HOW TO START THE HYDROGEN ECONOMY?

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Abstract: *The synergic electricity-hydrogen supply network will play key role in the future sustainable transport and energy systems. There are many challenges the prospective hydrogen economy is facing with, especially from the logistics point of view. The first stage can be the Vehicle-To-Grid integration, where electrically driven vehicles are able to download and upload energy from and to the national grid. In the logistics point of view V2G vehicles combined with the B4H box can be the first step in the Hydrogen infrastructure.*

Keywords: *V2G, H2G, fuel station network, hydrogen, B4H.*

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1. INTRODUCTION

Nowadays the transportation sector is one of the largest energy-intensive sub-systems. As the economies develop, there is an observable increase in the demand for transportation – both in the passenger and freight sub-sectors. The transport sector is, by itself, responsible for most of past and expected future growth of world oil demand, and because transport is 97% dependent on petroleum, these developments could have important impacts on oil markets and carbon dioxide emissions. The transportation sector is consuming the highest rate of crude oil in the world and as time goes by it will be increasing demand for oil.

The transport industry, as a result of globalisation and industrialisation, has not yet become "green" or environmentally friendly, despite the efforts made by the set world policy.

Recently, concerns about air pollution, oil insecurity - suddenly rising prices of oil and especially greenhouse gas (GHG) emissions have been driving a search for an alternative and less polluting new transportation fuels and vehicle technologies in the coming future. The need for a sustainable energy supply is becoming more pressing in the light of declining fossil energy resources, environmental pollution, climate change and the increasing dependency on the oil exporting countries of the Middle East.

On the way of searching for alternative fuels the hydrogen seems to be a probable winner, but there are strong competitors, like bio-fuels or electricity from renewable sources.

The second and third chapter gives an overview about the challenges of the development of hydrogen economy and distribution. Electricity driven vehicle fleets can contribute in the more efficient usage of the existing electric power infrastructure – as will be presented in the fourth chapter. The fourth chapter contains the analysis of the above mentioned hydrogen and V2G infrastructures alongside the main barriers the alternative fuel systems need to overcome. As a conclusion, we can highlight the pathway of infrastructure developments towards green fuel economies.

2. INFRASTRUCTURE DEVELOPMENTS ON THE WAY TOWARDS THE HYDROGEN ECONOMY

Hydrogen has for a long time been a well-known secondary energy carrier. The grown interest in the infrastructural use of hydrogen shows that this is a new challenge for mankind to secure the world's energy demand in a sustainable way. The use of hydrogen for energy production purposes competes with the direct use of clean primary energy and/or the use of electric energy based on renewable primary energy. As a substitute for other secondary energy carriers hydrogen is therefore under pressure of costs and/or must have advantages in comparison to the use of traditional energy carriers.

The literature describes a diverse range of possible futures, from decentralised systems based upon small-scale renewables, through to centralised systems reliant on nuclear energy or carbon-sequestration. There is a broad consensus that the hydrogen economy emerges only slowly. Rapid transitions to hydrogen occur only under conditions of strong governmental support combined with, or as a result of, major "discontinuities" such as shifts in society's environmental values, "game changing" technological breakthroughs, or rapid increases in the oil price or speed and intensity of climate change.

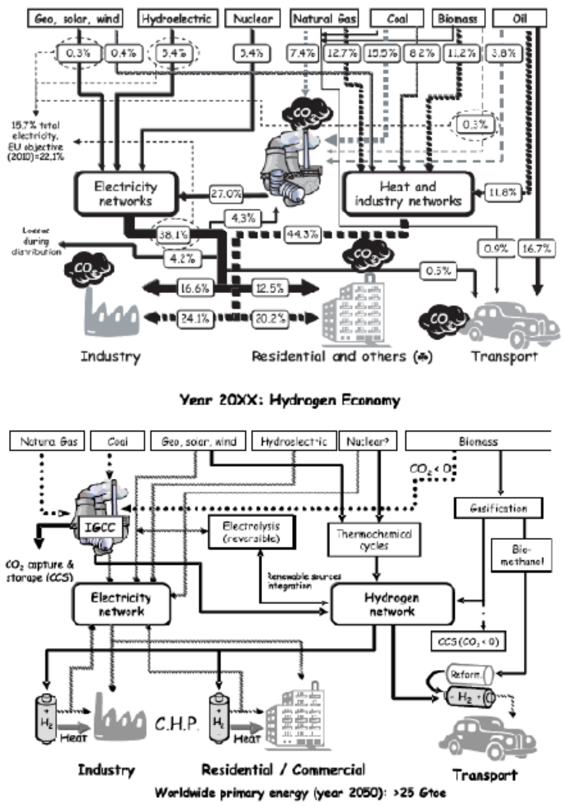

Figure 1. The traditional energy supply and the prospective hydrogen economy [1]

