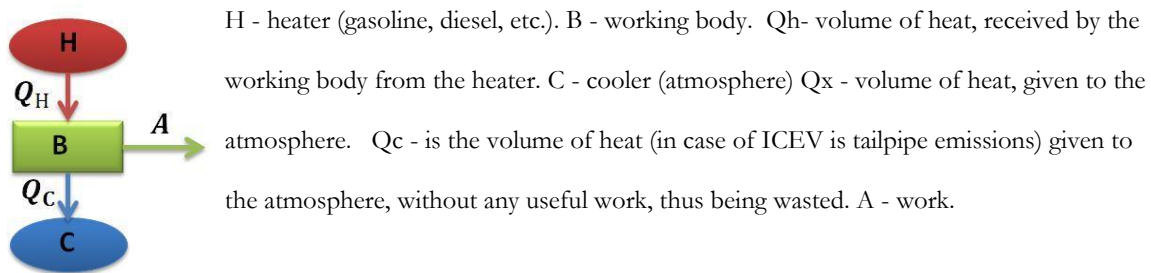
²⁵Catherine P. Ortega. Ornithological Monographs, Chapter 2: Effects of noise pollution on birds: A brief review of our knowledge. 2012. p.6. Retrieved from: <http://www.jstor.org>

²⁶Whorskey, Peter. "The deadly silence of the electric car." *Washington Post*, September 29, 2009, [http://articles.washingtonpost.com/2009-09-23/news/36775126_1_battery-electric-vehicles-hybrid-cars-hybrid-vehicles](accessed July 24, 2013)

²⁷Millward, David . "Plan to tackle 'silent killer' electric cars." *The Telegraph*, November 19, 2012, [<http://www.telegraph.co.uk/motoring/news/9688619/Plan-to-tackle-silent-killer-electric-cars.html>] (accessed July 24, 2013).

The problem is that there are too many factors devaluing the efficiency and foremost it is the construction of the engine and concomitant laws of physics. The core feature of the ICE is that it transforms heat into mechanical work. The principal scheme of the IC engine is drawn below:

Figure 1.5. A general scheme of the ICE



The second law of thermodynamics, which exists in several interpretations, one of which belongs to Rudolf Clausius, states that: “Heat can never pass from a colder to a warmer body without some other change, connected therewith, occurring at the same time”.²⁸ Simply saying, whatever we do, there is always an effect, which leads to warming of the outer air and this effect cannot be completely eliminated by any engineering measures in the cyclic process. In random process it is possible to turn some volume of heat completely into work, but if we want the working body go back to the initial position, there is inevitably a loss of heat.

With all technical improvements that have been done, the actual coefficient of efficiency of the gasoline engine is no higher than 14–26 percent²⁹. It means, that most of the potential energy is lost or transformed into tailpipe emissions. Electric motors in contemporary EVs, in turn,

²⁸ Clausius, R., and Thomas Archer Hirst (1867). The mechanical theory of heat with its applications to the steam-engine and to the physical properties of bodies, p.118. Retrieved from Google Books.

²⁹ U.S. Department of Energy, Fuel Economy: Where the Energy Goes, Available at: [http://www.fueleconomy.gov/feg/atv.shtml]

convert 59 to 62 percent of the energy from battery to the useful work of wheels, which allows the EV to gain higher mileage per unit of energy.³⁰

To compare average fuel efficiency and fuel expenditures we used specifications of 10 random models of electric and gasoline vehicles of 2011-2014 years of production. Vehicles were selected from compact and mid-size classes to avoid a high deviation. I compared annual fuel costs and the cost to drive 25 miles, as well as a mileage per tank or charge and then calculated the average of all indicators. The results are given in the table:

Table 1.1. Comparison of Fuel Efficiency and Fuel Expenditures of various models of EVs and CVs of 2011-2014

Type	Model	Model year	Fuel economy (city+highway) *	Cost to drive 25 miles**	Annual fuel cost**	Mileage ***
EV	<u>Honda Fit EV</u>	2013	118	0,87	500	82
EV	<u>Fiat 500e</u>	2013	116	0,87	500	87
EV	<u>Nissan Leaf</u>	2013	115	0,87	500	75
EV	<u>Ford Focus Electric</u>	2012-13	105	0,96	600	76
EV	<u>BMW ActiveE</u>	2011	102	0,99	600	94
EV	<u>Nissan Leaf</u>	2011-12	99	1,02	600	73
EV	Tesla Model S	2013	95	1,05	650	265
EV	Tesla Model S	2012	89	1,14	700	265
EV	<u>Toyota RAV4 EV</u>	2012	76	1,32	850	103
EV	Chevrolet Spark EV	2014	119	n.a.	500	82
ICE	BMW 328i	2011	22	4,41	2,650	319
ICE	<u>Nissan GT-R</u>	2013	19	5,11	3,050	333
ICE	Nissan Sentra	2013	34	2,63	1,600	404
ICE	<u>Ford Fusion AWD</u>	2012	19	4,71	2,850	282
ICE	<u>Fiat 500</u>	2013	30	3,23	1,950	284
ICE	Honda Fit	2013	30	2,42	1,800	286
ICE	<u>Toyota RAV4 4WD</u>	2012	24	3,73	2,250	343
ICE	Audi A6	2012	28	3,46	2,100	499
ICE	Dodge Avenger	2011	24	3,73	2,250	365
ICE	Chevrolet Spark	2014	34	2,63	1,600	282
Average for ICE			26,4	3,606	2,210	339,7
Average For EV			103,4	1,01	600	120,2

³⁰U.S. Department of Energy, Electric Vehicles (EVs). Available at: <http://www.fueleconomy.gov/feg/evtech.shtml>

Source: Data retrieved from the U.S Environmental Protection Agency. [<http://epa.gov>]

*The fuel consumption of EVs is given in miles per gallon gasoline equivalent (MPGe), which used by the U.S Environmental Protection Agency (EPA), combining 45% driving on highway and 55% in the city.

**Fuel estimates and prices for CVs are based on annual 15,000 miles driving and fuel prices in the U.S in 2012.

***Driving range is calculated assuming that 10% of fuel (battery capacity) in the tank(battery) will remain before refueling.

According to estimates in the Table, EVs are nearly four times more energy efficient, three times cheaper in driving up to 25 miles and four times cheaper in driving annually. However, the driving range of revised electric models is three to four times lesser than of conventional fuel cars which has been an all-time historic constraint for the electric car.

1.4 Energy Security and the Problem with Oil

Energy security, according to the IEA, is an uninterrupted availability of energy sources at an affordable price.³¹ Such supply often creates economic interdependency between states, which cooperate to gain access to energy or energy extraction sources. Economic interdependence combined with democratic governments and international organisations, according to famous Kantian Triangle, should systemically contribute to peace and enhance the absence of warfare.³² However the global interaction between states has rarely been close to perfect Kantian's and one of the dominant motives for civil and international military conflicts and wars have been energy sources, such as oil, with the profit and security they bring³³.

According to Ross, oil states are twice more likely to become authoritarian and more than twice as likely to engage in civil wars as the non-oil states³⁴. The Oil economy does not create

³¹ International Energy Agency official website. Definition of Energy Security.

[<http://www.iea.org/topics/energysecurity/>]

³² Russett, Bruce M., and John R. Oneal. (2001) Triangulating peace: democracy, interdependence, and international organizations., p. 35

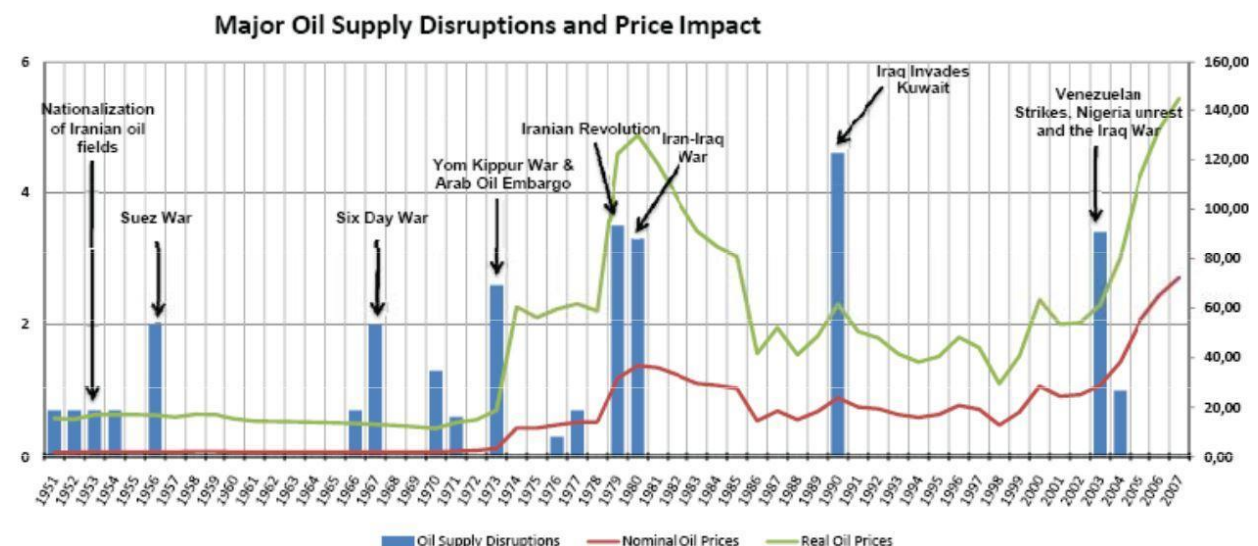
³³ Philippe Le Billon. The political ecology of war: natural resources and armed conflicts, p. 562, Political Geography 20 (2001) 561–584. Retrieved from:

[<http://www.cddc.vt.edu/ept/eprints/ecowar.pdf>]

³⁴ Ross, Michael. (2012) "The paradoxical Wealth of nations." in "The oil curse: how petroleum wealth shapes the development of nations", p.1. Print. Available online at: press.princeton.edu/chapters/s9686.pdf

economic interconnectedness, but only economic dependence. The largest oil-exporting countries are amongst those with the highest wealth disparity and the lowest human development indices³⁵. Furthermore, such economies often have poor social welfare, corruption, weak manufacturing sector and poor governance and are often characterised by such notions as resource curse or as having Dutch disease, which trigger civil conflicts and raise the price of oil. The relation between the price of oil and supply disruptions is given in the figure:

Figure 1.6 Oil Supply Disruptions and Price Impact



Source: International Energy Agency, IEA Response System for Oil Supply Emergencies , December, 2008.
http://www.iea.org/publications/freepublications/publication/EPPD_Brochure_English_2012_02.pdf

High dependency on foreign energy supply has been named as a key issue for the United States for decades and nearly every U.S president in recent decade expressed concern over such state of affairs, including Barack Obama, who said that, "there are few breakthroughs as promising

³⁵Terry L. Karl, Oil-Led Development: Social, Political, and Economic Consequences. CDDRL Working Papers, January 2007, Retrieved from:

³⁵ http://iis-db.stanford.edu/pubs/21537/No_80_Terry_Karl_-_Effects_of_Oil_Development.pdf

for increasing fuel efficiency and reducing our dependence on oil as electric vehicles"³⁶. It is yet mostly the Big Oil companies who lead the charts of the most profitable corporations in the world and the biggest investors in political campaigns and lobbying in the U.S.³⁷³⁸

In the European Union, gas disruptions in 2009 dramatically raised concerns over the foreign control of the energy supply.³⁹ The risks of energy dependence are also amplified by concentrated geographical diversification of energy imports. Russia has been the EU-15's most important exporter of oil and gas for decades and the Kremlin never denied that gas and oil supply are important political and economic tools. On the other hand, the price for oil heavily depends on OPEC investment and production decisions, the economics of non-OPEC petroleum liquids supply and often influenced by political fluctuations in the oil-exporting countries.⁴⁰ With oil being extracted in limited areas, there is no significant shift in oil imports geography expected, as shown on the Figure:

