„XII. IFFK 2018"
Budapest, 2018. augusztus 29-31.

# Examination of the sustainability of global penetration growth targets for electric vehicle drive systems

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Abstract: There are extremely ambitious figures now days circulating already in official and decisive papers for the possible penetration of the electric vehicle drivetrains by 2030 and beyond. If seriously examined the availability of global resources and the distribution of the key raw materials, industrial readiness, then have to conclude tough questions about the soundness of the targets.

## 1. INTRODUCTION

Have we taken the availability of the base materials required for the new technology into account or do we have to consider the "oil crisis" in the era of electric drive? An interesting discipline called geoenvironmental science has emerged recently; amongst others we can learn about the inventory of our natural resources from the representatives of this science and we can also arrive at important conclusions about the strategies of alternative drive technologies.

The 797-page American study published in 2017 [1] identified 23 critical, non-energy source, natural resources which are essential to modern and developing industries and the import dependence of which may result in serious industrial disadvantage for the United States (as well as many other developed countries, like the EU member states). Unsurprisingly just a few years ago we were not or hardly aware of most of these base materials. The European Commission also regularly monitors the availability of base materials. They examined 41, 54 and 78 elements in 2011, 2014 and 2017 respectively out of which the number of elements with availability classified as critical increased to 26 in 2017 (with nine new ones and three cancelled compared to 2014) [14].

If we have a look at the base materials of critical availability, many of them play key roles in energy transition, especially in the largescale electrification of transport. Moreover these materials become strategically critical because there has been great increase of the production of electric drive and electric energy storing capacity and in the current regulatory and incentive system we face up to two magnitudes of expansion. The sustainability of the processes of energy change may however be fundamentally influenced by the availability and the cost of these critical base materials. There is a great risk that global industrial production, the current map of the output of the automotive industry shall dramatically and suddenly change due to this process. The European Union and the United States otherwise rich in natural resources, is a clear step behind China in securing the strategic supplies of necessary natural resources. In 2014 China produced 20 % or more of over 40 mineral raw materials, including rare-earth elements 85 % of which is produced in China; according to the 2016 US Geological Survey 82 % of $_{74}$Tungsten, 76 % of $_{51}$Antimony, 73 % of $_{32}$Germanium, 68 % of $_{80}$Mercury, 66 % of graphite, 59 % of fluorite and 56 % of $_{83}$Bismuth is produced in China.

The European Union also had similar results in its investigation report [2], which is presented in Fig (1.).

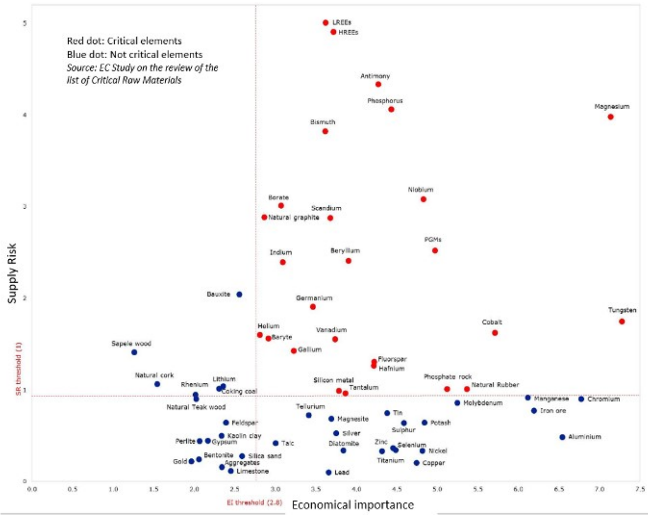


Fig. 1. Elements posing supply risks for the European Union, 2017 [14]

## 2. DEFENSIVE ELECTRIFICATION PLANS

By the increase in the sales of electric and hybrid vehicles, the demand for the production of Lithium-ion batteries is several times higher than the available capacity. As this is presented by the Bloomberg research [3]. The production capacity of the world was 103 GWh in early 2017 which must be increased to 12.5 times more by 2030. It is worth

CAETS
„XII. IFFK 2018" Budapest
Online: ISBN 978-963-88875-3-5
CD: ISBN 978-963-88875-2-8
Paper 12

Editor: Dr. Péter Tamás

showing the difficulty of the task by a few figures. The construction of Elon Musk's Gigafactory started in 2014, in the Nevada desert starts employing people in early 2018, planning to expand till 2020, to reach ten thousand employees. The production capacity of 35 GWh to be developed by 2018, will result in this output from 2019. It means that 33 additional plants of the same capacity need to be built worldwide in the next 12 years while the first stage of the Tesla plant is built and started in 5 years. Looking at the figures from another angle, $ 2 billion has been used up of the $ 5 billion investment of (the shareholders of) Tesla if the information disclosed is reliable. Counting with the large-size battery packs of the Tesla models it is true that every year 500,000 cars equipped with traction batteries produced there. And if we estimate the production life cycle of the batteries for 5 years, the cost of the production unit can be calculated as $ 800 per car due to the change of technology treated by rapid development.