We need Alternative Fuel Vehicles, but there have historically been six major barriers to AFV success[2]:

1) high first cost for vehicle,
2) on-board fuel storage issues,
3) safety and liability concerns,
4) high fuelling cost,
5) limited fuel stations: chicken and egg problem,
6) improvements in the competition: better, cleaner gasoline vehicles.

Considering the chicken and egg problem at the case of alternative fuel vehicles the question appears: What will be the first?[3]

1) Costumers will not purchase fuel cell vehicles unless adequate fueling is available.
2) Manufacturers will not produce vehicles that people will not buy.
3) Fuel providers will not install hydrogen stations for vehicles that do not exist.

3. THE HYDROGEN SUPPLY CHAIN

3.1 Hydrogen consumers – vehicles on the road

As hydrogen is one of the candidates of promising alternative fuels, the key element of a chain is missing: we are still waiting for the superior hydrogen cars. There are many new developments on this field, like the Chevrolet Equinox, what is an advanced, fourth-generation hydrogen fuel cell car. The car can go from 0-60 mph in less than 12 seconds and for a distance of approximately 150-200 miles (it is around 240-320 km) per fill-up. [4] In spite of all the efforts it seems that the hydrogen cars will not appear on the European roads in more than 10% rate in next 20 years. On the other hand there are many vehicle types and functions where the hydrogen projects have more chances, like forklifts, trams and public transport buses.

The fuel cell bus demonstration project Clean Urban Transport for Europe (CUTE), which ended in May 2006, was a historical project. It was the first field trial where a substantial number of fuel cell buses of the same kind was operated simultaneously. The objective of the project was to demonstrate and evaluate the new technology used for the Citaro fuel cell buses, including the hydrogen (i.e. fuel) infrastructure. The number of buses as well as the diversity of operation conditions, in addition to the total amount of kilometers and hours driven in the nine participating cities, presents a unique possibility for evaluation of the feasibility of current hydrogen-powered fuel cell vehicles. The nine cities participating in the CUTE project were Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm and Stuttgart. Three buses were operated for 24 months in each city. The aim of the CUTE project, and the chosen design of the bus, was to demonstrate and prove that hydrogen powered fuel cell buses can function in daily operation in urban European transport systems rather than to show the ultimate bus. [5]

3.2 Hydrogen distribution and transport

The centrally produced hydrogen can be liquefied and transported in specialized LH2 trailers or ISO containers to the refueling station. In the long-term when larger amounts of H2 can be sold to the market also pipeline systems can deliver H2 directly to the refueling station as today's practice for natural gas. Worldwide more than 1,200 km of industrial hydrogen pipeline systems are in use, some more than 60 years.(hydrogen infrastructure built-up)

H2 can be mixed with natural gas (up to 10%) and transported in existing natural gas pipeline, or it can be transported in dedicated H2 pipelines. H2 mixed with natural gas can be used in existing boilers and furnaces. Pure H2 can be used in fuel cells for electric power, heat, refinery products or distributed to retail outlets for H2-powered vehicles. H2 can also be liquefied and distributed by truck for vehicular use, and natural gas can also be reformed into H2 at retail outlets. This would be a less costly strategy for H2 distribution at the early stages of a H2-based transport system but it would not provide an opportunity for carbon capture and storage.

Also the efficiency is lower than in the case of centralized production. On the short term this efficiency can be 65–70% vs. 75–80%. Over the next decades, higher efficiencies may be reached: 70–80% vs. 80–85%. At last, reforming can take place on board of the vehicle using gasoline, ethanol, methanol or natural gas as the vehicle fuel. If gasoline is used, no changes to the fuel distribution infrastructure are required. However, with gasoline, virtually all of the environmental advantages of fuel cell vehicles would be lost.

