AN ANALYSIS WITH HYDROGEN APPLICATION IN THE MOBILITY SECTOR – POSSIBLE KEY VALUE PROPOSITIONS FOR PRESENT AND FUTURE MOBILITY APPLICATION

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Abstract
Renewable Energy Sources (RES) and efficiency improvements are the key factor for future energy application and energy transformation processes. The huge amounts of fossil fuel like coal, gas and oil that are burned daily through human activities, increasing demand by the growing economies and world population are changing dramatically our present environmental situation on earth. Hydrogen (H_2) as a green sustainable secondary energy source can help moving into an independent and "earth" friendly energy future.
The objectives of the article show the possible adoption, acceptance and diffusion on a realistic Energy application in present. This application is in the mobility market segment, which will be transformed in an environmental friendly energy sector in the coming years through technical, political and legal changes. The important value propositions of these applications will be discussed and evaluated using H_2 as a green energy source. Methodologically a primary energy model is used to show the efficiency chain from Well to Wheel and consequences for environmental and economic issues. The result will be analyzed and the important value propositions derived. The key value propositions and some economic and ecological key characteristics are discussed. These values will give an overview of present and future issues in this energy sector. New possible innovation processes with a new rethinking pattern could be the result out of the research. Further conclusions of this analysis can be used as one tiny mosaic part, for a possible energy transformation future with H_2 as a green energy source.

Keywords
Value Proposition, Hydrogen, Mobility Applications, Batterie Electrical Cars (BEC), Fuel Cell Vehicles (FCV), Well to Wheel

JEL Classification
N7, O13, O44, P18, P28, P48, P5, Q4

Introduction

Anthropogenic greenhouse gases which results from burning fossil energy sources like coal, gas, and oil through human activities on earth are changing our climate since the industrial revolution in the 1850th rapidly [Merrill 2007, Yergin 2007, Vallero 2014, Stern 2014]. The world's population is increasing by over 50% since 1960th to the present of 7.40 billion people [UN 2017]. At present more than 410 ppm CO_2 concentration in average is in the air [UCSD 2018]. CO_2 is the second most important greenhouse gas which influence our global warming process and therefore our live on earth in different ways [Hansen 2015]. Since the start of the industrialization in the 1850th the CO_2 emission increased over 40 %. The daily flow of crude oil, for example, is the unimaginable amount of over 92 million barrels a day [BP2017, IEA2017] or 14.310 million liters flow of crude oil per day. The coal production per day is about 21 Mil. Metric tons. Annual amount of greenhouse gases 2017 was 32.5 billion tons of CO_2. The CO_2 concentrations of the last 800,000 years in the atmosphere was more stable but for the last 150 years starting with the industrial revolution there is registered an alarming increase from an average concentration of 230 ppm CO_2 to over 410 ppm. Despite the clear indices, today still see parts of politicians and scientists climate change as a natural given and not made by man phenomenon. To deny man-made climate change on a scientific and political level is a crime against future generations. There are three main sectors in our energy infrastructure. The first sector is electrical energy supply, the second sector is the provision of heat energy and the third sector is the mobility or transport. This article explain how H_2 can be considered a green fuel and how is used for mobility applications. If H_2 is converted from a primary renewable energy source like water, wind or sun it can be validated as a green secondary energy source [Godula 2015, Dincer 20016, Fang 2017, Machhammer 2015]. H_2 has some advantages compared to present fuels for mobility application. Green H_2 has no environmental impact, it is storable in large quantities, can be transported and can be converted back into electricity or heat at later times. Todays mobility applications are combustion engines which work according to the thermodynamic principles [Langeheinecke 2013]. These combustion machines that convert liquid and gaseous energy carriers into kinetic energy by chemical reaction (combustion). The last milestones are connected to electrical drives. The concepts are battery electrical vehicles (BEV) and fuel cell vehicles (FCEV).