And the boost of demand does not only affect production capacity but also the need for raw materials.

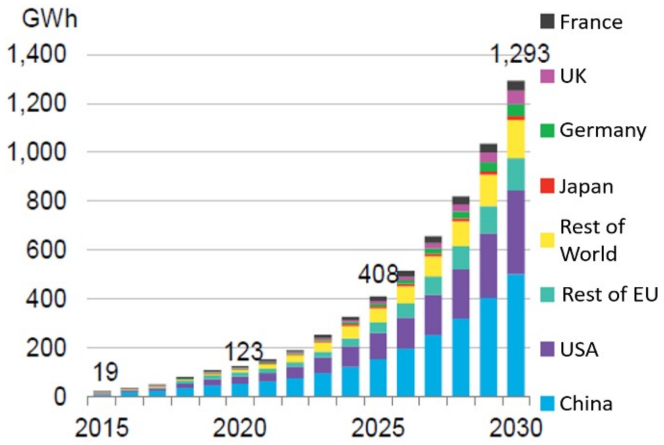


Fig. 2. The forecast for production capacity demand for Lithium-ion batteries for the purpose of vehicle drives between 2015 and 2030 according to the survey of Bloomberg New Energy Finance [3]

The differences between forecasts and scenarios is huge in the extent of the penetration growth of battery-electric vehicle. The comprehensive forecast of the International Energy Agency (IEA) [10] for 2030 shows about four times diversion in terms of the stock of EV's. The most ambitious B2DS (over 2°C) scenario counts 25 % share of electric vehicles by 2030 worldwide or 30 % in the countries supporting electrification. In terms of passenger cars the 30 % global share may even result of sales reaching up to 40 %. The 2DS scenario estimates the share of electric cars on the market to 18 % in 2030. According to the RTS (reference technology scenario) 55 million vehicles will be on the road in 2030 which means more than 5 % market share. Based on the increase of automotive production, which has recently exceeded 90 million, units and it is predicted between 100 and 110 million by 2030, to satisfy mobility demands resulting from higher population and GDP. In case of taking different scenarios into consideration, at least 6 million or according to the B2DS scenario around 30-33 million electric vehicles will be produced annually by 2030. The above-mentioned 1295 GWh battery production capacity by 2030 means approximately 45 million BEV battery sets.

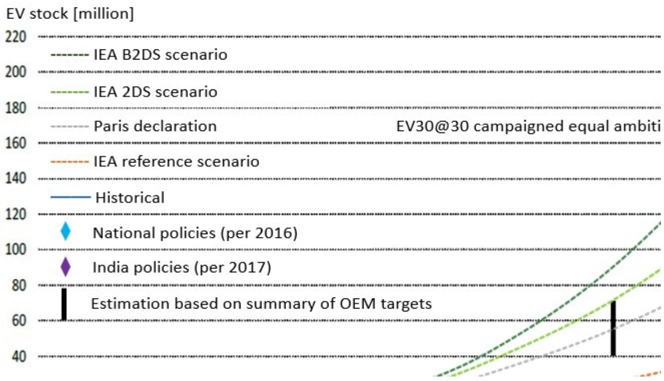


Fig. 3. Different scenarios of the global BEV stock, prepared by the International Energy Agency. Beyond the Paris declaration, almost double penetration targets have been created under the EV30 campaign.

The weakness of the IEA report [10] is that it virtually ignores the hydrogen fuel cell electric vehicles (FCEV) while hydrogen drive must be inevitably taken into account in the next technological matrix.

## 3. CONFRONTATION OF PLANS, TECHNOLOGY AND RESOURCES

Meanwhile one of the major pillars of the Clean Vehicle Package of the European Commission (published in 2017) is the electrification of road transport (including hydrogen) aiming to preserve the competitiveness of the European automotive industry directly employing 12 million citizens. In order to fulfil this endeavour however the road passes on very thin ice also due to the availability of raw materials. As we know, the relation of production & demand for minerals is shown by the trading prices. A typically warning example is $_{27}$Cobalt, which is one of the major components of the cathode of current Lithium-ion batteries as transitory metal; the average subscription price of $ 30,000/ton of the past years has risen over $ 80,000 by early 2018.

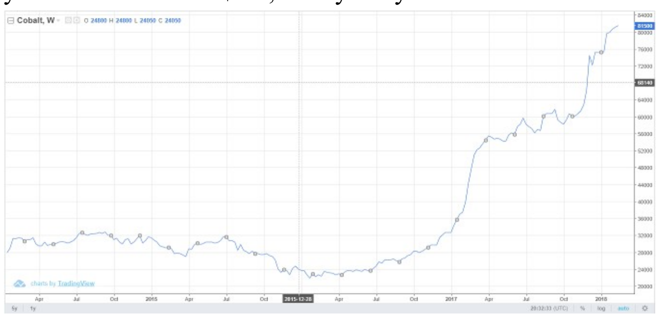

Fig. 4. One of the most emblematic, critical elements of the electric car industry is Cobalt. It is typically used in the cathode alloy component of Lithium-ion batteries however it

is also a potential material for alloys of permanent magnets in those electric motors which aren't deploy rare-earth elements. Most of the Cobalt comes from a problematic area, Congo. Its predictability is show by its price development, which close to three times higher within just a few months.