It is important to note that hydrogen requires considerably more energy for transportation than existing fossil fuels. H2 transportation by pipeline is hampered by the low volumetric energy density. The pipeline size quadruples, compared to natural gas pipelines. Moreover different materials must be used. Hydrogen transportation by ship is complicated by the very low temperature of liquid H2 (–253°C, 90 degrees lower than for LNG), and a low energy density (liquid H2 has about 40% of LNG's energy density). The boil-off losses amount to 0.2–0.4% per day (but this H2 can be used to fuel the ship) (Abe et al. 1998). High energy requirements and special techniques result in high transportation cost. Therefore international H2 trade is not very likely. It would make sense to locate H2 production closer to consumers (just as oil refineries have been located closer to fuel markets than sources of petroleum). In contrast, transport costs favour locating biofuels production close to the source of biomass supply rather than fuel markets.

3.3 Hydrogen storage

Conditioning: hydrogen has only a low volumetric energy density. Before it is transported or stored, it is therefore conditioned, i.e. compressed or liquefied. This is of particular importance if hydrogen is used in the transport sector, where the tank space is limited and requirements with respect to the cruising range are high. The highest volumetric density is achieved by liquefaction at -253 °C. However, the energy demand involved is quite high. For gaseous hydrogen storage on-board of vehicles, a pressure of 700 bars is state-of-the-art. To allow a smooth refueling process, hydrogen is compressed and stored at 880 bars at the filling station. CO2 emissions result from the use of electricity from the grid (EU-mix).

A number of H2 on-board storage systems have been proposed:

- liquid H2;
- gaseous H2 at up to 800 bars;
- binary metals hydrides;
- carbon nanotubes.

Liquid H2 on-board storage suffers from high distribution costs and significant energy losses. Gaseous H2 has lower energy use for storage, but there is a trade off between vehicle range, fuel tank size and compression energy.

3.4 Hydrogen production

Hydrogen fuel does not occur naturally on Earth and this is not an energy source; rather it is an energy carrier. It cannot be extracted like natural gas or oil, but needs to be released by applying energy. On the one hand, this represents a drawback because the process requires the input of primary energy carriers like coal, natural gas or biomass, electricity or high temperatures. On the other hand, the advantage is that a wide range of different feedstock's and energy sources can be used for hydrogen production. It is a new challenge for a mankind to secure the world's energy demand in a sustainable way – but there are several questions which still waiting for answers.

It has to be stressed that hydrogen is a final energy carrier like electricity or gasoline, so that the question of primary energy carrier demand is not solved by using hydrogen. The goal for future energy systems must be the development of clean and affordable new primary energy sources, not new energy carriers. All the same, hydrogen could be an important new energy carrier – for example in zero emission fuel cell vehicles or in E-hybrids (what could contain a Bio-Gasoline internal combustion engine with electrical generator and power electronics, a fuel cell box and different types of electrical and chemical accumulators).

H2 could be fed directly to appliances containing small fuel cells or burnt to provide heat or hot water. In this scenario, H2 would compete with electricity as a clean energy carrier in all sectors. However, while H2 might offer some potential full fuel cycle efficiency advantages compared to electricity, the high investment cost needed to compete with a distribution network that already exists would be a severe impediment to expanding H2 use in this direction. H2, however, faces no established CO2-free alternative for motor vehicles. While some alternative fuels have penetrated some niche markets (LP gas, natural gas, ethanol, methanol, and electricity), taken together, they account for less than 1% of worldwide gasoline and diesel fuel use.[6]

We can produce hydrogen in a different ways, from different raw materials and with different procedure.

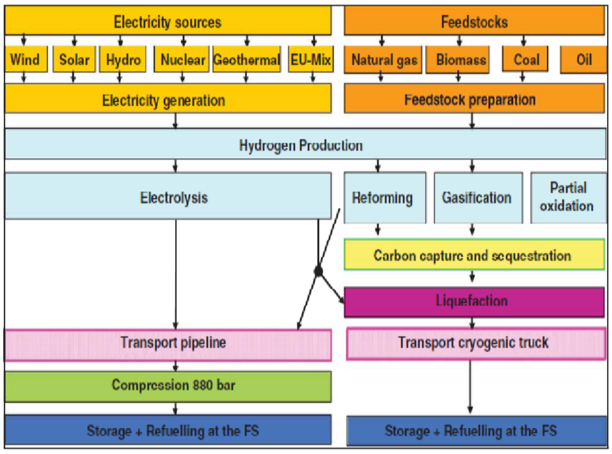

Figure 2. Sub-system of hydrogen pathways [7]

4. V2G – VEHICLE –TO –GRID

As future electricity and transport sectors will be coupled in the hydrogen economy, we have an also promising concept today for electrically driven vehicles. Vehicle-to-grid (V2G) technologies represent a potential opportunity to bring forward and accelerate a transition towards electric-drive vehicles by improving the commercial viability of new vehicle technologies [8].