³⁶ Fred Meier, Obama: Feds to buy only alt-fuel cars, sweeten incentives. USA TODAY, Mar 30, 2011. [<http://content.usatoday.com/communities/driveon/post/2011/03/obama-government-buying-only-alternative-fuel-vehicles-boost-incentives-find-more-oil-/1#.UeBIuG1c2hU>]

³⁷ FT Global 500 2012, Market values and prices. Financial Times, 30 March 2012. [<http://www.ft.com/cms/a81f853e-ca80-11e1-89f8-00144feabdc0.pdf>]

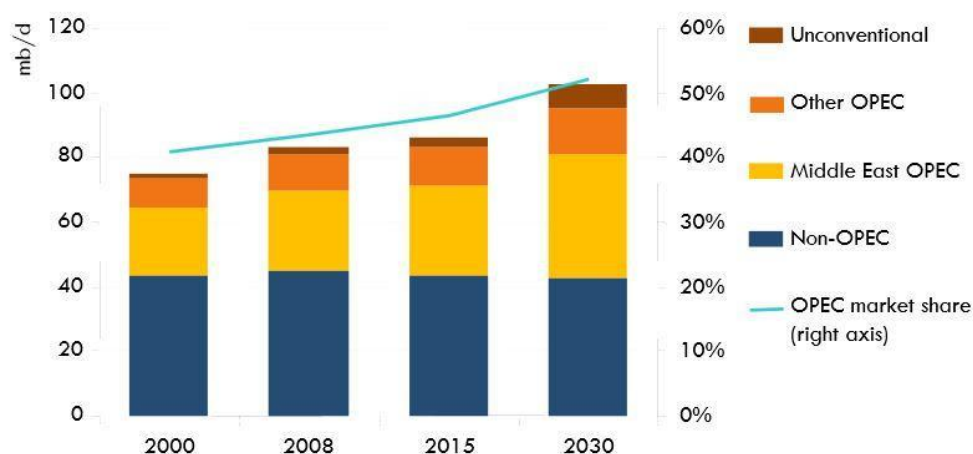
³⁸ Oil & Gas Industry Profile, 2013, Opensecrets.org, [<http://www.opensecrets.org/lobby/indusclient.php?id=E0>]

³⁹ CRS Report for Congress. Europe's Energy Security: Options and Challenges to Natural Gas Supply Diversification, July 11, 2013. Available at: [<http://www.fas.org/spp/crs/row/R42405.pdf>]

⁴⁰ EIA, Annual Energy Outlook 2013, Early Release Overview.

⁴⁰ [<http://www.eia.gov/forecasts/aeo/er/pdf/0383er/%282013%29.pdf>]

Figure 1.7 Oil exporting countries 2000-2030



Source: Jason Elliott, Emergency Oil Stockholding – IEA Experience. International Energy Agency. Slide 6.
[<http://www.energy-community.org/pls/portal/docs/622181.PDF>]

In 2011, the EU-27 energy dependency rate, including both electricity and oil, was 54 % and with current trends the number would increase to 70% by 2030.⁴¹ The problem with electricity is planned to be solved with renewable energy sources. Electricity from wind farms, various biofuels (including combustive briquettes and pellets from wood and agricultural waste), tidal waves and thermal solar power does not require rare expensive materials and can be manufactured domestically, although it does not mean it has to be. The main point is that in case of unforeseen energy disruption, the loss can be compensated by domestic production. The shift from burning oil to solar, wind and biofuel would allow electric vehicles to run on clean domestically produced electricity with 36%⁴² coming from renewable sources by 2020 and between 69% and 74 % by 2030 worldwide⁴³.

⁴¹Factsheet, Meeting of the European Council, EU Energy Policy, February 4 , 2011. [http://www.european-council.europa.eu/media/171257/ec04.02.2011-factsheet-energy-pol_finaldg.en.pdf]

⁴²Global Business Intelligence, “Solar and Wind to Push Global Renewable Energy Share to 36% by 2020”, March 27 2013.

[http://www.gbiresearch.com/pressreleasedetails.aspx?title=Power_~_Alternative_Energy&prid=213]

⁴³ Bloomberg New Energy Finance, “Strong growth for renewables expected through to 2030”. Retrieved from: [<http://about.bnef.com/press-releases/strong-growth-for-renewables-expected-through-to-2030>]

One of the most promising technologies, which creates economic interconnectedness and is effective in ecological terms is the solar thermal power generation. According to Desertec, only 0,3 percent of the desert area in Africa is enough to support the electricity need of Europe, Middle East and North Africa (EMENA).⁴⁴ A number of projects are currently being developed around the globe and one major initiative, a 2.000 megawatt Concentrated Solar Power (CSP) Plant is being introduced in Tunisia by TuNur Ltd. - a joint partnership between a group of Tunisian investors and UK-based Nur Energie. The project will supply some 700,000 houses across the Mediterranean by a high-voltage transmission cable presumably by 2017⁴⁵. It will put a value on land that has no or little alternative use, providing a low cost (around €0.08/kWh) clean energy.⁴⁶ The TuNur project might bring along many economic and political benefits for Tunisia in short and long-term perspectives. According to the organisation, the creation of around 1,500 direct and 20,000 indirect jobs for the manufacturing and operation of the CSP plant is expected.^{ibid} As the construction requires around 825,000 flat plate mirrors and steel heliostats, it will also build up a demand for new local manufacturing industries, while up to 60 percent of the total investment will stay within the country.⁴⁷ In case of success, the project would strengthen economic and political interdependence between Europe and Tunisia and would boost further North-South cooperation.

⁴⁴ Desertec Foundation Official Website. [<http://desertec.com>]

⁴⁵ Guest, Pete. "Vision in the desert: how Tunisian plains could provide all of Europe's energy." *Wired*, October 12, 2012, [<http://www.wired.co.uk/magazine/archive/2012/10/features/vision-in-the-desert>] (accessed July 25, 2013).

⁴⁶ Nur Energie Ltd, White Paper, April, 2011.
[<http://www.nurenergie.com/uploads/Nur%20Energie%20Ltd%20-White%20Paper%20%28DR%2019042011%29.pdf>]

⁴⁷ Wind Energy and Electric Vehicle Review, "Tunisia plans 2 GW Concentrating Solar Power plant to power Europe", January 29, 2012. [<http://www.evwind.es/2012/01/29/tunisia-plans-2-gw-concentrating-solar-power-plant-to-power-europe/16289>]

Another CSP is being constructed in Morocco with the planned capacity of 160 MW by 2015 and will help reduce Morocco's dependence on imported fossil fuel.⁴⁸ By 2020, the country is expected to generate up to 40% of electricity from renewable, mainly solar and wind sources.

The production of Electric vehicles and battery components does not rely on a limited number of suppliers and components can be manufactured in different places. It reduces the risk and diversifies economic relations. There are three main components of the battery - anode, cathode and electrolyte (lithium salts in an organic solvent⁴⁹). Lithium, being the most promising material for EV batteries, is used as a base material for anodes and is available in large quantities (over 100,000 tonnes) on all continents and countries such as Brazil, Argentina, Chile, USA, Canada, Russia, Serbia, Spain, China Zimbabwe, Congo et al (Appendix 1). Cathodes consists of largely available composites such as graphite (fourth most abundant chemical element), or nickel-cobalt-aluminum combination which are also found in numerous places. Therefore, EVs can be manufactured and used with a less risk of price fluctuation and greater economic interconnectedness between countries.

1.5 Power Sources

The battery capacity of electric vehicle was very limited in comparison to gasoline from the very beginning of the 19th century and even with new materials and technology used today, driving range of EVs has slightly changed in most electric models. For instance, Columbia Automobile Company claimed its Phaeton Victoria went a 100 miles on a charge, although

⁴⁸ Meza, Edgar. "Construction Begins on 160 MW CSP Plant in Morocco" *PV Magazine*. May 10, 2013.[http://www.pv-magazine.com/news/details/beitrag/construction-begins-on-160-mw-csp-plant-in-morocco_-100011255/#ixzz2a3Q4DIY6]

⁴⁹Wenige, Niemann, et al. Liquid Electrolyte Systems for Advanced Lithium Batteries. Chemical Engineering Research Information Center(KR). May 30, 1998. Retrieved 11 June 2010: [<http://www.cheric.org/PDF/Symposium/S-J2-0063.pdf>]

with the speed not exceeding 13 mph⁵⁰. Of those current models analysed in the Table 1.1, average mileage of new EV models is 120 MpGe, and then only with Tesla's 265 miles included, which is twice of an average EV.

The improvement of battery technology is a key to making electric car wanted by the majority of drivers. As the U.S department of Energy reported,

If significant advances were to occur in battery technology and the use of low - carbon energy sources for electricity generation, electricity (through battery - electric vehicles) could also substantially reduce transportation GHG emissions by 80 percent or more per vehicle in the long term. Aggressive deployment could reduce total transportation emissions by 26 - to - 30 percent in 2050 if a 56 percent LDV market penetration could be achieved, which is the optimal end discussed in the literature .⁵¹

An improvement of the technology and decrease in price so far has been relatively slow, which explains the fact that most average priced EVs have low capacity. Lithium-Ion batteries, for instance, increased capacity 5-8 per cent per year on average⁵². McKinsey estimated that battery costs could gradually drop from current \$500 per kilowatt hour to \$200 by 2020 and \$160 by 2025.⁵³ Therefore, if the current price of a 65 kWt battery is around \$30,000, it could downshift to \$10,400 in 2020, which would still constitute a significant share in vehicle's overall price.

A significant factor holding the price for batteries high is the unbalanced market. Current Lithium supplies are estimated at 38 Mt (million tonnes), which is enough to supply the

⁵⁰Overview of early electric cars 1895-1925, 1907 Catalog, Low-tech Magazine, [http://www.lowtechmagazine.com/overview-of-early-electric-cars.html]

⁵¹U.S. Department of Transportation, Transportation's Role in Reducing U.S Greenhouse Gas Emission, April 2010. [http://ntl.bts.gov/lib/32000/32700/32779/DOT_Climate_Change_Report_-_April_2010_-_Volume_1_and_2.pdf]

⁵²David L. Chandler, "Research update: Team observes real-time charging of a lithium-air battery". *MIT News*. May 13, 2013. [http://web.mit.edu/newsoffice/2013/real-time-charging-of-lithium-air-battery-0513.html]

⁵³Russell Hensley et al., "Battery technology charges ahead", McKinsey & Company, July, 2012. [http://www.mckinsey.com/insights/energy_resources_materials/battery_technology_charges_ahead]

highest demand until at least 2100⁵⁴, but the demand is not sufficient for such quantity and therefore the price remains high. Considering such market restraints it often takes 15-25 years for an innovative technology, tested and proved in a lab, to be applied in the final product.⁵⁵

Until there is a technological breakthrough, Lithium-Ion batteries are likely to be the dominant source of power for electric vehicles for at least the near time. Lithium-ion cells with cobalt cathodes hold twice the energy of a nickel-based battery and four-times that of lead acid. They are lighter and may achieve up to 10 years of operation.^{ibid.} According to Strategic Analytics, in 2010 98% of EVs used Li-ion batteries.⁵⁶

Car manufacturers still use a number of other technologies, such as nickel-metal hydride (NiMH) and lead-acid batteries, which store around 100 and 50 watt-hours per kilogram respectfully.⁵⁷ But each technology has its shortcomings. Lead-acid batteries, being inexpensive and reliable, have low specific energy output and life cycle, and operate poorly in cold-temperatures. NiMH batteries have longer life cycle than lead-acid but they are expensive in production, self-discharge faster and operate poorly in high-temperature conditions.⁵⁸ In the 90s and 2000s some models used Nickel-Cadmium batteries, but they were banned due to a high toxicity by the European Commission in 2006.