The different Lithium-ion battery chemistry processes and production technologies certainly require different amounts of Cobalt presented in the graph of Bloomberg.

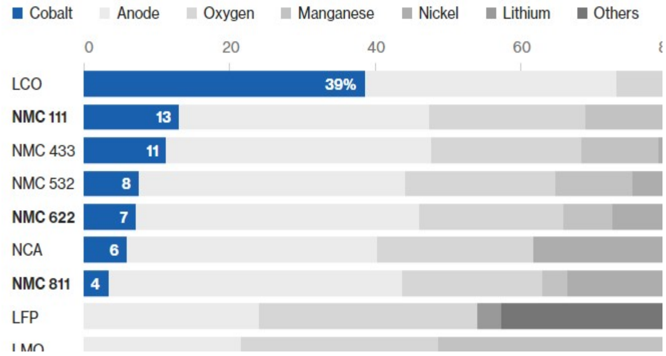


Fig. 5. The weight composition of some Lithium-ion batteries is show on the graph of Bloomberg New Energy Finance [3]. There are few options for the material of the anode, it is usually made of graphite.

The target in many battery research and development of the world the reduction of material usage and develop new components, which has effectively resulted until now the increase of the capacity and the decrease of unit costs. The specific energy density of average Lithium-ion batteries increased from 85 Wh/kg in 2011 to 125 Wh/kg in 2017 while prices fell to about half in the same period.

The flattening of the evolution curve in these two fields can be probably assumed. In-depth technical future research analyses like the report prepared in 2015 for the US Department of Energy [11] do not even look ahead for a decade. On the basis of the parameters for 2022 specified rather as development objectives, the energy density of 100 Wh/kg in 2012 is expected at 250 Wh/kg by then and the cost of production from 600 $/kWh at 125 $/kWh. At halftime the intensity of the development of energy density shows backlog, the energy density of the batteries in the new models launched in 2017 is between 103 and 152 Wh/kg, and the average value is 123 Wh/kg [12]. In the prospects of decreasing cost tendency models [13], the reduction of the cost of raw materials represents over 25 percent. This is to be achieved mainly by the expected reduction of the amounts used from the major raw component, as the main result of developments. It must be added however that in the moment of final investment decision for a battery factory, the selected technology to be used is vastly determined for years and unable to continuously and immediately follow the results of the latest R&D. Contrary, shortening the life cycle of the selected product technology however also results in the shortening the life cycle of the production capacity as well, which drives to a dramatic increase of specific CAPEX on the product.

Another component of battery production cost trends however is the change of trading prices of ore products on which it is difficult to generate a technical model to support the cost reduction. However it is extremely important to look at key base raw materials through a perspective of supply security. Identification and comparison of critical elements with the energy strategy has become necessary. If we survey what elements are critical generally in terms of the sustainability of transport and generally of energy transition, we can arrive at the following conclusions.

The 2017 report on the production of fuel cells (FC) [19] already provides an accurate analysis of the flattening of the improvement of cost trends. The American research project started also aims to further reduce the production costs of FC-s. The strongly sharpened DOE target value is 40 $/kW in 2020 from the starting value of 53 $/kW. The cost of the entire fuel cell system to be built in the vehicle was between 3,000 and 1,500 $/kW a decade ago, compared to which the current level is extremely low (the publishers of the study calculated the cost of the system for the Toyota Mirai at 233 $/kW of which 73% is the cell package). Little further achievement may be reached at the production of 500,000 units/annum (Toyota Mirai planned number of units is 1000/annum!) taking the 80 kW package as the basis. Analysing everything from making the membrane thinner, through the utilisation of the production line and lower specific use of platinum to higher energy density, not even calculating with potential rise of base material prices, 42.64 $/kW cost for cells is seen as achievable by 2020 and another 15 percent specific cost reduction by 2025. This however hides a high level of uncertainty in terms of the number of units and the cost of base materials (primarily platinum which was traded at daily peak of $ 80,400/kg prior to the economic crisis and at daily low of $ 27,600/kg afterwards in 2009 and the average of this decade is at the level of $ 53,000/kg), as well as the increasing investment costs ($ 5 million membrane production line cost was calculated in 2013 while the same was calculated as $ 20 million in 2016).

### *3.1 Antimony*

Fig. 5. The Antimony metalloid. Source of image: Tradium

An important complement of an alloy in modern industry applied in increasing toughness and hardness as well as corrosion resistance in lead-acid batteries as a 4-6 % alloy component of lead. Two thirds of global Antimony use is due to traditional batteries.

It is one of the riskiest elements on the European list, the United States covered 67 percent of its Antimony import from China where the volume of production is repressed by administrative tools as a result of which 14-18 qualified suppliers remained by the end of 2011 from the earlier number over 400 (Chegwidden and Bedder, 2012). Stocks in the USA are typically small in volume and cannot be economically exploited. The exploitable stock of antimony element found in over a hundred different minerals of the world was set at 1.3 million tons (Gubermann, 2014) although significant controversies exist (Laznicka, 1999 reported approximately five times larger stocks). The annual production in the middle of the decade was 159 thousand tons (Gubermann, 2015) allowing for the conclusion that no significant long-term increase of production is expected which primarily makes plans of developing stationary battery capacities more difficult.

