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H_2-Mobility Swiss

Analysis of the Situation to Realize an Initial Market for H_2-Vehicles in Switzerland

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Abstract

Fuel cell electric vehicles (FCEVs) amongst other options can play a key role in the transformation process due to their benefits in terms of zero local emission, superior fuel economy and comparable functionality with conventional vehicles. The automotive industry has matured fuel cell technology over the last decade and is ready for commercialization in years to come.

Market introduction however faces a couple of critical challenges that need to be addressed. Production ramp-up of FCEVs will need time to achieve the required economies of scale and deliver competitive cost. A completely new infrastructure for H_2 needs to be built including development of the associated industrial supply chain. Suitable production pathways for H_2 fuel need to be identified and developed along with their economics and based on sustainability criteria.

Establishment of the initial H_2 infrastructure will require coordinated action of market players and politics. Vehicle ramp-up shall be coordinated with the automotive companies. The legal framework with regard to safety aspects and permission of sites need to be developed in line with best available international practice and in coordination with other initiatives to apply common standards. Existing HRS concepts are suited for the initial market introduction. However, current station cost will require substantial reduction to allow development of a self-supporting business case. Economies of scale will have to be developed by clustering HRS investment. Technical concepts will need to be further matured and refined to fully address operational and business requirements.

Zusammenfassung

Brennstoffzellenfahrzeug können, gemeinsam mit anderen Optionen, eine Schlüsselrolle in der Reduktion der CO_2-Emissionen des Verkehrs spielen, da sie ohne lokale Emissionen, bei besserem Wirkungsgrad und etwa vergleichbaren Fahrzeugeigenschaften wie heutige Automobile betrieben werden können. Die Automobilindustrie hat die Brennstoffzelle im letzten Jahrzehnt zur Marktreife weiterentwickelt und ist auf dem Wege, diese Technologie in den nächsten Jahren zu kommerzialisieren.

Für eine erfolgreiche Markteinführung müssen jedoch einige kritische Hürden überwunden werden. Der Produktionshochlauf von BZ-Fahrzeugen wird Zeit benötigen, bis die für wettbewerbsfähige Kosten benötigten Skaleneffekte erreicht werden können.. Für die Treibstoffversorgung, muss ein neues Tankstellensystem mit der dazugehörigen Versorgungslogistik aufgebaut werden. Integriert dazu müssen geeignete Wasserstoffherstellwege lokalisiert und entwickelt werden, die den ökonomischen wie auch den ökologischen Randbedingungen genügen können.

Die Errichtung der anfänglichen H_2-Infrastruktur braucht eine konzertierte Anstrengung von Industrie und Politik. Die Einführung der Fahrzeuge muss mit den Fahrzeugherstellern abgestimmt erfolgen. Die rechtlichen Rahmenbedingungen für Sicherheit und Betrieb sowie Zulassung müssen mit den zuständigen Behörden auf Basis der heute bereits erprobten internationalen Standards entwickelt werden.

Heute existierende Tankstellenkonzepte sind technisch für den anfänglichen Marktaufbau geeignet. Für das Erreichen der Wirtschaftlichkeit im Tankstellenbetrieb müssen die Kosten jedoch deutlich gesenkt werden. Durch die koordinierte Beschaffung der Tankstelleninfrastruktur für die Anfangsausrüstung können Kostenvorteile entwickelt und genutzt werden. Die technischen Konzepte müssen weiterentwickelt werden, um die betrieblichen und wirtschaftlichen Anforderungen vollständig zu erfüllen.

Conclusions

The majority of automotive companies will start deliver serial FCEVs from 2016. Initial premium pricing of FCEVs will have to be leveraged by financial and non-financial incentive schemes to facilitate customer acceptance. About 15 hydrogen fueling stations will be necessary for Switzerland to support early vehicle deliveries. Existing sources of H_2 from chemical by-product can be utilized to fulfill early H_2 demand. They shall step-by-step be complemented by new production pathways from renewable energy based on electrolysis. The selection and the development of these pathways will have to observe competitive hydrogen pricing as a key element of the operational cost of the vehicles and comply with sustainability criteria.

The challenges of the change process need collaboration of all relevant industrial stakeholders including automotive companies, gas industry, equipment suppliers and infrastructure operators. They need as well a clear political mandate thus to establish a viable economic perspective and trigger the required investments. H_2-Mobility Swiss shall deliver the platform for coordinated action in Switzerland.