4.1 The concept

The V2G concept involves using parked vehicles to supply generation services to the electricity grid. TheV2G concept is one of the attractive ideas to synergize the electricity and the transportation sector. This concept with pure electric and hybrid-electric vehicles (which are capable to connect to the grid and load/unload electrical energy) could help to manage electricity resources better, and it empowers vehicle owners to earn money by selling power back to the grid when parking, depends on the current fuel/electricity prizes.

One factor which suggests such benefits may exist relates to the fact that private vehicles are parked on average 93–96% of their lifetime, during which time each represents an idle asset. Each parked vehicle contains underutilized energy conversion and fuel (or battery) storage capacity, and may actually create negative value due to parking costs. Accordingly, generating V2G power from parked vehicles can better utilize an expensive investment (particularly in the case of new and alternative vehicle technologies), thereby enabling cars to provide both mobility and energy services. Since average vehicles in the US travel on the road only 4–5% of the day, and at least 90% of personal vehicles sit unused (in parking lots or garages) even during peak traffic hours, the existing 191 million automobiles in the United States would create 2865GW of equivalent electricity capacity if all the vehicles supplied power simultaneously to the grid — an unlikely occurrence, because this amount is more than twice than the total nameplate capacity of all US electric generators in 2006.

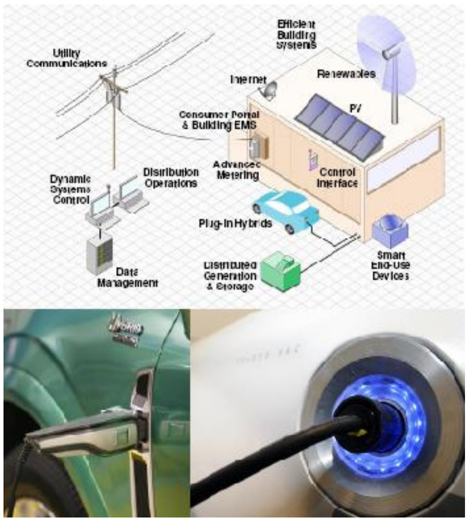

Figure 3. V2G system design [9]

4.2 Type of cars

There are a new upcoming technology in the transportation and power sector - Plug in hybrid electric vehicle PHEVs. These technologies include hybrid-electric vehicles (HEVs), fuel cell vehicles (FCVs) and battery electric vehicles (BEVs). Collectively, these options can be categorized as electric-drive vehicles (EDVs), because they all have the capability to produce motive power from electricity, rather than from the internal combustion engine.

These vehicles has a battery storage system of 4kWh or more, you can recharging a battery from an external source, and you are able to drive at least 10 miles (160 km) in all electricity mode. These vehicles are able to run on fossil fuels, electricity, or a combination of both leading to a wide variety of advantages including reduced dependence on foreign oil, increased fuel economy, increased power efficiency, lowered greenhouse gas (GHG) emissions and vehicle-to-grid (V2G) technology. In the market the best example for this car is the Toyota Prius this vehicle could originally be converted from a hybrid electric vehicle (HEV) into a plug in hybrid electric vehicle (PHEV) using an aftermarket kit and is now being manufactured as a both a HEV and PHEV.

The superiority of electricity-driven vehicles (trains, trams, trolleys, forklifts) both in their performance and environmental impact is widely accepted. Apart from the electricity-driven vehicles, the infrastructure for their use is also rapidly developing, such as chargers and battery systems, smart parking and charging stations [10].

5. LOGISTICS SOLUTIONS FOR SOLVING THE PROBLEM OF LIMITED RANGE

The main barrier of electric vehicle penetration is the limited range. It is still a question if the final solution is the hydrogen car or not. There are two different types of solutions for the problem from the logistics point of view: quick charging or on-board generation.