*3.2 Natural Graphite*

Fig. 6. Natural graphite from Sri Lanka. Source of image: Caesars Report

Graphite is known to be no more than a regular crystal structure of hexagonal plates consisting of carbon atoms (graphenes) Although the carbon atom is the fourth most frequent element of the solar system, only a very little portion of the carbon stocks in the earth's crust exists as graphite. First of all high level of cleanness is required for use. According to commercial classification the "amorphous graphite" powder is the least demanding ore, consisting at least 75% of graphite crystals and over one million tons of stocks is available of it. In "flake graphite" crystalline containing developed graphite crystal structures of 40 micrometres to 1 centimetre in size generally, in the residue containing carbon. The commercially available stock of this cleaner ore containing at least 8 percent of graphite crystals is estimated at 200 thousand tons. "Lump or Chip graphite" is found in vein and fracture filling of metamorphic rocks up to 3 metres in diameter and ore grade within 40-90 percent of clean graphite crystals. The only known deposits are the mines in Sri Lanka at the depth of 30 to 400 metres but the stocks probably do not exceed 100 thousand tons. Exploitation and selection is performed manually, providing over 90 percent graphite content.

Pricing of the produced graphite certainly meets the above categorisation there is no stock market listings, trading takes place on the basis of agreements between producers and users. The price data of the research [1] for the beginning of the decade shows $ 600-800 per ton for amorphous graphite of 80-85 % graphite content is, for flake graphite of 90 % graphite content is $ 1,150-2,000 per ton and for 99 % pure lump or chip graphite from Sri Lanka is $ 1,700-2,050/t.

A significant part of industrial graphite use is provided by synthetic, 99.9 percent pure graphite crystals. The price of this however was between $ 7,000-20,000 per ton in the period surveyed. Natural graphite supply was assessed as critically threatened by both the United States and the European Union, the latter in spite of the presence of European mining activities. As opposed to this, the deposits found in the United States are not exploited typically due to their uneconomical nature. Let us also note that approximately 10 years are required to prepare a mine for production.

China gives two thirds of the production of the world (639 kilotons, average of 2006-2010), India gives 15 percent and Brazil less than 10 percent (Olson, 2011). Due to the majority of the production, China has been dictating prices for decades and they have the opportunity to unfavourably set the export prices protecting the Chinese domestic steel- or battery industrial use, putting their industry into an advantageous situation.

Most of industrial graphite use traditionally takes place in metallurgy, however the high electronic conductivity, the thermal stability and the good lubrication capacity lead to rising use from new industries. The use of graphite is increased by fuel cell, high capacity rechargeable batteries and special light alloys. The anode of energy storages applicable for hybrid and fully battery-based drives almost exclusively require graphite [6, 7]. Almost 15 percent of the composition of lithium-ion batteries in terms of weight is graphite [8], i.e. taking 240 kg as an average BEV battery size, we can calculate with 45 kg of graphite. Calculating with the production of 10 million BEV units means 420 kt graphite used for this purpose only, which means close to half of the current annual production. Although thanks to the B2DS scenario drawn up by IEA in 2030 we will use so much graphite for batteries, which exceeds the total current mining production. Nevertheless in such case the prices will certainly become multiple times higher, significantly closing up to the prices of synthetic graphite which cannot substitute natural graphite in all cases.

According to the data of Asian Metal, a widely used trading platform (used in other references too, data reflects to early

March, 2018) the market of natural graphite showed 15-21 % increase in prices last year while the price of different manufacturer's prices for graphite electrodes showed 53 to 77 percent increase in prices in the same period of time.

*3.3 Cobalt*

Fig. 7. 3 gram piece of cobalt Source of image: images-of-element.com

The silvery grey metal is of key importance for modern technology in several fields. By using it in alloys the wear resistance and hardness of metals can be increased and magnetising capacity can be ensured. The major field of use of cobalt - reaching 30 % in 2011 - is as the component of rechargeable battery cathodes in lithium-ion, nickel–metal hydride, and nickel-cadmium battery types. They play an important role in consumer electronics, battery tools and hybrid and battery-driven electric cars. Nevertheless cobalt is also used as the alloy component of permanent and soft magnetic metals as well as to increase the heat resistance and stability of parts in turbines and aeroplane engines and generators. Cobalt has a similar function is cutting and milling tool profiles exposed to great wear.

The USA imports approx. 75-80 percent of its cobalt needs and the remaining 20-25 percent is from reuse. 55 percent of mined cobalt comes from Congo that poses great risks to supply capacity and of course handover prices, due to the danger of civil war and non-transparent relationships. Refined cobalt typically arrives from China. On the basis of taking the 214 mines with over 1,000 tons of deposit into consideration, the cobalt deposits of the Earth is estimated around 25.5-26 million tons although the most important ones are deep see deposits, laying below 6000 metres. Those are impossible to exploit today due to technical, economic and often legal obstacles. The onshore ore deposits are only 17 percent of total, and mostly in Congo. It is worth considering that in addition to deep sea, the deposits in Congo have concentrations of cobalt content close to 1 percent, while other deposits of minerals show around 0,1 percent cobalt content negatively influencing costs.