⁵⁴Paul Gruber, Pablo Medina, (2010) Global Lithium Availability: A Constraint for Electric Vehicles? p.1. Available at:

[css.snre.umich.edu/css_doc/CSS10-05.pdf]

⁵⁵Element Energy Limited, (2012). Final report for The Committee on Climate Change, Cost and performance of EV batteries. p.1. Available

at:[http://hmccc.s3.amazonaws.com/IA&S/CCC%20battery%20cost_%20Element%20Energy%20report_Marc_h2012_Public.pdf]

⁵⁶Ross Kenneth Urken, Tesla Debacle Highlights Need For New EV Battery Technology. Forbes, December 2, 2013.

[<http://www.forbes.com/sites/rosskennethurken/2013/02/12/tesla-debacle-highlights-need-for-new-ev-battery-technology/>]

⁵⁷John J.C. Kopera Cobasys, Inside the Nickel Metal Hydride Battery, June 25, 2004, p.4

[http://www.cobasys.com/pdf/tutorial/inside_nimh_battery_technology.pdf]

⁵⁸U.S Department of Energy Official Website. Batteries for Hybrid and Plug-In Electric Vehicles.

[http://www.afdc.energy.gov/vehicles/electric_batteries.html]

A number of innovative technologies, such as Aluminum-air and Lithium-air batteries are being tested and researched. According to a 2002 study at the University of Rhode Island, aluminum-air batteries were the most capable of having a travel range comparable to conventional vehicles with a potential energy density of 1kW-hr/kg compared with 0.4 kW-hr/kg for Li-ion. The research reported that such batteries were the "most promising candidates...in terms of travel range, purchase price, fuel cost, and life-cycle cost".⁵⁹ At the time of writing this paper, Israeli-based Phynergy reported to have made a breakthrough in extending the range of electric vehicle with the Aluminum-air technology.⁶⁰ The company claimed it developed a new system that prevented carbon dioxide from entering the cycle, which in the past was the main problem for such batteries. The outcome was a 1,609 km trip in a single charge for an electric vehicle. But the system has a significant drawback- it is not rechargeable and once depleted, battery with around 25 kg of aluminum has to be replaced. Applying such battery in a commercial use would be only possible if combined with a network of replacement stations, such as Better Place's (discussed in chapter 3). Lithium-air batteries on the other hand, could increase the the performance five to 10 times, but the technology is still under development.⁶¹

Comparative advantages/disadvantages and specifications of batteries are given in the table:

⁵⁹John Hewitt, Doe calls for a chemical battery with 5x capacity, within 5 years – can it be done?, *Extreme Tech*. December 5, 2012. Retrieved from [http://www.extremetech.com]

⁶⁰Phynergy Official Website. [http://www.phynergy.com]

⁶¹David L. Chandler, "Research update: Team observes real-time charging of a lithium-air battery". *MIT News*. May 13, 2013. [http://web.mit.edu/newsoffice/2013/real-time-charging-of-lithium-air-battery-0513.html]

Table 1.5 Comparison and specifications of car batteries

Chemistry	Lithium Ion	Aluminum-Air	Nickel-Metal Hydrid	Lead-Acid
Energy per unit mass +	100–265 Wh/kg	1300 Wh/kg	60–120 Wh/kg	30–50 Wh/kg
Range in an EV	120-265 miles	1,000 miles	80-100 miles	less than 80 miles
Price	\$300 per kW, \$10,000–\$15,000 per pack*	\$ 1.1/kg	\$500 to \$550 per kW	\$150-\$200 per kW
Lifespan	100,000 miles ⁶² , 400–1200 cycles	single use	500–1,000 cycles	500–800 cycles
Charge/Discharge Efficiency	80 to 90%	--	60–70%	50%–92%
Advantages	high charge density, slow loss of charge, rapid charge	high capacity, low cost	long life,	low cost
Limitations	high cost	non-rechargeable, must be replaced	high rate of self-discharge, poor performance in cold weather	Toxicity, high mass
EV Models	Tesla, Nissan Leaf	Citroen C1 (testing model)	Toyota Prius, GM EV1 (2nd gen) Honda EV Plus	Detroit Electric, EV1, RAV4EV.

Sometimes there is a concern over the lithium utilisation and environmental safety of battery production, but lithium-ion batteries can be utilized ecologically safely and the process itself

⁶²Cristen , Conger. "Will lithium-ion batteries power cars?." *How Stuff Works*.[\[http://auto.howstuffworks.com/fuel-efficiency/vehicles/lithium-ion-battery-car2.htm\]](http://auto.howstuffworks.com/fuel-efficiency/vehicles/lithium-ion-battery-car2.htm)

does not require complicated technological means⁶³. The battery consists of inert materials, such as carbon, iron phosphate, etc., as well as substances which are utilizable by 95% and even there are recycling facilities in many countries, the demand for lithium is still on a low level and it will take several years before the high scale recycling is needed.⁶⁴

Before batteries become more energy-dense a number of advanced technologies for the infrastructure could provide a solution. Volvo Group has been testing a system, which continuously supplies vehicles with electric power through power lines built into the road. Such system would allow a quick recharge for electric buses, when they collect passengers at stops.

Wireless charging systems can also be placed at parking lots and along city sideroads as well as private households. It would free the driver from a necessity to plug in every time and eventually would allow not to bother about the miles left till the battery depletes.

Some car manufacturers already produce electric models with built-in wireless chargers. The Rolls-Royce already supplies its electric 102 EX Phantom with a wireless charging system from HaloIPT and Infiniti's electric Leaf is supposed to have an option with wireless inductive charging system in 2014.

General Electric, Bosch, Halo, Evatran and other companies already offer wireless chargers which can be mounted into the wall. The cost of such systems varies from under \$1,000 to \$3,000 and the electricity delivery to the battery reaches 80% to 97% from the grid and takes the same time as from the plug.

⁶³Better Place Official Website, (2011) Do Lithium-Ion Batteries Support Sustainable EV Driving? [<http://www.betterplace.com.au/media/docs/Do-lithium-ion-batteries-support-sustainable-EV-driving-ONLINE-30a25a6c-7e05-4409-9db6-8ee71ef8f812-0.pdf>]

⁶⁴Denis Born. Recycling lithium batteries- the salvation for automobile industry/Переработка литиевых батарей – спасение для электроавтомобилей. August 15, 2009. 3D News.ru [<http://www.3dnews.ru/578276>]

2.0 HISTORICAL CHALLENGES FOR ELECTRIC VEHICLES

Such features of electric vehicles as regenerative braking, 100 km range and battery swap stations have already existed in early 1900s, but nevertheless electric vehicles had little market success, being mostly applied in niche segments, such as taxi fleets, public services or second cars. A number of factors led to the widespread use of ICE vehicles after 1900s in industrialised countries and to a gradual downshift of EV technology. This chapter will focus on the development of EVs in the U.S., Europe and the xUSSR. The main question to be answered is why EVs did not succeed in seizing the market of passenger automobiles.

2.1 The United States and Europe

The history of electric vehicles could be counted back from the point, when Luigi Galvani discovered the electric current in his lab or when Alessandro Volta found out that electrical energy can be stored chemically and made the first wet cell battery. In 1859, belgian Gaston Plante´ demonstrated the first lead-acid battery cell which was used in electric vehicles for a long time and still dominates in all ICE's as a starter battery. Each of these steps were essential links in a chain of discoveries, leading to the inception of first practical electric carriages in the USA and Europe in the mid-1880s.⁶⁵

Anderson divide the history of EVs into the Early Years (1890-1929) with the Golden Age on market from 1895 to 1905, Middle Years (1930-1989) and Current Years (1990 -present)⁶⁶. During the early years of “horseless carriages” many European countries, such as France, Scotland, England, Italy and Germany developed the technology independently. France was a pioneer in the industry, until it was and new enterprises were established the United States in

⁶⁵ Karl Georg Hoyer. The history of alternative fuels in transportation: The case of electric and hybrid cars. Utilities Policy 16 (2008) 63-71. p.1-2. Available online at: [http://web.uvic.ca/~jlutz/courses/hist317/pdfs/Hoyer%20History%20of%20Fuel%20Options.pdf]

⁷⁰ Darrel D. ,Anderson J.. Electric and hybrid cars: a history. McFarland, 2005. p.17.

1904⁶⁷. At that time, so as nowadays, the merit for a technological advancement of the vehicle was a race. The image of the fast and quiet electric car was amplified when Camille Jenatzy broke the first 100 km/hour mark with his racer *La Jamais Contente* in 1899 and gave another push for engineers to go on with the research.

In contrast, Germany's policy prioritised public electric transportation over a passenger fleet. Most of the research was conducted by the biggest company in the industry - Siemens & Halske, which is still (Siemens) the leading producer of public transport vehicles in Europe. German engineers were more interested in the gasoline engined vehicle, since it was mostly developed there by Karl Friedrich Benz, Gottlieb Daimler and Siegfried Marcus. The first German electric vehicle was known as the Lohner-Porsche, driven by steered wheel-hub motors (Porsche). During the first five years of series production approximately 65 cars were sold. Later Ferdinand Porsche modified it into a first functional, full-hybrid petrol-electric car. Despite a groundbreaking technology, the price was too high and he managed to sell only 11 vehicles. The production line had to be shut down due to the low return on investment.

With a few vehicles sold to private customers in Germany, electric cars were applied well in niche markets, such as taxi fleets. As Edgerton writes, around 20 per cent of motor taxis in Berlin between 1907 and 1918 were run by electricity and many fire departments replaced horses with electric cars.⁶⁸. They could afford storing several batteries for one vehicle, so drivers could replace them during the day. Thriving taxi businesses were also set up in cities of the U.S and Europe - already in 1897 there were 15 electric taxis in London and 13 in New York (rose to around 100 by 1900). They were called "horseless carriages", until a London newspaper coined the term "automobiles" in 1895.^{ibid}. Still today, taxi companies are major

⁶⁷IEEE Industrial Electronics Magazine [1932-4529] Guarnieri yr:2011 vol:5 iss:2 pg:46 -53 , M Guarnieri, When Cars Went Electric, p.46-47

⁶⁸Edgerton, David. The shock of the old: technology and global history since 1900. Oxford, 2007. p.9

customers for producers of EVs. But, as Kirsch argues, poor business management of the taxi companies caused the downfall of the technology.⁶⁹

Although electric vehicles appeared in the United States of America some decade after Europe, they soon increased in numbers. According to Mom, by 1900 there were 4192 vehicles registered in the U.S., of which 1681 (40,1 %) worked on steam, 1575 (37,5 %) on electricity and 936 (22,4%) on gasoline.⁷⁰ Therefore, it was a little indication of which type would dominate in the future. Steam-powered cars were the fastest machines on the roads of that time and prevailed among driving population, although later they were outnumbered by gasoline, because the former required up to 4.5 litres of water per every mile and due to vast boilers and water tanks were losing efficiency. The most unpopular were gasoline-powered vehicles, which produced noise and smell and functioned worse in low temperatures than electric vehicles⁷¹. The latter, clean and quiet but slow, were popular with the more practical-minded users. They did not require a manual effort to start and were often seen appropriate for running errands around town. As New York Times article reported in 1911:

“Ever since the small electric runabouts were introduced, about ten years ago, “they have always been popular with women. In the early days of motoring, the little electrics were about the only kind of motor car a woman could handle easily as the early gasoline cars required more strength to crank than most women possess. Another great advantage of electrics in years gone by was their quiet operation, as compared with gasoline cars, and this fact alone was responsible for their widespread use by women.”⁷²

⁶⁹ Richard F. Hirsh, Review of “The Electric Vehicle and the Burden of History” by David A. Kirsch, p. 388. Retrieved from: [<http://www.jstor.org>]

⁷⁰ Mom, Gijs. The electric vehicle: technology and expectations in the automobile age. Baltimore: Johns Hopkins University Press, 2004. Print, p. 34

⁷¹ Valdes-Dapena P., “Hybrid cars are so last century”. CNNMoney, April 24, 2006. [http://money.cnn.com/2006/04/18/Autos/alternative_fuel_history/]

⁷² New York Times. "Electric Vehicle Man's Arguments; He Presents the Case of His Product as Against Gasoline Car." Print. January 19, 1913. [<http://query.nytimes.com>]

And as "Electrical World" wrote in 1909:

"The average EV, as built today, has considerably more available mileage on one charge of battery than the average vehicle of ten years ago, and what is more, has a considerably greater mileage than is actually needed in the run of business or pleasure, except where a long tour is undertaken."⁷³

Since the technical parameters of existing engines were similar, the amount of research was relatively equal. In 1901, Thomas Edison came up with the nickel-iron battery (later used in some electric trucks in the USSR) which could store 40% more energy per weight unit than the existing lead-acid battery, but the production costs of the new cell were inapplicable to the mass market and so it was precluded from a wider use⁷⁴.