If successful, FCEVs could start contribute to vehicle sales in Switzerland from 2016 and establish a population between 500 000 and 800 000 vehicles in Switzerland by the end of the next decade. The associated environmental and energy efficiency benefits can provide a substantial contribution to fulfilling the objectives of the Energy Strategy 2050.

1. Introduction

The following report was elaborated between June 2012 and February 2013 in preparation of the H_2-Mobility Swiss initiative for the establishment of an initial hydrogen refueling infrastructure in Switzerland. The report was supported and sponsored by the Canton of Aargau, the Federal Office of Energy and the Paul Scherrer Institute PSI. It delivers a situation analysis of prevailing technical, economic and social aspects for the commercial introduction of FCEVs and hydrogen fuel in Switzerland as well as on key action areas for the establishment of a beneficial and supportive political framework.

Amongst various other sources, the report uses confidential information delivered from key stakeholders including automotive OEMs, industrial gas manufacturers, infrastructure providers and fleet operators displayed in **figure 1** below. In the framework of a Request for Information (RfI), captive data were delivered and are presented in anonymised and averaged form to protect confidentiality. In June and December 2012, two meetings where held with the stakeholder group where preliminary results were presented and discussed.

Assessments furthermore include a preliminary analysis of the existing political framework for the commercial introduction of FCEVs and hydrogen fuel based on consultations with the BfE and the Canton of Aargau.

Figure 1: Participants of the H_2-Mobility initiative

The analysis shall deliver the fact base for the development of a Swiss commercialization strategy and roadmap for the establishment of an initial hydrogen refueling infrastructure in the context of a dedicated national project while observing and utilizing interfaces and lessons learned from similar projects in other countries.

2. Swiss energy strategy and the role of clean transport

The Swiss Government decided in 2007 to introduce a new energy policy basically aiming to avoid a threatening future gap of energy supply for Switzerland[1]. This policy was centered on 4 pillars, namely increasing the energy efficiency of the energy system, extending the use of renewable energy, integrating large power plants to partly compensate the ageing fleet of existing power plants and intensifying foreign policy in the field of energy security. Switzerland released a CO_2-emission law aiming to reduce emissions within the country by 20% until 2020, related to the status of 1990.

By 2011, Switzerland was covering its energy demand with 19% from domestically produced renewable energy carriers and still relies with 81% on energy imports. The 20% local content consists of hydro power, firewood, waste-conversion as well as sun, wind, biogas, bio fuels and geothermal heat. Energy demand in Switzerland totaled 236 TWh in 2011, with 59 TWh thereof in the form of electricity. Hydro power plants contributed 53.7%, nuclear power plants 40.7%, fossil thermal power plants and others contributed with 5.6% to the total electricity production[2]. This production mix provides for very low emission of greenhouse gases from the power sector. Energy consumption is split into 35% oil based fuels, 18.7 % oil for heating, 24.8 % electricity, 12.2 % natural gas and 9.3% for all remaining consumers (**figure 2**).

