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Feasibility study on green transportation

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Abstract

This is a research report on a green transportation project. Green transportation relies on renewable energy sources rather than fossil fuels currently used extensively. Sustainability assumes low impacts on environment and balancing current and future needs. We are investigating introduction of electrical vehicles (EV) and issues which influence that EVs are rapidly becoming a mainstay in vehicle product lines. These issues are related to the remaining available reserves of fossil fuels, important for the further use of Internal Combustion Engines (ICE), from one side, and on the other side, availability and reserves of lithium and other metals, required for EV batteries and motors, which makes impacts on swiftness of green transportation introduction. This transition to EVs is characterized by the convergence of mobility and energy what can bring significant benefits to the entire society. There are also policy implications which direct the usage of green energy for EV charging and development of related infrastructure. Finally, we present the economics of green transportation and business models which ensure its sustainability.

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Keywords: Green transport; electric vehicles; fossil fuels; lithium batteries; fuel cells; sustainability; transition; green energy;

1. Introduction

This paper presents main aspects of the transition from internal combustion engines vehicles (ICE) to electric vehicles (EV). Transition is currently being extensively researched at RMIT University, [1, 2], [3], [4, 5] and the scope is much wider than topics which are discussed here. Specifically, the emphasis is on green transportation which is one of achievements intended to be accomplished by this transition. Apart from using electrical vehicles,

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the energy for them should come from the green sources. That is another research area, covered by the University, [6-11], [12] and other large energy and government stakeholders.

Transportation today is still mostly relying on fossil fuels. Their identified reserves will influence the rapidness of this transition. Electric vehicles will require significant amount of electricity for recharging of their batteries. This energy is to a great extent produced by burning fossil fuels. Because of increasing pollutions and greenhouse gas emissions, in the future more electricity will be produced from renewable resources. There are several factors presented here which influence the dynamics of this transition process.

First, this is amount of currently identified and economically available reserves. Considering that future energy will be mostly in a form of electricity, the paper discusses the main fossil fuel reserves: oil, gas and coal. Presented are their current reserves, factors such as their prices and technological innovations that impact on their availability and implications on relevant public policies. One of the factors that influence the sustainability of transportation is the amount of lithium reserves because it is used for electric vehicles battery production. There is still a question if there are enough reserves of this precious metal which has its role in electricity storage. We present out study and calculations which can illustrate its sufficiency for the future electric vehicle production.

2. Reserves - fossil fuels, lithium, metals

In last several years there was a dilemma about sizes of fossil fuel reserves and many assertions were made about their depletion and imminent diminishing. Fossil fuels, namely, crude oil, coal and gas are the main sources of world energy supply. The International Environmental Agency, in 2010, stated that oil production has reached its peak of 70 million barrels per day in 2006 and that in the following 25 years will not exceed 69 million. The projection was that in 2035 the oil production would be about 20 million barrels [13].

Another projection was related to the world's coal mining. The expectation was that it would reach its peak in 2011 before it starts its permanent decline. It was explained that reserves of the quality, high energy coal are already depleted and only the lower quality, harder to dig coal remain. The amount of energy obtained from the coal in 2050 would be only one half of those in 2010 [13].

All previous estimates were based on known reserves of conventional fossil fuels. In 2010, proven oil reserves were 1.35 billion barrels. Reserves of conventional gas were estimated at 6,600 trillion cubic feet and 861 trillion of tons of coal. The revised figures, according to BP's Statistical Review of World Energy in 2017, changed the global oil reserves to 1.7 trillion barrels [14]. Considering that the world consumes about 86 million barrels of crude oil per day, the conclusion is that the world would run out of oil in 55 years or earlier if production and consumption are increased [14].

Some other modeling shows that if the proportions of world's utilization to reserves for oil, coal and continues to expend fossil fuels at 2006 rates, they will remain another 40, 200 and 70 years, respectively [15]. All previous data present one view on available reserves of fossil fuels in the world. This view proclaims that these reserves are finite and that timely actions are needed by the governments to make policies which would give incentives for fossil fuels savings and their replacements by renewable energy.

2.1. Implications of high fossil fuel prices

High prices for fossil fuels have the expected tendency to increase supply and reduce demand. For example, in the period from 1950 – 1973, the average growth demand was 6.7%. After the price shocks in 70s and early 80s, the demand growth reduced to 1.6% in the period 1984-2008 [13]. Savings were made in every segment of consumer consumption. Car manufacturers significantly improved vehicle fuel efficiency. High fossil fuels prices were an incentive for producers to increase fuel production and invest in new research which was unprofitable at lower prices. The output in gas production significantly increased earlier unprofitable oil sands and oil shale exploitations. Oil shale deposits in the US Green River are estimated to be comparable with the entire world's proven crude oil reserves [16]. New technologies for fuel extractions became economical with higher fuel prices. In Canada, for example, oil sands reserves contain 179 billion barrels of oil which can be currently exploited with a profit and probably, the total reserves are ten times of this. It means that higher fuel prices increase proven reserves and spark new innovation for their productive exploitation.