Around 1912 the production of electric vehicles (both passenger and trucks) driven in the U.S peaked with 30 000 (little compared to 900 000 gasoline-engined cars). The growth was brought by steady improvements in battery capacity (65 miles per full charge with some models reaching 100 miles), growing numbers of "Garages for recharging" and a slight fall in electricity price (from 4 to 3,5 cents per kilowatt hour). A number of coin-operated charging stations was developed in New York city around back in 1900. The driver had to deposit a certain amount of coins to get a needed amount of watt-hours. Such system was effective and convenient, but it failed to develop within larger distances and was completely overtaken by a rapidly growing number of gasoline stations. Another innovative idea was a system of fast battery swapping, which allowed to insert fully charged batteries right away.

In Europe the number of EVs on the roads was significantly less, about 1600 in 1914.⁷⁵ Also around the same time the Woods Gasoline Electric appeared on the market, being one of the

⁷³ Low-tech Magazine, "Overview of early electric cars". [<http://www.lowtechmagazine.com/overview-of-early-electric-cars.html>]

⁷⁴ Høyer. The history of alternative fuels in transportation. p.3

⁷⁵ Mom, The electric vehicle: technology and expectations in the automobile age, p.252

most efficient of early hybrids, carrying a gasoline engine coupled to an electric motor generator. The car could be operated as straight gasoline vehicle as well as a straight electric, being what we now call parallel hybrid vehicle. The only drawback of this type was its price of \$2,650, which made it hardly competitive among other vehicles.

However shortly after some ascent the popularity of electrics started to decrease. The road infrastructure between cities in the U.S was steadily improving, causing demand for long-range trips, which EV's could not provide. In addition, the electrical infrastructure in the early 1900s was poor. Some areas used Edison's direct current, others Tesla's alternative. There was no standard voltage or frequency and residential electricity was rare. There were no charging stations along the way between some cities of the U.S and battery exchange systems were neither sufficiently standartized nor extensive enough. For instance, between New York and Chicago there was one space of 123 miles between charging stations and none between Salt Lake City and Sacramento.⁷⁶

It is suggested by some historians, that there was no such factor as responsibility for the environmental future from early automakers. Kirch argues, that they could not know, or did not give much thought to it, how their decisions would affect the future of the automobile industry. He also argues that even if the electric vehicle or other alternatives were more successful, they would still result in environmentally unfriendly development since coal was the primary energy source for several centuries and remains so until today.⁷⁷

EVs lost their biggest advantage of easy start with the invention of electric starter for the gasoline engine by Charles Kettering in 1912, although Mom noted, that "it is not correct to claim that the electric starter motor meant the deathblow for the electric car. But it did mean

⁷⁶ Anderson et al. Electric and hybrid cars: a history, p.21

⁷⁷ Stephen H. Cutcliffe, Review of "The Electric Vehicle and the Burden of History", p.327. Retrieved from: [http:\\ jstor.org]

the last nail in its coffin”.⁷⁸ The famous 1908 Model T of Ford Motor Company, preceded by Model K, were both working on gasoline, but firstly did not use electric starter and nevertheless were sold in big quantity. The price of Model T gradually decreased to \$260, due to production savings from the introduction of the assembly line and made it affordable for an average consumer.⁷⁹ It shortly gained popularity in other countries around the globe starting with England in 1911 and then in Germany, Argentina, France, Spain, Denmark, Norway, Belgium, Brazil, Mexico, and Japan. By 1914 Ford produced more gasoline cars than all other automakers combined in the US. Even though most basic electric vehicle cost under \$1,000, most were ornate, massive carriages designed for the upper class. They had fancy interiors, with expensive materials, and cost in between \$1700-3,000 by 1910.⁸⁰ Such product was not suitable for the long-term survival on the mass market.

Apart from a high competition and price, there were also restraints from the governmental policies. Electric cars in the U.S were charged a higher fee to cover wear and tear on the road’s surface because of a larger weight with heavy batteries.⁸¹ For instance, an early mentioned racing 1902 Lohner-Porsche Rennwagen carried 1800 kg of batteries only, together with four 1,5 kW motors being incredibly heavy.⁸²

⁷⁸ D. J. Santini, (2011) Electric Vehicle Waves of History: Lessons Learned about Market Deployment of Electric Vehicles, p.38. Retrived from: [http://cdn.intechopen.com/pdfs/18663/InTech-Electric_vehicle_waves_of_history_lessons_learned_about_market_deployment_of_electric_vehicles.pdf]

⁷⁹Ford Official Website, Model T Facts.
[http://media.ford.com/article_display.cfm?article_id=858]

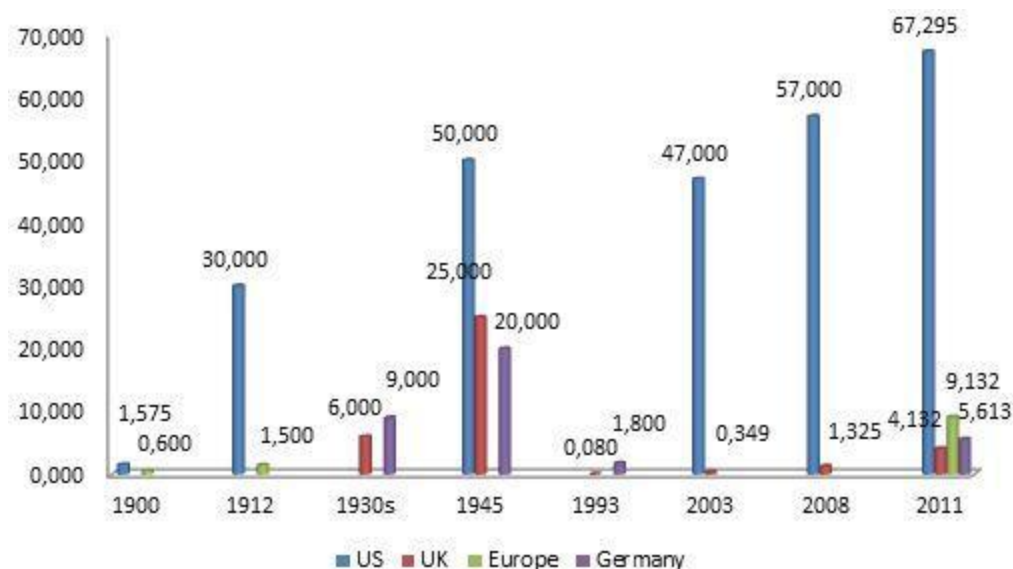
⁸⁰Anderson et al., Electric and Hybrid Cars: A History, p.5
Westbrook, M. H.(2001) The electric car: development and future of battery, hybrid and fuel-cell cars. London. Print, p16

⁸¹ Westbrook, M. H.(2001) The electric car: development and future of battery, hybrid and fuel-cell cars. London. Print, p16

By the early 1920s the production of electric vehicles for personal use in the U.S. was rapidly shrinking toward zero. As Santini writes⁸³, “The widespread 1912-1916 adaptation of a cost effective combination of electrical and mechanical features in the predominantly mechanical gasoline vehicle signaled the end of the electric passenger car about a decade later”. But commercial and industrial (non-road) trucks continued to grow in use during most or all of the 1920s and in some applications on into the 1930s. At the same time the number of EVs in 1939 in Germany numbered 9,000, and by 1944 reached 20,000. Such growth could be explained by the government’s aim to reduce the dependency on oil in war conditions.

The data on numbers of EVs during 1900-2011 is collected in the Figure:

Figure 2.1 Number of electric vehicles 1900-2011



Notes: Due to the narrow focus of the research, data includes all-electric vehicles only (both passenger cars and trucks) and not gasoline-electric or diesel-electric hybrids. The composition of the diagram is conditioned to the data availability. Data for the period of 1900-1912 is according to G.Mom. Data for the period of World War II is according to Høyer. In the UK during 1930s-1960s EV fleet consisted mostly from milk vans. Numbers of EVs in the US for 2008 were calculated assuming the average annual 4% increase over the period from 2003-2006. Data for the UK retrieved from Cenex.⁸⁴

⁸³ Santini, *Waves of History*, p.37-38

⁸⁴ Cenex.UK Electric and Hybrid Car Registration Statistics (Chart). Available at: [\[http://www.cenex.co.uk/programmes/plugged-in-midlands/electric-car-registration-statistics\]](http://www.cenex.co.uk/programmes/plugged-in-midlands/electric-car-registration-statistics)

In the period of 1960s and 1970s it was especially popular to “make love, not war” and environmental awareness and sustainable energy became very actual in the U.S and many European countries⁸⁵. Alternative forms of activism were on the rise and electric vehicles were part of the movement, as they represented, to a certain extent, the incomppliance with the policy of environmentally unfriendly gasoline and oil dependence. National Union Electric Company manufactured a Henney Kilowatt in 1959, which could reach a maximum speed of 64 km/h and cruising the same 64 km on a single charge. In a year the model was upgraded and the maximum speed and the range were increased to 97 km/h and 97 km respectfully. However, out of 100 models produced, only 47 were ever sold. Perhaps, the main reason was the price of \$3,600, while the average price for a gasoline car was around \$2,650.⁸⁶ In the U.S three bills in the Congress related to the Electric Vehicle Development Act of 1966, which provided funding for research and development. There was a total of 86 projects involved in the battery research in the U.S.

Starting in 1974, just a year after the 1973-1974 oil crisis, an electric “CitiCar” of the American company Sebring-Vanguard was introduced. It was able to travel 80-95 miles on a single charge with a maximum speed of 26 mph. There were around two thousand vehicles sold, mainly due to the low price (about half the price of an average vehicle). But the model had a number of limitations, such as low speed and specific design (modified golf cart), not appealing to general public. A hard blow came from Consumer Reports, which claimed that the model was “Foolhardy to drive...on any public road...acceleration was slow...steering was very quick

⁸⁵Stolley, Richard B. (1998), *Turbulent Years: The 60s (Our American Century)*, Alexandria. p.137

⁸⁶Micheline Maynard, 'Mad Men' And The Glory Of Mid-1960s Cars, March 22, 2012, Forbes.