If we consider that 30 percent of the 75 thousand tons annual cobalt use (in 2011) was given by batteries (mining was 109 thousand tons, refinery output was approx. 80 thousand t) and their global production capacities is expected to increase from practically zero to 1,295 GWh only for EVs, have to conclude; the refined amount of cobalt will be between 300 and 500 thousand tons, taking the development of battery technology into consideration too. The known deposit in the earth crust can be exhausted by this demand within a few years with the improbable scenario that output of mining can increase to multiple amounts keeping the price of cobalt at an affordable level. Without this however the exploitation of rocks at the bottom of the sea deeper than 6,000 metres and bringing them to the surface seems to be one, but very difficult way for supply. To view all of this, it is difficult to conclude that cobalt did not constitute the obstacle of further spread above the production of a few million BEV units per year.

Cobalt metal subscription prices are typically increasing in every category and in any time period. The past two years have seen significant increase; according to the statistics of Asian Metal, the increase of the last 360 days is between 30 and 40 percent.

*3.4 Rare-Earth Elements*

Fig. 8. Half gram of neodymium. Source of image: images-of-element.com

Fig. 9. 2 cm piece of dysprosium. Source of image: images-of-element.com

The 15 elements between atomic number 57 and 71 are abbreviated as REE and not infrequently are called lanthanides. To complete the REE group, need for the list the yttrium, which has very similar characteristics with atomic number 39. The rare-earth elements are demanded for uses in military, energy and other industrial applications based on their unique attributions. The major consumer of REE today is glass production however their use in magnets is increasing rapidly, considering that the neodymium-ferrum-bor magnets (known as NdFeB) are the strongest (their magnetic energy density exceeds 400 kJ/m3), this alloy composition is used in order to reduce magnet size and weight. NdFeB magnets were developed in the 1980s in order to manage the cobalt supply problems of the strongest magnets at that time, the samarium-cobalt magnets (energy density of SmCo magnets are around 250 kJ/m3). In addition to the traction motors of HEV and BEV the NdFeB type magnets are also widely used in the actuators of aeroplanes due to their high magnetic energy density. In electric motors smaller amounts preferred to use of REE elements, like $_{66}$dysprosium, $_{64}$gadolinium and $_{59}$praseodymium. Dysprosium improve the heat resistance of NdFeB magnets from 120°C applicability range up to 200°C (SmCo magnets resist up to 400°C) and the other two REE component serve for increasing the demagnetising resistance of permanent magnets.

Neodymium and praseodymium can partly replace each other in NdFeB magnets nevertheless the close to 21,000 t and 6,300 t annual REE production (2014) comes almost exclusively from China (and the use of this amount in magnets is respectively 89 % and 73 %) [15]. Moreover the two metals are found in about 4 to 1 rate in the ore, and their separation is rather difficult. There is a chance to somewhat reduce the specific use of the two elements (surveys show that the 31 % neodymium and praseodymium content may be reduced to 20 % by 2030 due to developments). Dysprosium is another necessary component of alloy in NdFeB magnets (up to 9 % mass percent) the 1,400 t of exploited amount of which also originates from China; it can be replaced by terbium of which a quarter of this amount is produced only, also in China. The price of terbium is more than twice as much as dysprosium and approx. ten times higher than the price of neodymium (Asian Metal 2016) and an extra problem is the high volatility of prices reaching tenfold levels [17]. The 330 RMB/kg trading price of PrNd seen in November 2016 rose to 480 RMB/kg by July 2017 occurred by the closing of smaller mines gripped on environment protection measures.


Fig. 10. Price changes of PrNd between October 2016 and July 2017 (Asian Metal statistics)

The weight of magnets used in electric motors is not insignificant; approx. 4 t magnet is found in a modern 6 MW wind generator (~1.6 t REE) which can be reduced by changes in construction but it causes loss of generator efficiency.

Of course the weight and energy density is more important in vehicle drives than in any other electric motor applications. Therefore most BEV and HEV are designed with NdFeB permanent magnet PSM (Permanent Synchronous Motor). Less frequently seen as the choice of designers is the ASM (Asynchronous Motor, Tesla is an example) and the EESM (Externally Excited Synchronous Motor). Although these do not contain REE, but they remain less popular due to the lower energy density and in case of EESM the more expensive production costs of the systems resulting from the much more complex structure. According to the report of JRC [15] the REE use of PSM motors may be reduced by up to 29 percent between 2015 and 2030. Today’s average traction motor magnets weight 1.5 kg/BEV, contain 24 % neodymium, 6 % praseodymium, and up to 9 % dysprosium. The latter may even be reduced to 2.5 % thanks to more advanced metallurgy and construction refinements. Despite of, still great increase of demand expected caused by the growing number of BEV and HEV production. Taking optimisation into consideration as well, the B2DS scenario may result in 8,000 tons of Nd and 2,000 tons of Pr demand increase by 2030 from vehicles. It must be added that the survey result of [15] shows that only by 2020, 3,000 t Nd, 700 t Pr and 800 t Dy surplus in demand may be expected