BEV drives have compared to standard injection combustion engines (ICE) a factor of 3 higher efficiency [Karle 2017]. FCEV as an alternative drive concept is using H_2 a fuel stored in high pressure tank and a fuel cell as an energy converter. All this transformations in the automotive industry are connected with a change of the entrepreneurial mindset and with business opportunities that desired new Business models with specific value propositions.

1. Scientific Aspects

Energy

In order to analyse and understand how energy is converted, the different energy sources like primary, secondary, final and usable energy terms must be defined. Primary energy is called the original source of energy. When these primary energy sources are converted to other forms, e.g. Biomass in pellets form, wind energy into electricity, petroleum through refinery processes in gasoline or diesel. The resulted energy is considered a secondary energy source. For example, the element hydrogen occurs only as chemical compounds in nature. This means that H_2 must be released from these different compounds. The necessary source of energy for solving these chemical compounds can be electrical energy (electrolysis), or biomass with a heat steam reforming or heat (at a high temperature) using solar thermal energy to separate and store H_2 as an element. The dilemma with all energy sources are conversion losses from an energy type to another.

H2 Mobility applications

The Mobility sector consume around 28% of the total final energy usage worldwide and are responsible for more than 23% of today's CO_2 emissions [Creuzig 2015]. In addition, these mobile applications are emitted toxic gases (NO_x) and fine dust. As fuels largely, fossil liquid and gaseous energy sources are used. As a possible solution for reducing climate change and energy dependence, green H_2 can be used as a transportable, storable and in large quantities available energy sources. Mobile H_2 applications are all means of transport that can be operated with H_2. Depending on the powertrain performance and storage technology, different applications with H_2 in the mobility sector are considered. The three different powertrains for mobile vehicles are: combustion engines, hybrid electric drives and purely electric drives. The fuel cell is the crucial component in the power train for H_2 mobility. Today's cars up to 3.5 tons with combustion drives (ICE) have an average overall efficiency of less than 20 %. This depends on many factors, as shown in a flowchart in Fig. 1. At the end of the efficiency chain, less than 20 % of the total energy remains on the wheel.

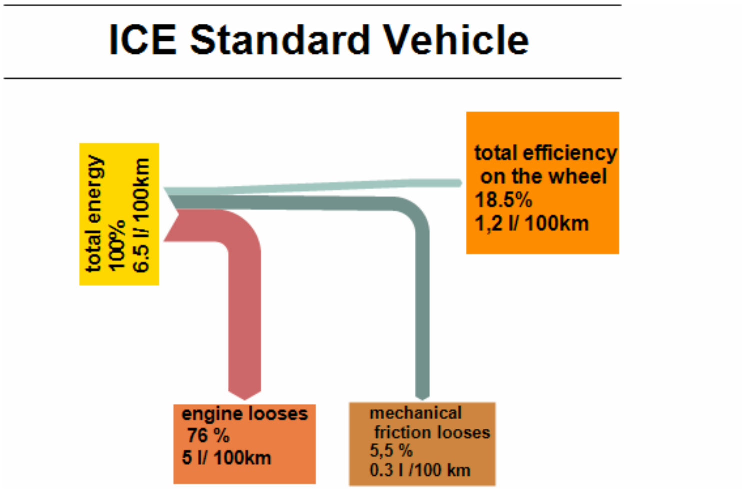

Fig. no. 1. Standard ICE Vehicle

Source: own contribution

Value propositions as a key element of a business model (BM)

The basic question in business models can be described as follows: Who buys from whom for how much? The key questions for answering what the task of a business model is shown in Figure 2.

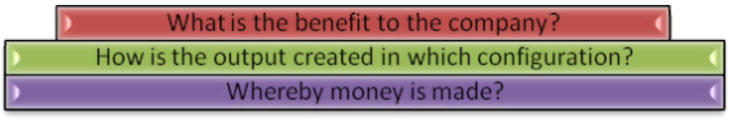

Fig. no. 2. Task of the BM

Source:source: Osterwalde 2009

The most important goals of business model structures are to ensure profitability and continued existence of the company, definition of business activities, visualization of activities, reduction of complexity, holistic understanding in the company so risks and potentials can be better estimated, identification of opportunities and risks means efficiency advantages and synergies internally and externally use and review strategic directions.
Using the BM according to Osterwalde, a business model is described of nine basic elements which show how an organization can be profitable. The (potential) customer is the focus of the business process. There are several categories that a customer considers important and that lead to the development of the benefit promise. The intersection of supply, market offer and customer needs results in the special customer value proposition.