[<http://www.forbes.com/sites/michelinemaynard/2012/03/22/mad-men-and-the-glory-of-mid-1960s-cars/>]

and unpredictable...braking tests went no better...felt as if it had no springs at all"⁸⁷ and had "major safety and operating problems"⁸⁸ Such reviews, coupled with a competition from fuel-efficient Japanese cars, seriously harmed the vehicle as a product and the company eventually went bankrupt. The design of the "Citicar" was bought by another company and the descendant, called Comuta-Car, was available for several years, but sales did not exceed 4,400 pcs.^{ibid.} The founder of the Sebring-Vanguard, Bob Beaumont, revived the effort in mid 1990s, with a fancy roadster called Tropica, which could run 130 km on one 8 hour charge, but an expensive car did not find a sufficient demand and only 25 vehicles were ever sold.⁸⁹

According to Hoyer⁹⁰, the 1990s has been the most intensive period in the development of the electric car. Much effort was put into the battery improvement, many R&D conferences on electric car took place and new enterprises were established in the U.S. and Europe. One of the most important initiatives in terms of legislation was a Zero Emission Mandate by the California Air-Resource Base, which demanded that 2% of all vehicles produced, must have zero emissions by 1998 and 10% by 2003.⁹¹ The legislation urged major car manufacturers to develop new efficient models and technologies. For instance, Toyota developed a first all-electric crossover utility vehicle (CUV) RAV4 with 89 kW battery, but made it available in limited quantity to customers, despite a long waiting lists of potential buyers. In total 1,484 items were sold from 1997 to 2003. Later Toyota cooperated with Tesla Motors to improve the efficiency of the model and the second generation with a 100 miles range was released in 2012. There was a number of other models produced, such as Ford Ecostar with 130 to 160

⁸⁷Chris Landers, "Columbia Man Recalls His Past Creating and Selling Electric Cars". August 6, 2008. City Paper. parag. 10. [<http://www2.citypaper.com/news/story.asp?id=16113>]

⁸⁸Bunkley, Nick. "Bob Beaumont, Who Popularized Electric Cars, Dies at 79", The New York Times, October 29, 2011. [http://www.nytimes.com/2011/10/30/business/bob-beaumont-who-popularized-electric-cars-dies-at-79.html?_r=0]

⁸⁹Citipaper, "Columbia Man Recalls His Past Creating and Selling Electric Cars"

⁹⁰Hoyer, The history of alternative fuels in transportation, p. 70

⁹¹California Environmental Protection Agency Official Website.[<http://www.arb.ca.gov>]

km, Ford Ranger with 100 km, Chevrolet S-10 with 72,5 km, Honda EV Plus with 160 km among others.⁹²

The most significant model EV1 was manufactured by General Motors in 1997. GM has invested heavily in its first electric model and initially designed it to be electric rather than an electrified version of the conventional car. The lead-acid battery of the first generation allowed 80-100 miles, while the second generation model of 1999 used nickel-hydrate battery which allowed 100 and 140 miles between charges. The use of light aluminum alloy in body and powertrain construction allowed to reduce the overall weight and increase the driving range. The outer panels were made of polyurethane, and the doors, roof, hood and trunk lid of composite material. Eventually the vehicle weighed just 1350 kg, with 530 kg accounting for the battery. The body was designed to be highly aerodynamic. To reduce the rolling resistance, tires were made narrow (175/65R14) with high pressure air, developed specifically by Michelin for the EV1.⁹³

As one of the leading GM's engineers Ken Baker said, "Our plan was to be battery agnostic - take the best available and focus on engineering the world's most efficient vehicle, which would give dramatically better performance once a better battery came along..The goal was to do a new car in a new way and see how quickly and efficiently we could do it".⁹⁴

However, after 1,117 items were leased, General Motors shut down the production and recalled all vehicles for destruction. GM stated that the programme did not meet expected sales volume and did not have enough return on investment into research and development. As former CEO of Chrysler and the head of product development at GM Bob Lutz said in LA

⁹³Charles, Murray. "Is GM's EV1 Still the Best Electric Car Ever? ." *Design News* , October 17, 2011, [http://www.designnews.com]

⁹⁴Gary , Witzenburg. "At Witz End - GM's EV1, the True Story, part I.", parag. 8, Autoblog Green, August 15, 2008, [http://green.autoblog.com/2008/08/15/at-witz-end-gms-ev1-the-true-story-part-i/] (accessed July 25, 2013).

Times, We lost over one billion dollars on that experiment." An article in NY Times claimed that EV1 was "too expensive and quirky to find wide acceptance"⁹⁵

However, the model was well accepted by consumers. A documentary Who Killed the Electric interviewed many ex-owners of the EV1, including such Hollywood stars as Tom Hanks and Danny DeVito, who claimed to enjoy driving the car and regretted the cancellation of the programme. ⁹⁶

The "gilded age" of the electric car could be much more successful, if the car automakers were more willing to promote electric cars. There were hardly any precedents, when people lighted candles for the R.I.P of the electric car, as they did in front of GM building in California, after the EV1 was cancelled. After G.M. and DaimlerChrysler and the Bush Administration sued the California Air Resources Board , the ZEV mandate was cancelled and the most powerful legal tool for to make automakers produce electric vehicles was eliminated. By 2000s most of the automakers discontinued their EV programmes.⁹⁷ It took nearly a decade for the electric car to return with several models of Nissan, Tesla, Mitsubishi and others.

2.2 Former Soviet Union (FSU)

The history of electric vehicles in the Former Soviet Union is interesting in terms that in a planned economy marketing had nearly no impact on the development of the technology and frankly, the economic preferences of users had lesser impact on sales than in open economies

⁹⁵Micheline Maynard. "Cleaner Cars Are Here, if You Can Find Them." NY Times, September 9, 2001, [<http://www.nytimes.com/2001/09/09/business/09FUEL.html>] (accessed July 25, 2013)

⁹⁶ Interview with Danny DeVito, Who Killed My Car?Youtube.Uploaded on Jan 12, 2007. [<http://www.youtube.com/watch?v=rJBLocSokDE>] (accessed July 25, 2013)

Interview with Tom Hanks, Hanks GM EV1, saving the world Dave.Uploaded on Sep 23, 2006. [<http://www.youtube.com/watch?v=3ldmWebfIUU>]

⁹⁷ Timeline: History of the Electric Car. PBS News. [<http://www.pbs.org/now/shows/223/electric-car-timeline.html>]

of the Western countries. The most important factor for the electric propulsion was the possibility to adopt the technology on a vast territory of the FSU.

In the early 20th century, the future Soviet Empire was retrograded in comparison to more industrialised economies of Europe and the U.S. and only several big industrial centres progressed. According to Shugurov., first electric automobiles were constructed by the Russian engineer Ippolit Romanov and built in 1890s jointly by the factories named after Peter Freze and Evgenii Jakovlev⁹⁸ The latter firstly produced gasoline vehicles and supplied engines for the joint venture, but when passed away, there was no one to replace him. Before Freze managed to export gasoline engines from French “De Dion-Bouton”, he produced electric vehicles in small quantities. The first electric omnibus constructed by Romanov had regenerative braking and the capacity equivalent of 6 horse powers with 64 km per charge and weighted 720 kg, 350 of which were of battery. The vehicle was tested in St. Petersburg in 1901 and was given a green light by state authorities to operate on ten lines of the city. Romanov planned to introduce 80 vehicles, but financial conditions proposed by the government and his own financial restraints prevented his plans.^{ibid}

There were also numerous challenges for the automotive industry in general. In the beginning of the century, the road infrastructure was very poor and the emphasis was put on the construction of railroads, which were more available for the public. In later decades the emphasis was on the military machinery, which was too heavy to use electric propulsion and therefore there was little chance for passenger electric cars to develop independently. However, fuel shortages during the First and the Second World Wars led to an increase of

⁹⁸Shugurov L.M. *Automobiles of Russia and USSR*. 1993, Part 1, p.7. Print. / (Шугуров Л.М., Автомобили в России и Советском Союзе, 1993, Часть 1)

trolleybuses, which filled nearly every city of the Soviet Union. Such vehicles were a good solution for urban areas due to high carrying capacity and low exploitation costs.

Despite many attempts of Soviet electrical engineers to come up with a vital solution for EV batteries, no viable technology which would allow mass production was invented. The efforts were undertaken several times by various institutions. Some prototypes appeared mainly in University labs in 1930s. In 1935 scientists at Moscow Energy Institute created the LET (short for laboratory of electric current) - electric truck designed for the transportation of waste. It weighed around 4,2 tons and could carry 1800 kg. With 13 kW battery it had a range of up to 40 km with a maximum speed of 24 km/hour, but the primitive construction was not suitable for the mass production and the model remained a single piece ever built.⁹⁹

Some models of electric buses and trolleys were built at the same time, but very few reached the streets. In 1948 Central Research and Scientific Automotive Institute (NAMI) produced two models of electric trucks on lead-acid batteries, which delivered post within Moscow. Later on, Lviv Automotive Factory (LAZ) in the former Ukrainian SSR produced ten pieces of these models with iron-nickel batteries, which were exploited during 1952-1958 in Leningrad (Current Saint Petersburg).¹⁰⁰

The functioning of so called Local Economic Councils (Советы народного хозяйства) in 1957-1965, decentralised the control over the automotive enterprises and allowed them a certain autonomy to develop mutual “business” relationships, which boosted the development

⁹⁹Batterygarbage carrier LET/Аккумуляторный мусоровоз ЛЭТ. October 12, 2012. Fuerzatecnologica.com [http://fuerzatecnologica.com/content/akkumulyatornyy-musorovoz-let]

¹⁰⁰ Tokmanov N.M., History of the Automobile in Russian and the Soviet Union, February 2010. (Токмаков Н.М., История электромобиля в Советском Союзе и России) Retrieved: May, 2013 [http://www.samodelkin.komi.ru/history/ussr.html]

of conventional automobiles. As the aviation shifted from piston to jet engines, the supply of higher quality gasoline increased and increased the efficiency of gasoline vehicles.¹⁰¹

In the following 1970s the research was done for both electric and hybrid vehicles. Among research institutions were Scientific and Research Institute of Motor Transport (NIIAT), All-Union Scientific and Research Institute of Electromechanics (VNIIEM), All-Union Scientific and Research Institute of Electric Transport (VNIJET) and a number of automobile factories, such as VAZ, ErAZ, RAF and UAZ. But no vital solution was achieved. As an author of “Elektromobili” (Electric Vehicles) O. Stavrov wrote in 1968, “No electric vehicles are used in the Soviet Union”¹⁰²

However, in 1976 a series of electric microbus RAF-2203 was launched at Elgavskiy automobile factory. With a heavy 630 kg battery pack they still had a limited range of up to 70 km, although could be charged to a 70% capacity within an hour. Several pieces of RAF- 2203, produced for judges were even modified with solar panels, but apparently the capacity was still not enough to fully charge the heavy powersource and the production was discontinued. Some time later, during 1980-1985 there were 65 pieces of a passenger electric UAZ-3801 produced. With one full charge the model could go for around 50 km, and with the installation of regenerative braking system the range increased to around 75 km. As a chief constructor Nikolay Kuznetsov commented at Philadelphia auto expo in 1978, “Our vehicle was the only one working on the alternative current.”¹⁰³

In the same period a passenger electric VAZ 2801 was recommended for the production by the Ministry of Automotive Industry of USSR. Unconventional model with big signs on the side saying “Electro” was used for the public needs in cities and enterprises, such as delivery of

¹⁰¹ Shugurov, Automobiles of Russia and USSR. 1994, Part 2, p.7

¹⁰² O. A. Stavrov, (1968) “Electromobili”, Transport, Moscow Typography No 19. Print. p.7

¹⁰³ The history of creation, modelling and modification of UAZ/История создания, модели и модификации автомобилей УАЗ. Uazbuka.ru [<http://www.uazbuka.ru/history.htm>]

post or breakfasts. The exploitation of around 50 pcs. revealed its ability to perform certain tasks, but the production was shortly shut down due the low capacity of nickel-zinc battery, used in the vehicle.¹⁰⁴

By and large, no battery technology could provide a descent alternative to the conventional transportation in the Former Soviet Union. One of the latest electric prototypes of the FSU was Moskvich-2141E1 with a 19-30 kW motor, 110 km max speed and approximate 100 km driving range. But despite good characteristics, the project was not developed further due to high production costs.¹⁰⁵

2.3 China

In the beginning of the 20th century, when the automotive industry emerged and rapidly developed in the U.S. and Europe, China was still largely an agrarian economy with no more than eleven cities of more than 100,000 people¹⁰⁶. First vehicles were imported from abroad, mainly from the United States in 1901 and ran mostly on the streets of Shanghai. For many decades, the Chinese economy was based on the natural resource export under the influence of Japan and first attempts to create a producer sector began only in late 1930s¹⁰⁷. But the wartime conditions postponed such objectives and urged the government to focus on building military self-sufficiency. The efforts were renewed only in early 1950s by the communist government.