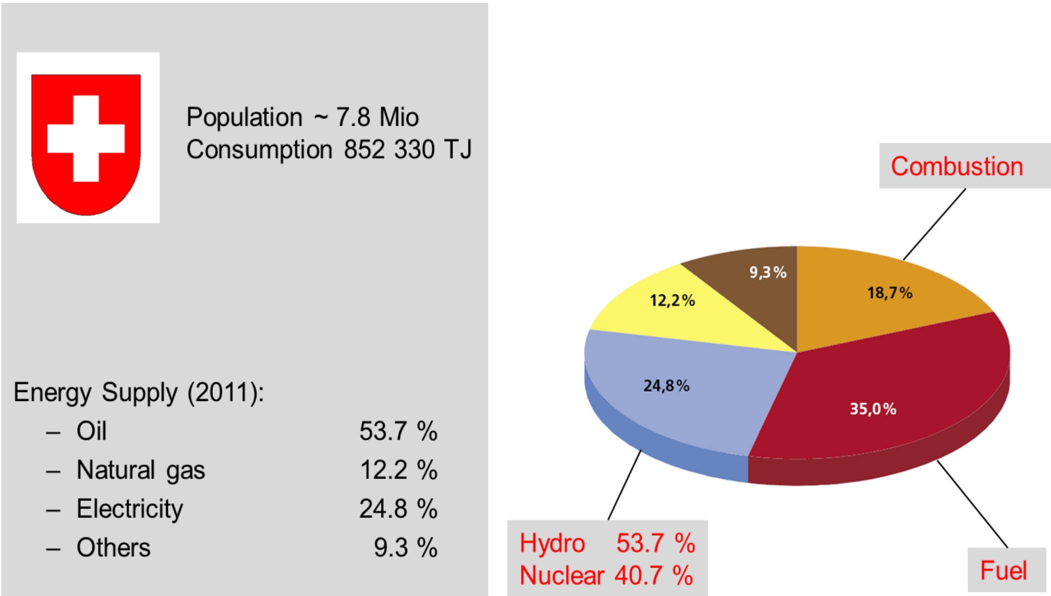

Figure 2: Energy Supply Sources and their Share in overall Energy Consumption – 2011

As consequence of the Fukushima reactor accident, the Government and Parliament decided in 2011 to suspend the permission process of three new nuclear power plants and phase-out electricity production based on nuclear power in Switzerland at the end of the lifetime of the existing power plants. At the same time, elaboration of a new Energy Strategy began comprising measures in energy and fiscal policy, research and related policies. It is currently in its consultation phase and will be implemented by 2015.[3]

The new Energy Strategy will include ambitious mid-term targets for the improvement of energy efficiency and the increase of electricity production from hydropower and other renewables. Electricity consumption shall be stabilized until 2020 and energy consumption shall be reduced by 35% until 2035 and by 50% until 2050. The transport sector shall contribute to these objectives by reduced energy demand and CO_2 emissions. Actions under consideration are displayed in the next graph.

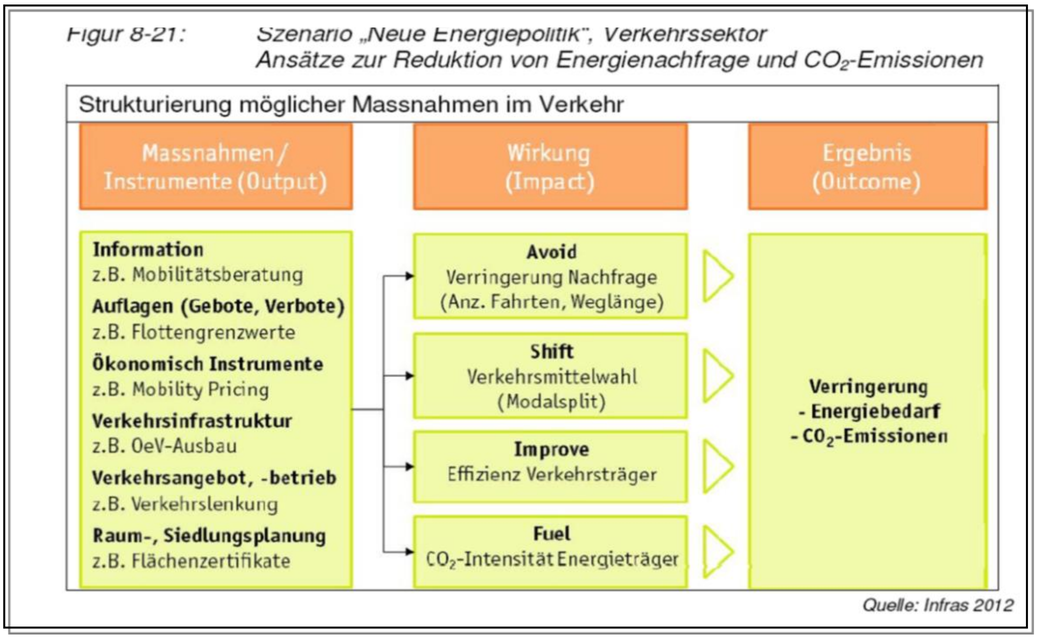

Figure 3: Potential actions to reduce energy demand and CO_2 emissions in the transport sector

Substitution of nuclear power plants by other alternative power technologies while keeping track with the reduction of greenhouse gases will establish a big challenge for the entire energy system. The building sector, the industrial and service sectors and of course the transportation sector will have to contribute a substantially larger share to emission reduction and efficiency targets while the largest contributions will have to come from the building and the transportation sector. Substitution in the building sectors will require increased use of electricity from renewable energy carriers instead of fossil fuels. In the transportation sector, the implementation of CO_2-emission legislation in line with the EC regulation establishing fleet targets of 95 g by 2020 for passenger cars as well as 175 g by 2017 and 147 g by 2020 for light duty trucks is very likely. These targets cannot any longer be achieved by conventional drivetrains. Introduction of new, efficient and clean propulsion technologies will therefore be mandatory for the success of the Energy Strategy 2050.