2. Methodology

In order to be able to compare potential benefits in today's mobility applications, an own calculation model is designed and used. This primary energy model serves to illustrate the different mobility applications from the economic and ecological point of view. The results can be used to identify characteristic and distinguish features for the applications that are critical to customer behavior. Depending on the rating of these features by the customer, the product will be more or less successful on the market. For the primary hydrogen energy conversion model (Fig.3) following parameters for calculation purpose and comparisons are essential: *conversion losses, fuel cell application type, energy carrier, efficiency chain of the application, output energy type, environmental impact.* The calculation model is using input data from GEMIS (global emission model). An identical reference model for fossil energy sources compares (mirrored) the data with the primary hydrogen model.

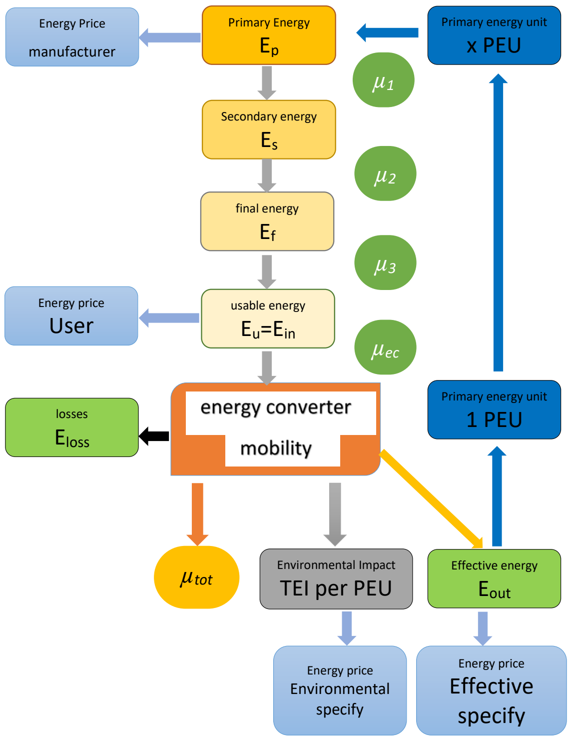

Fig. no. 3 Primary energy model

Source: own contribution

The research methodology is based on following equation which can be classified in energy conservation equations, energy efficiency chain and environmental impact calculations.

The energy conversion equation indicates the importance of energy losses for energy applications.

$$\sum E_{in} = \sum E_{out} + \sum E_{loos} \quad [1]$$

$$\dot{E}_{in} = \sum E_{in_1} + \sum E_{in_2} + \cdots + \sum E_{in_n} \quad [2]$$

$$\dot{E}_{out} = \sum E_{out_1} + \sum E_{out_2} + \cdots + \sum E_{out_n} \quad [3]$$

$$\dot{E}_{loos} = \sum E_{loos_1} + \sum E_{loos_2} + \cdots + \sum E_{loos_n} \quad [4]$$

Energy Efficiency chain take to account that the total efficiency is less than the efficiency each conversion step, that the energy is following well to the wheel.

$$\eta_{tot} = (1-\eta_1)*(1-\eta_2)*(1-\eta_3)*...(1-\eta_x)*\eta_{ec}$$
$$E_{in} = Q_p*(1-\eta_1)*(1-\eta_2)*(1-\eta_3)*...(1-\eta_x) \quad [5]$$
$$\eta_x = conversion\ losses$$
$$\eta_{h2} = \frac{\sum E_{out}}{\sum E_{imput}} \qquad \eta = \frac{E_{out}}{E_{input}} \quad [6]$$
$$\eta_{tot} = \frac{E_{out}}{E_{primary}} \quad [7]$$