2.2. Implications of technological innovations

Technological innovations also will influence the time horizon of fossil fuel exploitation. They will enable the finding of currently unknown reserves and improve efficiency of current exploitations and oil extractions. As a result, the total reserves of fossil fuels increase every year instead of their expected depletion. For example, in a period of 2007-2009, for every barrel of oil produced, 1.6 new barrels were discovered. If new technologies were applied to replace traditional oil extraction which is still present in about a half of all oilfields, new amount of almost 125 billion barrels would be recovered [14]. New discoveries and revisions of existing reserves under exploitations have been increasing for many years. New technology enabled deep water drillings which were impossible few decades ago. In 2013, a deep water output was 6% of the total production. New fields were discovered offshore of Brazil, Angola, Nigeria and Sierra Leone. The latest developments are not limited by the depth of the water. The exploitation is now possible at any place in the world.

Future technology innovations will enable exploitations of oil under Arctic's ice. US Geological Survey found that Arctic has the largest intact oil and gas reserves which amount about 20% of the global hydrocarbon assets. More than 400 fields have been already discovered with estimated reserves of more than 240B of barrels [17].

Technological innovations are also present in energy storage, smart grids and electricity generation from renewable resources where will affect every segment of supply chains. New storage technologies will improve the feasibilities of wind and solar energy sources which are currently expensive because they require scarce batteries to store energy. Smart grids will regulate global distribution of energy and prevent devastating shutdowns. The following Table 1 presents several new technologies which will change energy industry in the following decades.

Table 1. Technological innovations.

New technology	Description
Fuel Cell	Allowing transport vehicles to run on hydrogen and oxygen, releasing only heat and water as emissions, still requires fossil fuels which will be replaced by renewable energies
Lithium-air batteries	Solution for capacity problem will enable the long-range electric cars
Tidal turbines	Underwater pinwheels utilize the energy from wave movement
First Generation Smart Grid	Responsive 'micro-grid' system with smart meters in every household will send usage information in real time allowing adjustments in availability to fluctuate according to the latest needs
Space-based Solar Power	Solar panels which wirelessly transfer energy is fulfilling the old Nikola Tesla's vision
Redox Flow Batteries	Energy storage technology with a good capacity retention after thousands of cycles

2.3. Forecasts and scenarios

In 2000, the Intergovernmental Panel on Climate Change made a Special Report with 40 emission scenarios, climate change modeling and forecasts. This report included forecasts on future fossil fuel prices, technology developments and other issues associated with fuel exploitation. Although, in 2010 world oil production reached 85 million of barrels a day and the equivalent of gas and oil was 2.900 millions of barrels per annum, some of these scenarios predicted ten times bigger gas production, 300 million per day oil production and exponential growth of coal production up to 2100 [18]. In spite of such significant increases in estimates, the Special Report states that will be enough fossil fuels for a prolonged period in the future. Currently, fossil fuels constitute 76% of the total energy consumption while the remaining 24% of spending is made up of renewable sources as presented in Table 2:

Table 2. Electricity generation by fuel (based on data from [8]).

Fossil fuels and renewable sources	% of world consumption	Comment
Oil	3.5	Global growth consumption - 1.8%, first price increase from 2012
Natural gas	23.2	The largest increment (since 2010) in energy consumption - 3%
Coal	38	First annual growth – 1% (since 2013), the lowest share 27.6% (since 2004)
Nuclear power	10.3	Global annual growth – 1.1%
Hydropower	15.9	Annual growth – 0.9% (comparing to 10-years average – 2.6%)
Renewables	8.4	Annual growth – 17%, the share in global power generation rose from 7.4 to 8.4% (wind – ½ of growth, solar – 1/3 of growth, biomass, geothermal)

The fact that more than 60 countries have already passed their peaks of oil production and that major coal reserves and production are located in only six countries (one half in China) can imply that the future oil production can face some challenges.