The BMW i3 car was designed for urban mobility. The 170-hp electric motor, which twists out up to 184 lb-ft of torque, receives its power from a 22-kWh, liquid-cooled lithium-ion battery. Thanks to the optional SAE DC Combo Fast Charging hardware, that battery can fill to 100 percent in about 30 minutes. The 220-volt Level 2 J1772 charger, meanwhile, takes care of business in about 3 hours. The motor works in concert with a single-speed transmission to send power to the rear wheels. The i3 uses regenerative braking to help keep the battery running as long as possible. In a research project, which involved 1000 participants and more than 12.5 million driven miles, BMW found that the average daily driving distance was around 30 miles (48 km). When viewed through that prism, the i3's 80 to 100 miles (129 to 161 km) of range looks more. BMW says that ECO MODE can add an extra 12 percent. In addition to the all-electric version, buyers can choose to equip the i3 with a 34-hp 650cc range-extending two-cylinder engine, essentially turning the car into a Volt-like series hybrid. That engine will not power the wheels but will serve strictly as a back-up power reserve, adding range and versatility [11].

The Tesla Roadster is a battery electric vehicle (BEV) sports car produced by the electric car firm Tesla Motors in California. The Roadster was the first highway-capable all-electric vehicle in serial production for sale in the United States in recent times. Since 2008 Tesla had sold more than 2,400 Roadsters in 31 countries through September 2012, and most of the remaining Tesla Roadsters were sold in Europe and Asia during the fourth quarter of 2012. The Roadster was the first production automobile to use lithium-ion battery cells and the first production BEV (all-electric) to travel more than 200 miles (320 km) per charge. The world distance record of 501 km (311 mi) for a production electric car on a single charge was set by a Roadster on October 27, 2009, during the Global Green Challenge in outback. According to the U.S. EPA, the Roadster can travel 244 miles (393 km) on a single charge of its lithium-ion battery pack, and can accelerate from 0 to 60 mph (0 to 97 km/h) in 3.7 or 3.9 seconds depending on the model. To charge the hall battery is takes 3 and half hours but the Tesla Supercharger recharges Model S quickly. Superchargers are for refueling quickly on road trips. A Supercharger can charge about half the battery in 20 minutes. All Model S vehicles with the 85 kWh battery can use Superchargers as can properly equipped 60 kWh battery vehicles. Tesla has a 8 years battery warranty for the 85 kWh battery and it is with unlimited miles.

The B4H (box-for-hydrogen) concept is not a technical solution yet, but a special on-board storage and generation method based on the logistics viewpoint we are developing in the frame of our research (in Szabó-Szoba R&D Laboratory, Széchenyi University, Győr). The B4H concept offers to use hydrogen boxes as an on-board filling option in avoiding the hydrogen filling problem. These standardized hydrogen boxes can take place at any hydrogen-electric hybrid car working with fuel cell units. The electricity chain has lower energy losses, and the energy in the battery is excellent for V2G operation (normally there is no need for hydrogen). Users need the fuel cells only if they are travelling more like usual (driving more, than 150km), to extend the range of the car. The B4H boxes are located in the car trunk and connected with the vehicle hydrogen tank. This box can accept two simple, isolated hydrogen barrels, each of them with 1 kilograms of hydrogen. With this quantity of hydrogen we can drive around 260 kilometres. These boxes and the filling mechanism are controlled by the on-board computer in the car which automates the process. Refuelling do not requires special filling infrastructure at the fuel station, because all the mechanisms are in-built around the hydrogen system of the car. The automated changing of empty tank starts with pushing the change button on the box, when the valve can close automatically. After ventilating and providing secure environment, the box ejects the empty tank. We should put the new 1kg hydrogen tank in the box and it will be automatically attach itself to the system. (The technical parameters of boxes require many innovative solutions we are searching for by using the TRIZ inventive principles. The prize of a box and hydrogen barrel seems to be high – the promise is that we can save a lot by mass production and by more flexible and simple distribution and refuelling cost).

This type of distributed storage and commerce – in the early phase of hydrogen vehicle penetration – is more suitable. Buying a new hydrogen tanks is possible not only at the fuel stations, as users can buy it from offsite machines, and they can leave the empty tanks there as well. Finally it wolud be much easier and faster to refill the hydrogen tank and continue the trip by using the B4H concept.

6. CONCLUSION

Providing sustainable energy systems for future generations is one of the main challenges the world is facing with today. In spite of the promises of the prospective hydrogen economy it is hard to forecast how we should develop the infrastructure we have today – but we can conclude that it is inevitable to investigate the possible strategies from the logistics point of view.

Based on our research we can say that V2G cooperation can contribute in green economy development efforts.

The V2G systems provide deep insights about the nature of cooperation between the vehicles and the national grid, but we need to extend the range of these vehicles – the B4H concept we got after theoretical logistics research can be one critical stage of future developments.

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