For the environmental impact calculation is used the total Environmental impact indicator. (TEI)

$$TEI = Q_{primary} * CO2cf \quad [8]$$

$CO2cf$ = *CO_2 conversion factor/primary energy factor*
TEI = *Total Environmental Impact*

For calculation of the connection power for one and three phase system following physical equation are necessary.
3 phase systems: $P = \sqrt{3} * U * I$ [9]
Single phase systems: $P = U * I$ [10]

In the calculation one primary unit PEU is the base to compare. For each energy unit a special amount of CO_2 emissions is polluted. The efficiency chain goes from the primary energy source back to all efficiency conversion process up to the application self.
For the research analysis a standard energy power conversion system driven with a fossil source (standard conditions in Germany) was used. Alternative energy sources like Wind and PV for a RES were used as comparison. The application example is a medium size H_2 driven fuel cell car like Toyota MIRA or Hyundai NEXO, a normal standard petrol car and a BEV like the TESLA 3 model or BMW I3. The research is based on one Primary Energy Unit (PEU) used on the output energy on the wheels of the mobility application. The environmental impact is based on PEU and the CO_2 conversion factor from GEMIS 4.9 Energy prices and calculations on today's situations
Following aspect for important key values will be more looked, analyzed, evaluated.
Energy cost for the consumer, Infrastructures for refuel, Distance range of the mobility, applications, special leasing/financial offers, environmental bonus, filling time, tax relieve situations, Restriction driving bans, investment costs, economic calculations, maintenance and warranties [Staiger 2017]

3. Research Analysis and Results
The case study 1 "ICE with petrol and electricity fossil fuel source for BEV and FCEV" represent a comparative analysis of the three different energy sources for mobility applications. These are petrol, electricity from the standard electrical grid that normally is produced of a mix from fossil energy sources and RES. As a reference for the calculation was used the GEMIS data of 0,565 kg CO_2/kWh for electricity mix in Germany. Using a FCEV or a BEV with today's electricity from the grid in compare to a petrol car makes ecologically no sense.

The case study 2 "ICE with petrol and electricity from a renewable energy source BEV and FCEV" represent a comparative analysis of the three different energy sources for mobility applications. These are petrol, electricity from a renewable energy source in that case wind energy. As a reference for the calculation was used the GEMIS data of 0,02 kg CO_2/kWh.

The levelized energy cost in Germany for one kWh in Germany is between 0,04- 0,08 €/kWh in present [Wirth 2018].
Using a FCEV or a BEV with renewable energy from wind in compare to a petrol car makes ecologically and economically sense. The environmental impact using H_2 as a green energy produced from wind generators is 10 times lower than a petrol car. The energy cost is still double of BEV because of the higher efficiency but it is 40 % lower through the levelized production cost of 0,12 € / kWh than a petrol driven car.

Case study 3 *usage of power and energy*
This case study compares the filling time and the necessary power for the three different mobility vehicles. The objectives of the case study should compare the different storage and charging concepts and the consequences for the different customer.
Vehicle 1 has a 45l petrol tank, the BEV a 50 kWh batterie and FCEV 6.4 kg H_2 pressurised tank. For a petrol and a FCEV the time needed is less than 3 minutes. For charging up a BEV in a short time like 0,5 h or 1 h with special charger adapter there is a special electrical infrastructure necessary. This charging concept needs a special grid connection power.
To charge the BEV in 30 minutes with a 50 kWh Batterie you need a connection power of > 100 kW. Or the current will be > 173 A. A private building cannot deliver this amount of energy in this short time. Looking to a filling station with 10 fast charger a connection power of greater than 1 MW is necessary. Different studies showing that in the future to build an infrastructure for BEV will be far more expensive in compare of a H_2 infrastructures (..).
IEC and FCEV are using common materials for the storage system. BEV using special alloys like Li and Kobalt for the Batterie systems. These materials are not environmental friendly if something occurs like a fire as well the dependencies of the materials are very questionable. A research from KMPG shows the dependencies of this material from different countries like Kongo (KPMG 2018). Another point is a live cycle assessment of the different used materials in terms of environmental impact and energy usages. Table 1 shows the different customer values in regards on storage and Material usage for the different vehicles types.