2.4. Implications on government policies

The total amount of currently estimated and not yet discovered reserves of fossil fuels leads to the conclusion that fossil fuels will not be exhausted at least in the near future. From the economic point of view, fossil fuels will not come to an end because, with lower supply, their prices will rise prohibitively high and energy demand would shift toward nuclear energy which becomes a viable alternative source. Technological innovations will also influence supply and demand in terms that fuel prices would remain economically affordable. All these aspects will have implications on government policies. To mitigate potential risks, governments made policies having in mind CO_2 and other pollutions, global warming and generally sustainability under assumptions that fossil fuels will gradually disappear. These policies were related to the subsidies of other forms of energy, especially renewables.

2.5. Lithium reserves

Considering the current global transition from vehicles with internal combustion engines to electrical vehicles, the legitimate question is if there is enough lithium and other material needed for large number of future EVs in the world. Lithium can be extracted from lithium minerals (spodumene and pegmatite) and from lithium chloride which can be found in brine pools. The biggest production from minerals is in Australia while the brine production is significant in Chile, Argentina, Bolivia, China and US.

The total economically extractable world reserves in 2014 were estimated at 9.9 millions of tons while identified reserves amounted to 39 millions of tons. Annual lithium production (excluding US) was about 36 thousands of tons [20]. To calculate the maximum realistic capacity for rechargeable lithium ion batteries we can take the theoretical limit of charge capacity per kg of lithium is 3.861 A•h/kg [19], efficiency of 73% for the cobalt-oxide, 3.6V battery. We are getting the result of about 10kW per kg. If we take for this calculation the average electric car (e.g. Fiat 500e or Volkswagen E-Golf) which requires 24 A•h battery, it means that we need 2.4 kg of lithium for one vehicle.

If all economically lithium reserves in 2014 are used for the car batteries, the number of produced cars would be enough to be equivalent to Switzerland standard (540 vehicles per 000 people). In meantime, new discoveries increased identified reserves in 2017 to 53 millions of tons (Bolivia 9 million, Chile 7.5 million, US 6.8 million tons) while annual lithium production (without US) reached 43.000 t [20]. Considering all previous data about total economically and identified lithium reserves, new calculations show that it can be produced more than 18 million vehicles/year or 22.1 billion electric vehicles in total. The highest number of vehicles per capita in 2017 was in US (940 vehicles/000). If this standard is assumed for the whole world it would be equivalent to 7.3 billion of vehicles.

At the moment, about one half of lithium is used for batteries. It is possible to substitute some lithium compounds in ceramics, greases and manufactured glass with calcium, magnesium, zinc, aluminum, sodic and potassic fluxes. In addition, new technologies are being developed which will enable profitable exploitations of spodumene ore with less than the current threshold of 6% of lithium. They will also improve the current battery efficiency of 73%. New, prospective sources of lithium are also jadarite, hectorite clay, geothermal brine and seawater. Taking into account the total number of vehicles that could be produced with currently identified reserves of lithium (22 billion), lithium substitutions in non-battery products, the better yield and utilization of identified reserves and expected results from new potential sources and mining explorations (Serbia, Canada, Congo and Russia), the conclusion can be made that it will be enough lithium for the future electric vehicles production.

2.6. Other battery materials

There are several other metals and minerals which are used in a production of batteries. The anode of lithium batteries is made from graphite where lithium is interposed into graphite structure. Depending of the required characteristics, several lithium oxides are used for battery cathodes: lithium-cobalt, manganese, phosphate and nickel-manganese-cobalt. Almost 80% of world cobalt consumption is used for batteries. Annual production in 2017 was 110.000 tons while world reserves are currently estimated at 25 million tons. Manganese world reserves are large but 90% concentrated in two countries (South Africa and Ukraine). This metal cannot be substituted in its main applications. Nickel's annual production in 2017 was 2,100.000 tons while world reserves are estimated to 130 million tons [20]. New researches are being conducted in central Africa and the Arctic region. Based on currently identified reserves, the conclusion is that it will be enough battery metals for the future electric vehicle production.

3. Transitional changes

As increased urbanization brings more people to the cities one of the key requirements is becoming the sustainable transportation. This assumes the satisfying needs by the most efficiently, safely, seamlessly and ecologically moving people and goods. In brief, the sustainability means having low impact on environment and making balance between current and future needs. Such transportation is not only focused on electric vehicles, it includes machine-to-machine applications, vehicles and devices that are aware of their own locations and sharing possibilities. Also, it spans on buses, trains, teleworking and various local transactions.

Sustainable transportation implicates new kind of mobility where automotive systems converge with information technologies, infrastructure, services, finances and seamless communications integrated within new business models. Such convergence will bring the most flexible and cost effective transportation modes and options. This flexibility sometimes could mean the using even internal combustion engines but ideally at its minimum. Instead, the most environmentally appropriate electrical sources of energy are greatly encouraged.