¹⁰⁴Short Automotive Directory of NIIAT, 10th ed. revised, Moscow: Transport, 1985, p.27/ Краткий автомобильный справочник НИИАТ

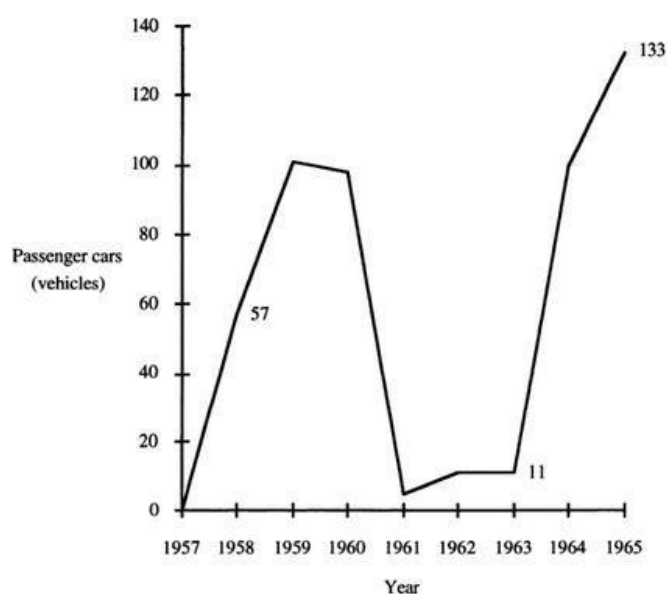
¹⁰⁵Tokmanov, History of the Automobile in Russian and the Soviet Union, [http://www.samodelkin.komi.ru/history/ussr.html]

¹⁰⁶Bairoch, Paul. The economic development of the Third World since 1900. Berkeley, 1975. p.156. Print.

¹⁰⁷Perkins, Dwight H., and Gang Zhao. China's modern economy in historical perspective: sponsored by the Social Science Research Council. Stanford. 1975. Print. p.109. Retrieved from Google Books

The construction of the first automotive factory (FAW) began in 1953 in Changhun city with the help of the Soviet Union¹⁰⁸. The internal demand for passenger automobiles was weak and therefore first cars were heavy trucks and utility vehicles. The first model was a four-ton Soviet ZIS 150. By the mid-1950s the manufacturing of passenger vehicles started, but those were designed for party members and the numbers were extremely negligible. In 1962, according to Harwit, only five vehicles were produced in the whole country (see Table):

Table 2.1. Annual Vehicle Production in China 1957-1965



Source: China's Automobile Industry, as quoted in Harwit, China's automobile industry, p. 18

In 1980s the production of passenger cars was still very limited. They were only available for senior officials and there were strict regulations even for party members on the usage of automobiles. But international relations and domestic situation changed with the death of Mao Zedong in 1976. China began to open its doors to other countries, as Holweg et.al put it,

¹⁰⁸Harwit, Eric. China's automobile industry: policies, problems, and prospects. Armonk, N.Y, 1995. p.17

“Developing Productive Power” became the priority¹⁰⁹. Such relaxation led to a transition to the market economy and increase in customers and production of automobiles. Two largest factories, the FAW and Dongfeng, controlled by the government, lacked flexibility and smaller factories started to appear to satisfy the growing demand for automobiles. Their number grew from 55 in 1979 to 114 in 1985.^{ibid.}

We can surmise that the development of EVs in China did not take place for at least two reasons. As was mentioned above, USSR brought technical expertise on automobile construction to China in 1950s, when there were few working models of electric vehicles, let alone the mass production. Since a big share of vehicles was produced primarily for military vehicles and heavy trucks, which required much energy for a long range, there was no chance for the electric propulsion¹¹⁰. Although more automobile factories emerged by late 1960s, there was a large dependency on import from other countries, which at that time produced, and imported respectfully, mainly gasoline engined vehicles. For instance, there were 133 vehicles manufactured in 1965, while 2,632 were imported in the same year.^{ibid}

Economic circumstances were more favorable towards a specific electric transport, which started to appear in 1960s. To satisfy the demand for a cheap personal transportation, electric bikes and motorcycles or electric two-wheelers (E2W) were introduced by the government, but had little success for several decades until the rapid economic development of 1990s¹¹¹. From 1998 to 2008 annual sales of E2Ws increased from 40,000 to 21 million and reached over 100

¹⁰⁹ Matthias Holweg, The past, present and future of China's automotive industry: a value chain perspective. P.5 Cambridge. Retrieved from: [<http://www.research.ed.ac.uk/portal/files/7765689/Oliver.pdf>]

¹¹⁰ Harwit, China's Automobile Industry. p.17

¹¹¹ Chi-Jen Yang, Launching strategy for electric vehicles: Lessons from China and Taiwan. Technological Forecasting & Social Change 77 (2010). p.831. Retrieved from: [<http://people.duke.edu/~cy42/EV.pdf>]

million in 2000s¹¹². The popularity and growth of such transport was due to its inexpensiveness and thus affordability, compared to private cars and even public transportation. In 2006, 350 people out of thousand owned bicycles, 90 owned motorcycles, and only ten owned a vehicle. Another important factor was the ban on motorcycles. Yang compares the Chinese E2W policy to a similar in Taiwan with only difference that the latter did not ban gasoline motorcycles and subsidized E2W. The result was that despite spending NT\$1.8 billion on various subsidies in forms of tax reductions, promotional activities, R&D, etc., sales remained very low and the policy was acknowledged unsuccessful. The early scooters and bikes had numerous technological shortcomings, which took a lot of test and trial to solve. But the difference in China was that customers had no choice but to fix and overcome those technical problems.

A spectacular growth in Chinese economy started with economic reforms in 1978, which opened the economy to foreign investment and with the creation of special economic zones with special conditions for foreign investment. Since early 1980s China's economic growth averaged 9.9 percent in terms of real GDP and by 2010 PRC became the world's second largest economy after the U.S.¹¹³ Due to economic growth a total urban population rose from 26% in 1990 to 52.6% (712 million people) in 2012¹¹⁴. It significantly increased the number of automobiles in cities and turned the country into one of the the largest energy user with highest air pollution in the world. The number of domestically produced automobiles was

¹¹²Weinert, Jonathan X., and Davis California. (2007) The rise of electric two-wheelers in China factors for their success and implications for the future. University of California, p. Retrieved from: [http://publications.its.ucdavis.edu/publication_detail.php?id=1125]

¹¹³ Guy C. K. Leung, Raymond Li, Melissa Low. Transitions in China's Oil Economy, 1990–2010.p. 484

¹¹⁴Shan Juan. "Nearly half live in urban areas and 13 percent are over 60." *China Daily*, April 29, 2011, http://europe.chinadaily.com.cn/china/2011-04/29/content_12418282.htm (accessed July 25, 2013).

increased due to financial subsidise by the government and due to shrinked market of the US and Japan in 2008 financial crisis.¹¹⁵

While the World health organisation standard for safe air is 25 micrograms of particulate matter (PM2.5) per cubic meter, the level in Beijing is balancing between 300 and 900.¹¹⁶ To realise the extent of the pollution, one could look at examples when flights in Beijing airport are grounded because pilots can't see the way or when a burning factory in Zhejiang province is unnoticed by neighbors for three hours because of the the smog.^{ibid.} One could hardly believe that selling fresh air in cans would ever be the case, but according to Chen Guangbiao, he sold 10 million of those during ten days of January 2013.^{ibid.}

Although the government has been promoting renewable energy through laws and regulations, coal still constituted astonishing 69% of the total energy production in 2010. According to estimates, the share of the coal will be 50% to 58% by 2030 and 30% to 47% by 2050, while the rest of the electricity will be generated by nuclear and renewable sources.¹¹⁷ Such energy mix significantly reduces the benefit of using electric vehicles in the country. But the increase of electric vehicles has been a part of the renewable energy policy of China and a number of regulations were introduced to boost sales. The government set an ambitious goal to increase the share of electric cars to 10 percent of total by 2015 and a number of incentives have been introduced, such as a subsidy of around US \$19,000 from the government. Particular cities

¹¹⁵ Xinhuanet, 2010. China has reached to number 1 in vehicle production and sales in 2009 (in Chinese).

Available from: [http://news.xinhuanet.com/auto/2010-01/11/content_12791236.htm] as quoted in Scenario analysis on alternative fuel/vehicle for China's future road transport: Life-cycle energy demand and GHG emissions Xunmin Ou, Xiliang Zhanga Shiyang Chang

¹¹⁶ Dwight , W. Morrow. "Is China's Pollution Testing the People's Patience?." *Huffington Post*, August 22, 2013, http://www.huffingtonpost.com/daniel-k-gardner/is-chinas-pollution-testi_b_3616962.html (accessed July 25, 2013).

¹¹⁷ The number depends on the energy scenario. For more information see: Nan Zhou et al., (2011) China's Energy and Carbon Emissions Outlook to 2050.P..32 Available at: [http://eaci.lbl.gov/sites/all/files/LBL_4472E_Energy_2050.April_.2011_1.pdf]

offered additional benefits such as exempts from restrictions on issuance of license plates.¹¹⁸ In 2011 a \$15 billion 'New Energy Vehicle Development Plan' was drafted to promote electric and plug-in hybrid cars¹¹⁹.

However, the proliferation of the electric car has been slow due to familiar issues. The price of an average EV was still higher than of conventional cars, partly due to high import taxes on batteries.¹²⁰ Chinese consumers had little willingness to make compromises regarding the charging time and driving range and switching to fuel-efficient vehicles in general. An example is the recent record high demand for oil in the country. In march 2013 the government introduced new fuel standards, aimed to reduce air pollution and smog in cities. The rules demanded more fuel efficient light vehicles, while lowering demands for cars with a higher volume of engine. Instead of intended outcome, the regulation led to a higher demand for the bigger cars and the demand for oil grew to 9,99 million barrels/day in June 2013, 11.7% higher versus the same period of 2012.¹²¹

¹¹⁸Bill , Sweet . "Is China Backing Off From EVs?." IEEE Spectrum, August 25, 2011, <http://spectrum.ieee.org/energywise/green-tech/advanced-cars/is-china-backing-off-from-evs> (accessed July 25, 2013).

¹¹⁹Viknesh , Vijayenthiran. "China Rigs Electric-Car Incentives Against Chevy Volt, Foreign Cars." Greencar Reports, May 10, 2011, http://www.greencarreports.com/news/1059704_china-rigs-electric-car-incentives-against-chevy-volt-foreign-cars (accessed July 25, 2013).

¹²⁰Antony , Ingram. "Despite Pollution, China Still Isn't Committed To Electric Cars." Greencar Reports, March 11, 2013, http://www.greencarreports.com/news/1082811_despite-pollution-china-still-isnt-committed-to-electric-cars (accessed July 25, 2013).

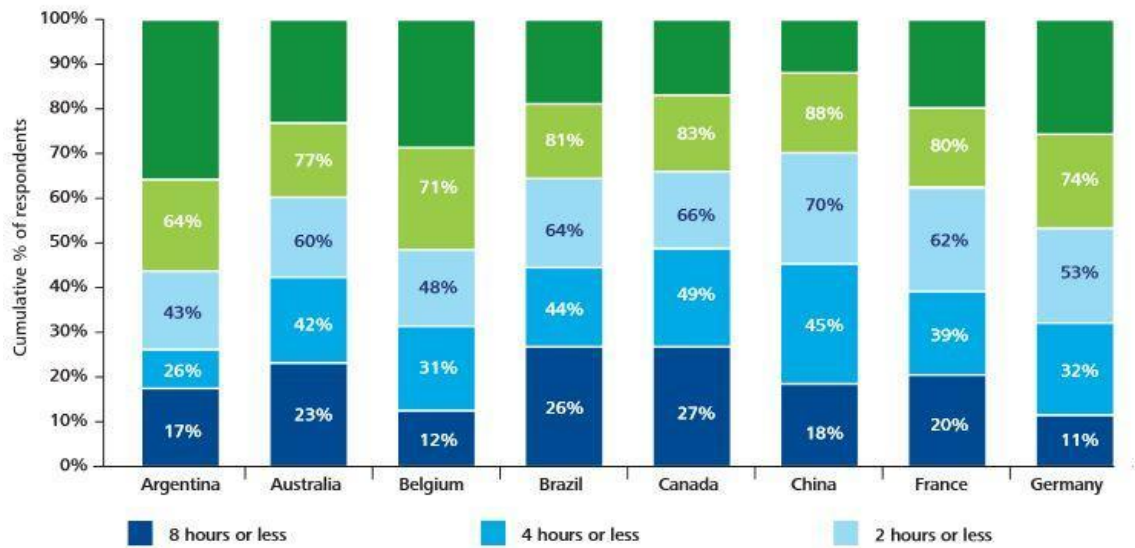
¹²¹"Platts Report: China Oil Demand Rises 11.7% in June Versus a Year Ago." Platts, July 23, 2013, [<http://www.platts.com/PressReleases/2013/072313/No>] (accessed July 25, 2013).