Table no. 1. Case study 3 storage and charging overview

	ICE	***BEV***	***FCEV***
	Power and energy storage		
Efficiency	0,25	0,85	0,5
Tank/Batterie size	45 l	50 kWh	6.4 kg
Energy contents	418 kWh	50 kWh	211 kWh
Distance range	700 km	300 km	600 km
Filling time	0,05h	1h/5h	0,05
Electrical power for filling	1 kWh	10kWh/ 50 kW	1 kWh
Electrical current	3A	173A	6A
	Different Value propositions and rating		
Charging time	3min	0,5h – 8 h	3 min
Power for charging/filling	< 1 kW	100 kW	< 1kW
Special charging tools		Cables/plugs	

Easy to use/handle			
Environmental friendly	CO_2, NO_x		
Critical materials storage		Li, Ko,	Pla

Source: source: own contribution

Using a batterie vehicle sounds very simple and easy. When it comes to the charging aspects and distance range it looks different. For Urban usage like distances of 50 km/day ideal means of transport. For longer distances and fast reaction times critical to look at. As well for larger vehicles like heavy transport, Buses or trains fuel cell-based system will have bigger advantages in compare to battery driven vehicles. There will be no ideal power train solutions for vehicles.

4. Result of the H2 Mobility analysis

The comparison of the three-different power train of present standard vehicles, shows the importance of the energy carrier which is used for driving the vehicles. The efficiency chain between the primary energy source and the efficiency of the vehicle is the key point for success. Using different fuel types will change opportunities and variations of customer values for the mobility vehicles. Through new innovations in the power train and storage alternative new combinations of technologies type can bring forward innovative BM structures with destructive effects of existing BM (see TESLA 3 Model)
Table 2 shows a summaries Matrix of the key aspects and values for the different types of fuel using in the case studies (CS1 fossil and CS2 renewable energy)

Table no. 2. Summarise of the case studies

Case studies	Ref.	Ref.	CS1	CS2	CS1	CS2
Fuel type			Fossil	RES	Fossil	RES
Key values			BEV fossil	BEV RES	FCEV fossil	FCEV RES
Different Value propositions and rating						
Energy contents kWh	418 kWh		50 kWh	50 kWh	212 kWh	212 kWh
Distance range km	750km		300km	300km	650km	650km
Filling time h	3 min		0,5 – 5h	0,5 - 5h	3 min	3 min
Energy cost per kWh PEU	0,54		0,32 €	0,14 €	0,75 €	0,44 €
Energy cost per km €/km	0,093 €/km		0,04€/km	0,018€/km	0,08€/km	0,046 €/km
Investment cost €	25.000 €		38.000 €	38.000 €	68.000 €	68.000€
Leasing/Financial models						
Maintenance cost						
Tax relive						
Grands			4.000 €	4.000 €	4.000 €	4.000 €
Safety						

Warranties						
Environmental impact	1,4		1,6	0,05	3,85	0,14
Driving ban						
infrastructure						
Power for charging/filling						
Special charging tools						
Easy to use/handle						
Environmental friendly						
Critical materials storage						

Source: source: own contribution

The matrix shows the different case studies information. The valuation is done in three different colours which gives a first impression about the key values. The first rating would take the FCEV with a green H_2 produced form Wind. Depending of the valuation of the values and how important this are and the customer segments (long/short distance driver, availability 24 hours for the car, size of the vehicles) a simple analysis can be made out of the matrix. The matrix could be expanded with other alternative fuel and production processes like synthetic fuels from power to gas applications, biogas reforming processes and others. In the energy traffic analysis, the CO_2 emissions could be reduced over 90% in compare to the today´s reference vehicles, if H_2 is produced out of renewable energy sources like Wind, PV or another RES. The analysis takes todays energy cost for Wind generators. The cost (depreciation cost) for the electrolysis unit and pressure riser unit is not included. That is depending of future innovations for standalone systems or possible decentralized filling station. The potential of cost reduction through higher quantities (economy of scale) is huge.