Achieving the sustainability of transportation requires new mindsets and changes in a way of thinking. Changes have pervasive character and include all segments. Electric vehicles are getting cheaper and their adoption will rise because of their increased affordability. Drive-sharing will also increase causing the reduction in total numbers of vehicles. Very soon, we will have autonomous vehicles, passengers and commercial, on our roads with lower operating costs, congestion and number of accidents.

Apart from changes in mobility there are changes in the energy domain, too. In the past, there were large central power stations which created significant pollution for the whole environment. Such models are increasingly getting abandoned. Energy production, storage and distribution become decentralized and located closer to the end customers. Instead of coal and other pollutants more renewable sources of energy are used for producing clean energy. All processes related to energy are automatized and controlled by operators and consumers. New ways of using energy will create new business models. Gradually, different forms of energy are getting transformed into electricity. That is also one of key changes in mobility paradigm with the emergence of electric vehicles. Changes in one domain instigate changes in other domains and inspire constantly new innovations. Supported by timely policies and progressive thinking they can create smart cities and make sustainable living in them.

Electric vehicles will help to accomplish some climate and ecological targets but they must be strongly embedded into smart cities structure. Their batteries can be used also for the creation of new services. Charging stations must be digitally controlled, integrated with smart buildings and located according to the onset of shared driving and emerging autonomous vehicles.

Transition to electric mobility is dependent on many participants responsible for local infrastructure, on entire energy production and distribution and how new mobility will be exercised. Policies at different levels of government need to support such transitions and stimulate a high use of electric vehicles in forms of electric taxies and public transportation. The high intensity of their travelling offers opportunities to significantly reduce emission of greenhouse gases.

4. Toward the green transportation

There are currently two ways in addressing the lowering greenhouse emissions and lower pollutions. Both approaches assume gasoline free driving. These approaches are related to two technologies which are currently under intensive research and development, namely - fuel cells and lithium-ion batteries electric vehicles.

4.1. Fuel cells technology

Fuel cells are a technology where electricity is generated by chemical reactions. They have two electrodes, anode and cathode, where reactions produce electricity in a form of electrical particles which are carried by electrolyte and accelerated by catalysts. Direct current is produced by stacking fuel cells which also need hydrogen as a basic fuel and oxygen. There are several types of fuel cells: alkali (AFC), molten carbonate (MCFC), phosphoric acid (PAFC), proton exchange membrane (PEM) and solid oxide (SOFC). They are presented in Table 3:

Table 3. Types of fuel cells (adapted from [21]).

	Fuel	Electrolyte	Efficiency %	Operating temperature (ºC)	Catalyst	Cell output	Comment
AFC	Hydrogen and Oxygen	Potassium hydroxide in water	About 70	150	Platinum	300 W -5kW	Used in Apollo program
MCFC		Sodium or Magnesium carbonate	60 - 80	650	Nickel electrode	Up to 2MW (design 100MW)	High temperature too hot for home use
PAFC	Gasoline	Phosphoric acid	40 - 80	150 - 200	Platinum	200kW 11mw	Internal parts must withstand acid
PEM	Purified fuel	Polymer	40 - 50	80	Platinum	50-250 kw	For homes and cars
SOFC	Hydrogen	Calcium or Zirconium oxide	60	1000	Platinum	100kw	For large applications

Both technologies have their benefits and drawbacks. Fuel cells use external reactants and their refueling is much faster than in case of battery electric vehicles. It is less efficient than petrol but it has much higher energy density and specific energy than lithium batteries [21].

One of main disadvantages of battery electric vehicles is their capacity and much lower ranges in comparison with traditional vehicles. In this regard, the fuel cell vehicles have such advantage to be able to carry more energy while having a slightly lower range then ICE vehicles. The additional downside of BEV is the length of recharging time. At the best, Tesla S with the largest battery pack and 120kW supercharger needs more than 40 minutes for the full charge. The charging time is often considered at 80% of full charge because the remaining 20% are charged at much slower pace. This is another advantage for fuel cells vehicles because they need only few minutes.

The further advantages of fuel cell vehicles are their standardized refueling (SAE J2601 standard), good reliability on lower temperatures, very low level of noise and little environmental impacts. Battery electric vehicles have one alternating current, two direct current and Tesla proprietary type of charging in US alone. Europe and China have different standards of battery charging. Fuel cells' hydrogen charging is still lagging although California and some other regions have plans for building more charging stations. This undeveloped infrastructure and higher manufacturing costs due to expensive catalysts are some of fuel cells vehicles disadvantages.