contrary to year 2015, if we take e-bikes also into account additionally to BEV and HEV.
Currently the largest amount of NdFeB magnets is used in piezo-electronic devices from the industrial sector and the automotive industry, taking 25 % of the 79,000 ton world production in 2015. Wind turbines meant 10 %, electric bicycles 8 % and HEV and BEV traction motors 7 % of the cake of magnets. The B2DS scenario presents approx. 50,000 t higher demand for magnets by 2030 from the automotive industry. The fact is especially alarming from an industry policy perspective, that over 85 % of the production of NdFeB magnets found in China, beside of approx. 10 % in Japan and the remaining less than 5 percent comes from the USA and the EU combined. What could this mean for the future of automotive industry outside China, where the industry operated on semi-capitalist bases and market regulators determined by the political leadership differing fundamentally from the Western models?

The past year has seen 5-10 % of increase in the price of neodymium metal while Pr metal paid 17 % more to China (Asian Metal) and the price of Dy did not significantly changed in the same period.

In addition to the rechargeable batteries of electronic home appliances the electric driven vehicles, especially the HEVs are using commonly nickel-metal-hydrid (known as NMH or NiMH) batteries, which anodes made from a $_{57}$Lanthanum-based alloy. Approx. 10-15 kg of Lanthanum can be counted for a hybrid.

Although not all the REEs are rare, as shown in their names; the most frequent $_{58}$Cerium for example can be found in the earth crust in larger amounts than copper or lead. The exposedness in the case of REE-s results from the fact that China has provided the vast majority of production for decades now, producing over 90 percent in the average of the last decade. China has started administratively limit their production in the form of quotas, licences and taxes in order to preserve national deposits to cover domestic demand and on the other hand to reduce the unfavourable environmental effects of mining [1]. Consequently, there is greater activity to search for deposits outside China. The REE resources of the earth crust is estimated around 130 million tons but the exploitation of many is still not solved. As opposed to this the total mining production is “only” 130-140 thousand tons which apparently projects sufficient resources for long time. However, the forecasted expansion of the market of HEV and BEV prescribe at least doubling of the current mining output as soon as the middle of the next decade in case of each discussed REEs.

The increase of production is a long process, can even last for a decade. The demand driven traded price, especially in case of those materials which amounts are low and production comes from a very few places, may easily increase even to a magnitude higher level. And that already can be seen in the past years.

### *3.5 Tellurium*

Fig. 11. Tellurium metalloid, with 3.5 cm diameter. Source of image: images-of-element.com

This material is less used in transport however the situation of solar cell production is fundamental in terms of expanding current renewable power generation capacities. From the current thin film technologies the cadmium-tellurium film is spreading especially in the emerging industries of China and India. Although there are other uses as well, like the rubber industry, electronics and medical equipment production, two thirds of worldwide consumption still came from the production of photovoltaic and thermoelectric units (Anderson, 2015). These industries have all shown strong development in recent years so the demand for tellurium may significantly increase in the forthcoming period.

Tellurium is an extremely rare material in the earth crust, typically coming to the surface as a side product and there is very little information about exploitable resources, estimated around 24,000 tons. Only two major deposits known, where primarily tellurium is exploited, one in China and one in Sweden (tellurium is a little bit below the limit of strategically extra risky assessment line of the EU probably due to this Swedish resources). These two provide the determining approx. 70 tons of mining input part to the 450-470 tons of refinery output. The demand for tellurium resulted an over 17 percent price increase in China within one year (Asian Metal).

### *3.6 Copper*

Considering the significant deposit in the earth crust, copper is not listed among critical elements but it is worth mentioning that on the 31st International Copper Conference in Madrid (07/03/2018) the EVs coupled demand for raw material became an important issue. According to a summary by Deloitte expert, Tim Biggs one single BEV requires approx. 80-100 kg copper compared to the 20-30 kg use of today's vehicles. He also highlighted that the increasing demand for copper will be limited by the availability of cobalt; he thinks that the amount of available cobalt will be enough for only 5 million BEV-s in 2030. According to Benedikt Zeumer, from another major analyst company, McKinsey & Co. the automotive industry will have half million tons of extra copper demand by the producers as early as 2020. Although the deliverable stocks are seen by analysts as relatively reassuring today, for example the mining problems in Chile in 2018 may affect not less than 2.5 million tons and the analysts say that there will be 169,000 tons of deficit in 2018 also influencing prices. According to the report of Asian Metal only a copper delivered from a premium warehouse (Cathode Premium 99.99 % min) showed significant price increase last year.

## 4. IMMEDIATE AND DIRECT ENVIRONMENTAL EFFECTS OF MODAL SPLIT

The environmental effects of human being is inevitable exists. The externalities caused by transport, air and noise pollution as well as other means of load are often in focus. Nevertheless surveys have rarely covered all the elements related to mobility.