3.0 EMERGING BUSINESS MODELS, NICHE MARKETS AND STARTUPS IN THE ELECTRIC VEHICLE INDUSTRY

3.1 Solutions for the Infrastructure. Case Studies: Better Place, Green Way.

Battery has been the crucial factor in the development of the electric car since the very beginning beginning and the driving range of commercially viable electric cars has remained largely unchanged for a century. The Nissan Leaf of 2009 and the Mitsubishi i-MiEV of 2010 have nearly the same range as the 1908 Fritchle Model A Victoria - 160 kilometres on a single charge, although the former have much better power sources in terms of durability, weight and performance. Even with new lithium-ion batteries and improved energy consumption it still takes from 30 to 90 minutes to charge the electric vehicle to 80% capacity with a special charging device. Although most drivers travel about 37 miles per day on average, the '*range anxiety*' constantly deters potential customers. In early 2011 Deloitte has conducted a profound online global survey to explore consumer adoption of electric vehicles, capturing the views of more than 13,000 people in 17 countries. Drivers were asked about their driving range and the willingness to purchase an electric vehicle. On average 80 percent of respondents said that they drive less than 80 kilometers per day, while average electric vehicle today can offer twice of that. Only 63 percent and 67 percent of respondents from the U.S. and France were satisfied with a range of 480 kilometers or less, while the average range of the gasoline car was 700 kilometers. Another important finding was that less than a quarter of drivers considered acceptable 8 hours charging time (average for current EVs, see figure):

Figure 3.1. Consumer expectations for recharging time of EVs.



Survey question: Considering your expected vehicle use, what is the longest time to fully recharge the battery that you would consider acceptable when buying or leasing electric vehicle?

Source: Deloitte Touche Tohmatsu Limited Global Manufacturing Industry group. Available at: [\[http://www.deloitte.com\]](http://www.deloitte.com)

In 2008 Shai Agassi founded a *Better Place* - startup company aimed to create a different vision for electric vehicles with a system of fast battery swapping called EasyDrop. Customers would pay for the car, but the company owned the batteries and when drivers need recharge, they simply exchange the battery at one of the Better Place stations. Simple and efficient, swapping a battery in 5 minutes seemed a brilliant idea, although it was not new. According to Kirsch, Hartford Electric Light Company introduced the system of battery exchange for electric trucks back in 1910 and similar system was introduced in Chicago by Milburn Light Electric in 1917.¹²² But in recent years there was no such option for EV owners anywhere in the world. As the analysts of Deutsche Bank wrote, “the company’s unique business model could lead to

¹²²Kirsch, *The Electric Vehicle and the Burden of History*, p.156

a “paradigm shift” that causes “massive disruption” to the auto industry, and said the company has “the potential to eliminate the gasoline engine altogether.”¹²³

The EasyDrop system seemed to resolve centuries-old drawbacks of the infrastructure for the electric vehicle, allowing it to drive long distances, decreasing the cost of the car and making possible to update batteries with no extra cost. Seeming advantages of the project attracted attention from such car manufacturers as Nissan and Renault and governments of Israel and Denmark. Simon Peres, the president of Israel, himself negotiated with the management of the Better Place to make it a part of the economic policy to incent consumers to buy zero-emission vehicles and of the alternative energy strategy. But after nearly six years of operation and \$850 million investment, the company filed for bankruptcy with insufficient revenues to cover operating costs. Despite a strong political support from the Israeli government, managers of Better Place could not persuade Israeli people to take on the electric car. With 38 swap stations and 1,8 thousand charging stations installed around the country, only about 750 vehicles were sold.¹²⁴

But the company has proved that it is possible to overcome the technical side of the problem in a consumer friendly way, which solves many related problems and could have saved money for customers. According to company’s estimates, the cost of the electric mile in 2010 was \$8c, which is two times cheaper than average gasoline engine. And with the constant improvement of battery’s life it could go down to 2c per mile in 2020.¹²⁵ If the technical success of the company was coupled with economic, the startup could have revolutionised the transportation

¹²³Chuck , Squatriglia. "Deutsche Bank Loves Shai Agassi's Plan to Bring Us EVs." *Wired*, April 14, 2008, [<http://www.wired.com/autopia/2008/04/deutsche-bank-l/>] (accessed July 25, 2013).

¹²⁴Gunther, Marc . "Better Place: what went wrong for the electric car startup?." *Guardian*, March 5, 2013, [<http://www.guardian.co.uk/environment/2013/mar/05/better-place-wrong-electric-car-startup>] (accessed July 25, 2013).

¹²⁵Shai Agassi: A new ecosystem for electric cars. (Presentation) TED, ted.com

system of Israel, at least. As of June 2013, the process of bankruptcy was ongoing, but there was already an interest from investors to bring the Better Place back to operation.¹²⁶

The story of the Better Place has opened a vision for a number of other companies around the globe. A Green Way of Slovakia has introduced a similar business model to EasyDrop in the goods transportation sector. The company is planning to build a network of battery swap stations around Slovakia and plans to give electric vans for lease. Similar to Better Place, the company offers a swap of the battery in 7 minutes. As of June 2013, there have been 2 stations installed.

While for the PEV users the factor of convenience and recharging time is among the most important, for the transportation companies the major item of expenditure and thus importance is the cost of driving per kilometer. As mentioned earlier, the application of such business model has been proven successful a century ago by Hartford Electric Light Company and Milburn Light Electric. A study conducted at the MIT showed, that even with an initial purchase of battery, the use of electric trucks could earn from \$900 to \$1,400 per year for each machine if the Vehicle to Grid (V2G) system is used. Compared to the use of gasoline it means a reduction of 7 to 11 percent in vehicle operating costs.¹²⁷

3.2 Tesla Motors

Nikola Tesla was one of the most influential figures in the history of electricity, whose inventions brought the use of electrical applications to an entirely new dimension. He was an author for nearly 300 patents worldwide regarding electrical transmission of power, electric lightning, alternating current motors, turbines, aerial transportation and other. What attracts

¹²⁶Avi , Bar-Eli, & Daniel , Schmil. " Home Business Two groups eyeing purchase of Better Place: American Jews and Canadian investors ." Haaretz, March 06, 2013, <http://www.haaretz.com/business/two-groups-eyeing-purchase-of-better-place-american-jews-and-canadian-investors.premium-1.527415> (accessed July 25, 2013).

¹²⁷ "Electric Delivery Trucks Make 'Cents'." Evworld , February 03, 2012, [<http://evworld.com/news.cfm?newsid=27350>] (accessed July 25, 2013).

attention in Tesla's biography among enthusiasts and researchers is the story written by one of his biographers, Marc J. Seifer:

"...a standard Pierce Arrow, with the engine removed and certain other components installed instead. The standard clutch, gear box, and drive train remained.... Under the hood, there was a brushless electric motor, connected to the engine.... Tesla would not divulge who made the motor. Set into the dash was a "power receiver" consisting of a box ... containing 12 radio tubes.... A vertical antenna, consisting of a 6 ft. rod, was installed and connected to the power receiver in turn, connected to the motor by two heavy, conspicuous cables.... Tesla pushed these in before starting and said: "We now have power." ¹²⁸

The story is about an alleged Tesla's electric vehicle which he drove around the New York city and surrounding area in 1934. While there is no documentary evidence available regarding his invention, there is a highprobability it was possible, given Tesla's extraordinary talent and a special interest in the wireless transmission of energy. In his article in "Electrical World and Engineer" he described the moment when he discovered the transmission:

"It was on the third of July — the date I shall never forget — when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the advancement of humanity...The tremendous significance of this fact in the transmission of energy by my system had already become quite clear to me. Not only was it practicable to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress upon the entire globe the faint modulations of the human voice, far more still, to transmit power, in unlimited amounts, to any terrestrial distance and almost without loss." ¹²⁹

¹²⁸Seifer, Marc J. Wizard: the life and times of Nikola Tesla : biography of a genius. Secaucus, 1996., p. 419

¹²⁹Thomas Valone, (2002). Harnessing the Wheelwork of Nature: Tesla's Science of Energy. Retrieved from Google Books

Also when writing to Benjamin F. Miessner in 1915 Tesla stated: “ I made more striking demonstrations, in many instances actually transmitting the whole motive energy to the devices instead of simply controlling the same from a distance “. ¹³⁰

There is an opinion, that his invention was attacked by several media reporters who claimed it was a “black magic” and Tesla eventually removed the device from the vehicle in anger and left no schemes or any drawings of the technology. ¹³¹

Although no one could replicate Tesla’s vehicle, his genius inspired a group of entrepreneurs to rediscover his achievements and establish Tesla Motors - a company in Silicon Valley, which innovated the electric car and started a historical revolution in the automotive industry.

The first model of the company - Roadster Sport - became the first mass produced electric sport car, pioneered the use of lithium-ion batteries in electric vehicles and achieved a record breaking range of 395 km on a single charge. The model’s luxurious appearance and high performance enhanced the public image of the electric vehicle just as La Jamais Contente did in 1899. Finally those people who were willing to voluntarily pay for the shift from the oil-based economy and could afford a 100,000 dollars electric car finally got a well-designed vehicle with a powerful motor. As Road Track reported, “The Roadster, however, was a more expensive, more niche variant of an already very expensive, very niche car”. ¹³² But the role of the Roadster was to prepare the ground for the launch of the Model S -- more convenient and less expensive sedan with 65 and 85 Kw motors and a range of 330-426 km at 88,5 km/h respectfully. With 4500 pcs. initially planned for 2013, the company sold 4750 vehicles in the first quarter of the year and reported first profits after repaying a \$465 million loan to the

¹³⁰ Tesla, Nikola, and Leland I. Anderson. Nikola Tesla: guided weapons & computer technology. Breckenridge, Colo.: Twenty First Century Books, 1998. pp. 227-229.

¹³¹ EV World, "Nikola Tesla's 'Black Magic' Touring Car." Available at: [\[http://www.evworld.com/article.cfm?storyid=1062\]](http://www.evworld.com/article.cfm?storyid=1062) (accessed July 25, 2013).

¹³² Jason , Cammisa. "Return to Power: the 2013 Tesla Model S." Roadtrack, February 25, 2013, [\[http://www.roadandtrack.com/car-reviews/road-tests/road-test-2013-tesla-model-s\]](http://www.roadandtrack.com/car-reviews/road-tests/road-test-2013-tesla-model-s) (accessed July 25, 2013).

government nearly ten years before a scheduled term. The car received numerous awards, including a nearly best ever rate 99 out of 100 in Consumer Reports Testing¹³³ and Best Car To Buy 2013 by Green Car Reports¹³⁴.

Launching Model S was another step to the production of an affordable “Ford Model T of the 21st century”. In his blog Elon Musk simply outlined the strategy of TM:

1. Build sports car
2. Use that money to build an affordable car
3. Use that money to build an even more affordable car
4. While doing above, also provide zero-emission electric-power generation options¹³⁵

Initially there was a problem of the infrastructure for the customer to feel secure while driving through the US, but Tesla introduced the Supercharger - a network of charging stations with solar carport system. Built by SolarCity, a related company in Tesla’s sustainable energy plan, stations operate with almost zero marginal energy cost after the installation.¹³⁶ The Supercharger network revolutionised the whole notion of “refuelling” the car, being forever free for the owner of 85 Kw version of Tesla S Model. The version with 65 Kw motor can be upgraded for additional costs (2000\$). As of June 2013 eight stations operated in the US and the company’s plans are to cover 100% of the U.S. and Canada by 2015 (Figure 3.2) The company also promised to install battery swapping facilities for Model S, which from the very beginning was designed with the ability to drop the battery out from under the bottom in few seconds.