4.2. BEV advantages

One of chief advantages of battery electric vehicles is their higher energy efficiency in terms of energy required to travel between two places. It is based on differences between battery and fuel cells' electrochemical reactions. The simplicity of the BEV technology in comparison with FCV technology has as a result much lower production costs. BEV which is used in a city environment and able to recharge overnight is the most economical solution.

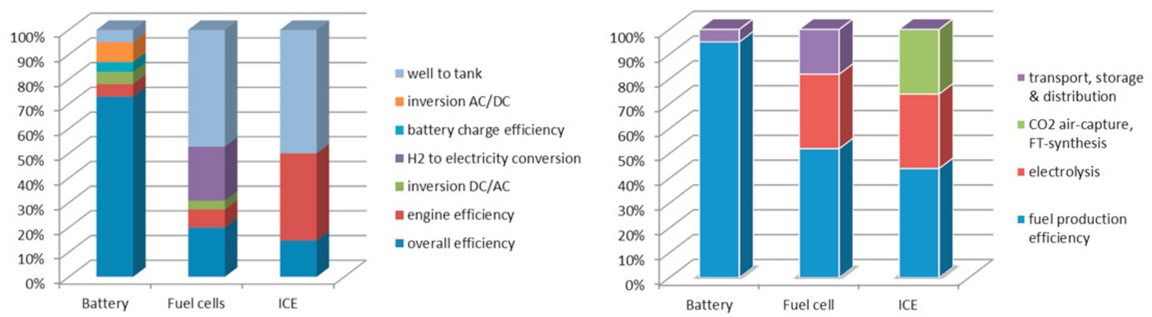

Fig. 1. (a) fuel production efficiency; (b) overall efficiency (based on data [22]).

The Fig. 1(a) shows 'tank-to-wheels' efficiencies which do not include fuel and electricity generations and their provisions to the vehicle. With these loses included, it is possible to calculate the 'well-to-wheels' efficiencies, presented on Fig. 1(b).

4.3. Complementary technologies

The previous comparisons show that is still uncertain which driving technology will replace ICE technology and become dominant in the future. Both, BEV and FCV, have their benefits and disadvantages. BEV's restrictions are their range and charging time. FCV is lagging in its commercialization due to lower efficiency, higher manufacturing costs, undeveloped hydrogen fuelling production pathways, energy storage technology and infrastructure. To improve adoption of fuel cells technologies, the US government is making new policies and is giving R&D incentives for researching new ways of producing hydrogen using emerging biological methodologies.

To overcome some FCV deficiencies, the design of fuel cells was changed by adding the energy storages similar to vehicles with electric engines. The reason for this is to improve their efficiency by utilizing the regenerative braking energy to produce electricity. In the same time it improves the responsiveness, because it is quicker to activate the current from energy storage instead of supplying hydrogen from the reservoir and air to the cell. FCV is becoming similar to hybrid electric vehicles with energy storages. They can be designed as a plug-in vehicle to emulate BEV efficiency advantage by providing opportunity to drive as electric vehicle. Two technologies can converge and create a new synergy which would enhance their benefits and reduce their disadvantages.

5. Conclusion

This paper presents a vision of the future mobility requirements and sustainable energy sources, based on the research of transition from internal combustion engines vehicles to electric vehicles. Fossil fuels reserves are getting depleted and although the situation is still not critical, considering environmental reasons such as greenhouse gas emission and pollution, the transition process becomes irreversible and is getting in acceleration. Pricing dynamics of fossil fuels, technological innovations in this domain and newly identified reserves shows that even scenarios with ten times higher consumptions of fossil fuels comparing to today's would not be critical.

Some estimates and forecasts have predicted that lithium could be the bottleneck of this transition. A very simple calculation rejected these predictions with a conclusion that it will be enough lithium for all electric vehicles plus all other battery and non-battery lithium applications. The transition will make changes in both, mobility and energy, often creating synergies and new business models. Sustainability of transportation will assume also the sustainability of living in increasingly urban environments. Technological innovations, green energy sourcing, smart cities planning, infrastructure development and policy creation will be the main features of this transition.

Currently, there are at least two technologies which will propel electric vehicles in the future, batteries and fuel cells. Both technologies can have a future by reckoning on strengths in their specific segments. BEV is the optimum solution for short city routes while FCV have advantages in longer routes of large trucks and passenger buses. Both technologies are considered 'green' and good for environment because they do not produce greenhouse gasses and air pollutants and especially because they shift the battle for green transportation from millions individual vehicles to one central energy production place. At the moment, BEV are leading the competitive race but new government policies and increased investments in R&D are expected to deliver better performances and higher efficiencies of FCV in addition to their improved refueling and recharging infrastructure. The best outcome for society would be the creation of future synergy of both technologies which would accentuate the best their features.

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