Considering that transport is an energy transformation process, while the energy source is converted into kinetic energy with the assist of the vehicle. This process is starts with the production of the vehicle and approximately ended at the dismantling. Materials and energy is primary required for production, in which human work can certainly be identified too. In order to produce kinetic energy by the vehicle, the transport energy source does not only need to be used, but first it also needs to be made available for use.

Production of vehicles is a more and more complex process requiring natural resources in which the increasing use of special raw materials and complex production techniques is a natural consequence of technological development. However like in gold mining cyanogen poisoning is not an acceptable consequence of the activity, in the automotive production it is important to take details of environmental load into account. Recently the energy demand of producing batteries for EVs has come to focus as well as the question of the resulting environmental footprint.

Several scientific analyses have been prepared in the past years about the energy intensity of battery production, the results of those were discussed in-depth in the 2017 publication of IVL Swedish Environmental Research Institute [4]. The average energy (typically electric) consumption of the production is 586 MJ/kWh. Covering this shows significant difference in $CO_2$ intensity depending whether a battery is produced based on the badly structured Chinese grid or from the power mix of a more favourable production site as it has been presented by Chinese researchers too [5].

They considered 28 kWh capacity BEV battery packages per vehicle, three different lithium technologies were analysed, those production occurred $CO_2$ emission is between 3,061 and 2,705 kg. The details of the Swedish report [4] show that the actual associated emission of the production is definitely higher, between 150 and 200 kg/kWh. To make it more understandable, ~4,9 t $CO_2$ is emitted by the production process of a 28 kWh battery pack, which equal to burning 2,085 litres of petrol. Taking the consumption of a petrol car from the same category (5 l / 100 km), 42,000 km-s have to be driven to reach this level of greenhouse gas emission.

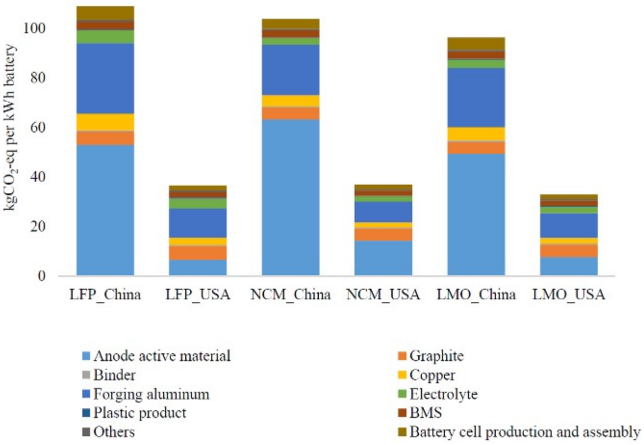


Fig. 12. The $CO_2$ footprint of producing three lithium-based batteries subject to the same production site according to the analysis of Chinese researchers [5]. The Swedish comparative study [4] sees approx. 50 percent larger footprint.

These values however do not include the environmental load of recycling at the end of the life, considering that there is no widely applied technology and industrial capacity yet available for lithium-ion batteries. Directive 2000/53/EC of the European Union on end of the life of vehicles declares, that the manufacturers of the vehicles shall be responsible for recycling at least 85 % of the weight of the vehicles. Directive 2006/66/EC on batteries declares that the marketers of batteries shall be responsible to collect 95 percent of batteries and recycle at least 50 percent of their weight. The Swedish report [4] covers the processing capacities of used batteries in Europe today and shows what materials are partially recovered. The destruction of each kg of batteries typically results in 2.5 kg $CO_2$ footprint, and the reuse of the recovered materials in battery production results in approx. 3.5 kg/kg $CO_2$ reductions in terms of the weight of lithium batteries, only improving the balance of the entire life cycle by no more than 5 percent.

It is somewhat more widely known that the favourable environmental effect or advantage of using electric cars on global warming only exists beside of those grids where the power mix generated by low carbon intensity. In this field Norway is the world champion, producing a significant part of its power mix by hydropower, free of $CO_2$ and even without nuclear power plants.

On the other end there is China, where the strong governmental efforts to spread electric cars is paired with a high $CO_2$ intensity, polluting, and in too large part coal based power grid. Only if halving the level of the carbon footprint by the Chinese power mix, could electric cars reach other advanced technologies and fuels in terms of the emission of greenhouse gases. This will last long even in the case of installing significant renewable power generating capacities and forced pace converting coal power plants to natural gas, considering that in the forthcoming years still intensive growth of consumer demand and population must be supplied.

## 5. TECHNOLOGICAL DEVELOPMENT VS. SPIRAL OF COSTS

A frequently heard sentence today is that electric cars are much simpler and consist of fewer parts than the ones with internal combustion engines and therefore they will soon have a competitive advantage. The truth is that the production of a basic, small 4-cylinder otto-engine is approx. $ 500 to which of course - in order to fulfil modern emission requirements - a catalytic converter must be calculated with an amount of approx. $ 300. Apart from the catalytic converter almost everything else is required for an EV too. The same safety equipment, chassis rigidity and suspension must be built in, not to mention the arsenal of electronics provided by a modern car. The high voltage battery pack and motor of an electric car, pricing and competitiveness are the key to the wide penetration (if the background infrastructure in considered as granted completely and meeting demands).