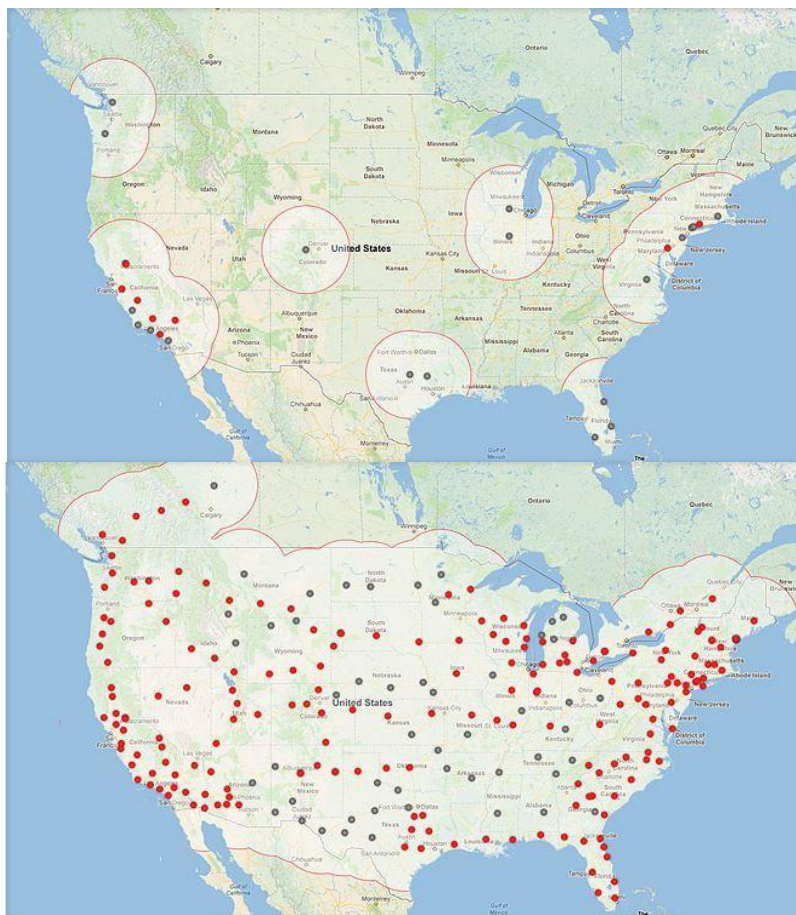
¹³³ LeBeau, Philip. "Consumer Reports: Tesla Model S Among Best Ever Reviewed." CNBC News, May 9, 2013, [<http://www.cnbc.com/id/100722346>] (accessed July 25, 2013).

¹³⁴ Ireson, Nelson. "Tesla Models S Rates 99/100 In Consumer Reports Testing." Motorauthority, May 9, 2013, http://www.motorauthority.com/news/1084065_tesla-models-s-rates-99-100-in-consumer-reports-testing (accessed July 25, 2013).

¹³⁵ Elon Musk, The Secret Tesla Motors Master Plan (just between you and me), (Blog). [http://www.teslamotors.com/fr_CH/blog/secret-tesla-motors-master-plan-just-between-you-and-me]

¹³⁶ “Tesla Motors Launches Revolutionary Supercharger Enabling Convenient Long Distance Driving.” Tesla Motors Press Release. September 24, 2012[<http://www.teslamotors.com/about/press/releases/tesla-motors-launches-revolutionary-supercharger-enabling-convenient-long-dista>]

Figure 3.2.Amount of Supercharger stations in the U.S and Canada by 2015



Source: Davies, Alex . "MAPS: Here's Tesla's Plan To Cover America In Superchargers." Yahoo Finance, May 30, 2013, [<http://finance.yahoo.com/news/maps-heres-teslas-plan-dramatically-174010352.html>] (accessed July 25, 2013).

One of the key aspects of Tesla's business strategy is direct-to-customer online sales to avoid independent dealers, which, as Tesla Motors believe, are not interested in promoting the alternative to gasoline engine vehicles, which bring them the lion's share of the profit¹³⁷ As CEO Elon Musk said, "Traditional dealers may not be the best advocate for electric cars because they rely largely on gas-powered vehicles for revenue". Such strategy reduced the final price of vehicles, avoiding a third party margin, but was strongly opposed by car dealers and

¹³⁷ Rocco, Matthew . "Tesla CEO Pushes for New Car Sales Model." FOX Business, June 05, 2013, [<http://www.foxbusiness.com/news/2013/06/04/tesla-ceo-fights-for-new-electric-car-sales-model-in-us/>] (accessed July 25, 2013).

even authorities of particular US states. North Carolina Automobile Dealers' Association lobbied a law, which was aimed to bar Tesla and other automakers from direct sales and implied to prohibit "using a computer or other communications facilities, hardware, or equipment" to sell or lease a car to anyone in North Carolina. Some 49 owners of Teslas in the NC state and other supporters responded with creating a website to prevent the passage of the law. A month later the bill was rejected by the state legislature.¹³⁸

Similar bills in the New York State were aimed to make it illegal to license or renew licenses for Tesla stores within the NY state. The measure was lobbied by NY state auto dealers, but was postponed until January 2014. At the time, Tesla was the only car manufacturer in the U.S which sold vehicles directly without intermediary agents.

Another factor which helped Tesla Motors stay on the market is tax deductions. As of 2013 every buyer gets a US \$7,500 federal tax credit with the purchase of a new Tesla acquired for personal use. Some states offer additional incentives from \$2500 (California) to \$4,000 (Illinois).¹³⁹

Yet more significant source of revenue for Tesla comes from selling Zero Emission Vehicle Credits (ZEV). The California Air Resources Board (CARB) obliges car automakers to produce a certain number of Zero Emission Vehicles and since some automakers don't meet the regulation, they have to buy credits from other companies to avoid high fees.¹⁴⁰ Tesla's income from such credits, according to LA Times estimates, amounted up to \$35,000 per each Model S and could bring \$250 million to the company.

¹³⁸Anti Tesla Bill Backed By North Carolina Car Dealers is Dead. Greencar Reports. Accessed in June 2013 at: [http://www.greencarreports.com/news/1085059_anti-tesla-bill-backed-by-north-carolina-car-dealers-is-dead]

¹³⁹ U.S Department of Energy. Federal Tax Credit Up To 7,500! [<http://www.fueleconomy.gov/feg/taxevb.shtml>]

¹⁴⁰California EPA, Air Resources Board.2011 Zero Emission Vehicle Credits. [<http://www.arb.ca.gov/msprog/zevprog/zevcredits/2011zevcredits.htm>]

Tesla Motors has been a combination of political and economical success. But the development of such concept would be hardly possible without a broad vision and entrepreneurial skills of its founders and staff. Elon Musk holds degrees in physics and economics and has accumulated a great experience in business, created a \$1,5 billion worth PayPal and founded the first private company to launch satellite to Earth's orbit. Alan Cocconi, on the other side, was one of the leading experts in the construction of electric vehicles, being responsible for the technology used in one of the most technically successful electric cars - EV1 of General Motors.

4.0 CONCLUSIONS

This research has brought arguments pro and contra the use of the electric car, providing the analysis of its historical challenges and foreseeing its rising importance in the future. As a number of analysed scientific works has shown, electric cars offer a better environmental and economic solution than conventional vehicles and when combined with alternative energy generation, reduce negative consequences of energy dependence. Currently the positive impact of EV's on the environment is offset due to the fact that most energy intense economies, such as the U.S. and China are heavily reliant on the black electricity, but since the world's energy mix is leaning towards renewable energy domination by 2050, electric car's GHG emissions are likely to significantly decrease with time.

Although electric vehicles are more sustainable, there have been numerous barriers for the market since the beginning of the 20th century. In the early years of automobiles, when speed and distance were not pivotal, electric car took advantage of its quietness and reliability, but with the development of better and cheaper internal combustion engined vehicles, the shift to latter went without much compromise. For most of the time EV's were more expensive and less convenient in use, although there were numerous independent attempts to increase battery capacity. While electric cars were available on the European and U.S. markets, they were very limited in the Former Soviet Union, where only few models were released, but none gained a wide spread.

Most electric car manufactrers failed due to various reasons, which were directly or indirectly related to the heavy and limited powersource, but there has been an unprecedented development of new technologies and business models during recent decades. Among many companies operating on the market, we studied Tesla Motors as one of the most successful electric car manufacturer at the time being. The case of the company shows how historical

challenges being resolved with a better technology and new market solutions. The case study of the Better Place has shown that even with new solutions for the infrastructure, such as quick battery replacement, and with the strong governmental support, there is still a consumer's behavior, which is crucial for the market success of the electric car.

Appendix 1.

World lithium resource, deposits greater than 100,000 tonnes Li.

Deposit	Country	Type	Resource (Mt Li)	Avg. Concentration (% Li)
Uyuni	Bolivia	Brine	10.2	0.0532
Atacama*	Chile	Brine	6.3	0.14
Kings Mountain Belt	USA	Pegmatite	5.454	0.68
Qaidam*	China	Brine	2.02	0.03
Kings Valley, NV	USA	Sedimentary Rock	2.0	0.27
Zabuye*	China	Brine	1.53	0.068
Manono/Kitotolo	Congo	Pegmatite	1.145	0.58
Rincon	Argentina	Brine	1.118	0.033
Brawley	USA	Brine	1.0	--
Jadar Valley	Serbia	Sedimentary Rock	0.99	0.0087
Hombre Muerto*	Argentina	Brine	0.8	0.052
Smackover	USA	Brine	0.75	0.0146
Gajika	China	Pegmatite	0.591	--
Greenbushes*	Australia	Pegmatite	0.56	1.59
Beaverhill	Canada	Brine	0.515	--
Yichun*	China	Pegmatite	0.325	--
Salton Sea	USA	Brine	0.316	0.02
Silver Peak*	USA	Brine	0.3	0.02
Kolmorzerskoe	Russia	Pegmatite	0.288	--
Maerking*	China	Pegmatite	0.225	--
Maricunga	Chile	Brine	0.22	0.092
Jiajika*	China	Pegmatite	0.204	0.59
Daoxian	China	Pegmatite	0.182	--
DXC*	China	Brine	0.181	0.04
Olaroz	Argentina	Brine	0.156	0.07
Other (producing)*	Brazil, Canada, China, Portugal	Pegmatite	0.147	--
Goltsovoe	Russia	Pegmatite	0.139	--
Polmostundrovskoe	Russia	Pegmatite	0.139	--
Ulug-Tanzek	Russia	Pegmatite	0.139	--
Urikskoe	Russia	Pegmatite	0.139	--
Koralpa	Austria	Pegmatite	0.1	--
Mibra	Brazil	Pegmatite	0.1	--
Bikita*	Zimbabwe	Pegmatite	0.0567**	--
Dead Sea	Israel	Brine	--	0.001
Great Salt Lake	USA	Brine	--	0.004
Searles Lake	USA	Brine	--	0.005
Total			38.33	

Source: Paul Gruber, Pablo Medina, (2010) Global Lithium Availability: A Constraint for Electric Vehicles? p.11
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2011	Viacheslav Krasov's School of Fast Reading. Certificate of Successful Completion achieved
2010	Driver's License of "B" category (passenger vehicles) obtained in Kyiv, Ukraine
2010	Bryan Tracey's training: <i>How to double your sales and increase the productivity</i>
VOLUNTEERING	
2011 — present	▪ Translator for the International Film Festival <i>STEPS</i> ▪ Translator at <i>The Youth Leader Magazine</i> ▪ Correspondent, <i>Bokeh.com.ua</i>
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