Conclusion

Reducing the amount of CO_2 emission in the mobility sector two important points must be considered as a result of the analysis. Fossil fuel must be substituted with a renewable energy source and secondly to improve the efficiency chain for energy usage in the mobility applications. Electricity as a renewable energy source can be used direct to charge BEV and indirectly producing H_2 as a green secondary energy source for storage in the FCEV. Both concept for the power train have pro and contra, depending on the importance of the customer segments. There are no ideal vehicles type to satisfy all the customer needs. With the presentation of the different value propositions a good estimate can be made for the individual customer segments. H_2 as a green secondary energy source for the mobility sector is a future alternative in the energy infrasture. Economically H_2 is in compare to fossil fuel sources still more expensive. This difference will change constantly with new renewable energy technologies, learning curves, higher quantities and decentralized H_2 production units. In present H_2 produced out of wind, PV and hydro Energy is nearly competitive with today’s fossil driven energy conversion systems.

A clear view must be placed on today's old energy transformation processes. Efficiency potential of over 40% must be addressed and implemented. From today’s perspective H_2 which is produced out of different RES can reduce the dependencies on fossil fuels, saving CO_2 emissions and minimize the climate change in the future.

References

Creutzig, F., 2015. Energy and environment. Transport. A roadblock to climate change mitigation? *Science New York*, 350, pp. 911–912.

Dincer, I., 2016. *Sustainable hydrogen production. first edition*. Amsterdam: Elsevier.

EIA, 2017: Key World Energy Statistics. IEA Publications. France

Fang, Z., 2015. *Production of Hydrogen from Renewable Resources*. Heidelberg:Springer Science.

Godula, A., 2015. *Hydrogen production by electrolysis*. Weinheim: Wiley-VCH.

Hansen, J., 2016. Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming is highly. *Atmos. Chem. Phys.*, 16, pp. 3761–3812.

Karle, A., 2017. *Electromobility fundamentals*. 2., edition. Munich.: Carl Hanser Verlag.

KPMG, 2018. *Global automotive survey 2018*, [online] Available at: <https://gaes.kpmg.de/#intro> [Accessed 25.05.2018]

Machhammer, O., 2015. Economical / ecological consideration for the production of hydrogen in large plants. *Chemie Ingenieur Technik*, 87(4), pp. 409–418.

Merrill, K.R., 2007. *The Oil Crisis of 1973-1974. A Brief History with Documents*. Bedford: St. Martin's.

Osterwalder, A. & Pigneur, Y., 2013. *Business model generation. A handbook for visionaries, game changers, and challengers*. New York: Wiley&Sons.

Staiger, R. & Tanţău, A., 2017. *Business models for renewable energy initiatives. Emerging research and opportunities*. Hershey, PA, USA: Business Science Reference (Research insights).

Stern, D., 2014. Anthropogenic and natural causes of climate change. *Climatic Change*, 122(1-2), pp. 257–269.

UCSD, 2018. *Latest CO2 reading*. [picture] Available at: <https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/mlo_full_record.png.> [accessed 25.05.2018].

UN, 2017. *World Population 2017*. [pdf] Available at: <https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_Wallchart.pdf> [accessed 25.05.2018].

Vallero, D., 2014. *Fundamentals of air pollution*. 5 editions. New York: Academic Press.

Wirth, H., 2018. *Actual Facts to Photovoltaics*. Freiburg: Frauenhofer Institut.

Yergin, D, 2007. *The Prize: The Epic Quest for Oil, Money and Power*. New York: Amazon.