The International Copper Association [18] compared the possibilities of 50 kW capacity electric motor sized for hybrid vehicles, proving that of the high copper content induction motor together with the inverter is suitable for replacing the NdFeB PSM motors and resulted USD 390 lower production cost in 2013. However weighing 40 percent more (+10-12 kg), having 25 % lower torque due to its lower energy density, but requiring 10-15 % more power and therefore consuming 900 kWh more power on average in 120,000 miles. The price difference was generated by the increase of the cost of magnets in the PSM motor since a motor with a permanent magnet containing REE was calculated with $ 260 production price in 2011, in comparison the cost of the same reached $ 590 in 2013 (which exceeds the production cost of a 50-60 kW capacity 4-cylinder otto-engine). Since then the price of high energy density magnets have further increased. By the approx. 50 percent expansion of demand for REEs needed in electric motors by 2030 the price of the critical Ne/Pd, Dy base material may increase up to 2-3 times higher. This projects the probability of further price increase of high performance PSM motors in the future.

The huge demand for the batteries presented in chapter II drives to the potential increase of raw material prices, topped with the short return expectations of many capital-intensive investments, may result a potentially sudden stop of the specific price reduction triggered by technology improvements, and a long term average price can anchoring around 200 $/kWh. As a result of this however the $ 6,000 production cost disadvantage of BEV vehicle (average 28 kWh battery pack) may be preserved. Over the inflexion point of the demand-offer balance curve of any base material presented, the shortage of base material or even the shortage of battery production capacity may result an increase of the production price of the power storage unit.

On the conventional Otto-engine side however the survey of ABN Amro analyst [20] showed that due to the reduction of the number of vehicles equipped with internal combustion engines and the increasing offer resulting from the recycle of raw material the demand for palladium and platinum may even decline dramatically in the forthcoming period, also resulting in drop of price. The forecast also presenting extreme spreading scenarios until 2040 may result in up to 35 % reduction of global use in case of platinum which could result in the price of 32,800 $/kg in 2017 at the time of preparing the report, reducing to 10,600 $/kg. The decrease of demand for palladium may even reach 70 percent which could send the price of 34,900 $/kg down to 3,500 $/kg. One of the scenarios examined inspects intensive FCEV spread in the case of which they expect the increase of global demand for platinum while decrease in case of palladium. The two effects may balance each other in terms of costs. In all other cases the raw material cost of catalytic converters may strengthen the existing competitive advantage of vehicles equipped with internal combustion engines.

## 6. CONCLUSIONS

We can conclude that, in the event that the change of structures in automotive technology becomes excessive, one or more of the raw materials will probably reduce the sustainability thereof or reverse it in a worse case. It is doubtful that the possibilities of the industry and the framework of natural resources can ensure the complete and forced conversion of our energy systems in a sustainable way.

While the relation of expenditure versus benefit at a favourable employment of an alternative fuelling and technology may provide a positive balance of externalities in long terms. Example provided by a comprehensive study [21], summarize the balance of making LNG-based transport widespread in Hungary could yield up to HUF 50 billion (approx. $ 200 million) annually for the next 20 years, compare it to the current harmful situation of transport. The over price of a technology split process may be very high if it is excessively forced, resulting an unnecessary increase of the global decarbonisation process cost. The mankind of this century must use its resources to reduce the concentration of greenhouse gases in order to hold back and avoid climate change. Technologies and tools need to be preferred on which can provide the greatest effect from our available resources, moreover in the territory where the effect thereof can be proven. We must allow not implementing a balanced development from the variety of alternatives, based on comprehensive survey of advantages. In the age of Big Data we cannot conclude effective and reliable results, deploy strategies based on the old engineering approach, which started by bordering the problem or task somewhere and calculated only within that. There is more and more need for in-depth scientific analysis, which can examine the processes aiming to avoid $CO_2$ emissions in all aspects (including the sustainability of industrial production) and to compare their effects as much locally as possible.

Several vehicle propulsion systems are available which offer environment friendly options today to reduce the transport related externalities. The in-depth knowledge of the availability of natural resources, as well considering the demand-cost curve is needed to examine the penetration growth of alternative solutions, to achieve comparability and balanced regulatory systems. In weighing these the entire life cycle must be taken into account, adding the examination of the possibility of local energy supply and in assessing all these the cost indexes showing the total expenditure for the given region must also be taken into account in contrast with the monetarisation of the available reduction of environmental effects at local and global level. An inflexion point is almost inevitably found in the cost curves of the deployment of alternatives. The specification and consideration of these curves allow us to determine optimal strategies and right distributions of the available technologies. This is the only way to ensure that deploy our economic and natural resources, drives to an effective global climate protection.

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Online: ISBN 978-963-88875-3-5
CD: ISBN 978-963-88875-2-8
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Editor: Dr. Péter Tamás