3. The Rationale for Fuel Cell Electric Vehicles

Clean Propulsion Concepts

It is common sense amongst all automotive OEMs that electric drive trains will play a key role for converting to a future sustainable transport system. At the same time, there are different opinions with regard to the role of the different options, i.e. Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV) or Fuel Cell Electric Vehicles (FCEV) in this process.

The Coalition Study[4] elaborated by McKinsey in 2010 and supported by major automakers, utilities and oil companies is suggesting a balanced scenario for the different options with each of them having a more or less substantial stake in the future vehicle population. There are however factual reasons to challenge this assumption.

One of the fundamental requirements and key concerns when looking at vehicle properties is sufficient range in combination with short refueling times. A realistic driving range for state-of-the-art battery vehicles is approximately 150 km with the need to recharge the battery for several hours after each trip. PHEV have a very limited electric driving range of up to max 60 km and their real advantage compared to state-of-the-art diesel is in urban drive cycle, only (see **figure 4**). This is suggesting that the real benefit of BEV and PHEV only exists in urban transport conditions while in all other transportation modes they are facing critical constraints.

Typical customer use patterns of today's conventional vehicles do however require a multi-purpose, multi-range vehicle which is not limited to short driving distances, except for a small portion of the overall vehicle population and a fraction of second family cars. This is establishing a critical limitation for the large-scale market penetration of BEVs and PHEVs. In simple terms, batteries are too heavy, and have too less energy content to establish a mainstream vehicle solution that is suited to address a wide range of customer demands. In contrast, FCEVs can provide both, acceptable range and short refueling times similar to conventional vehicles. In addition, they feature zero local emissions and superior fuel economy particularly when operated with hydrogen from renewable sources.

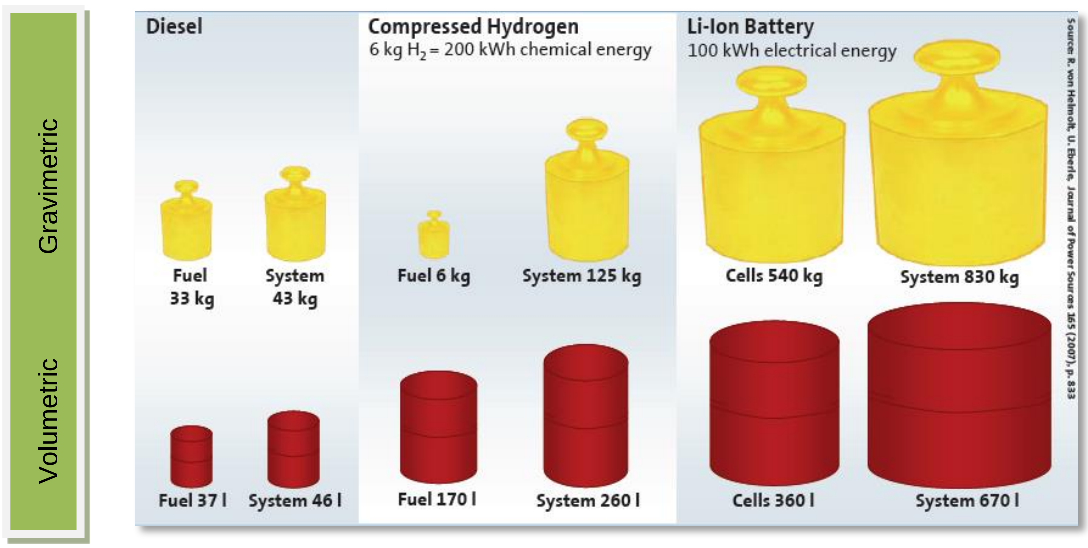

Figure 4: Comparison of storage density between Diesel, Fuel Cell and Battery[5]

Each option, i.e. BEVs, PHEVs and FCEVs, would furthermore need a specific infrastructure for their broad market introduction. Recharging of batteries does typically take up to 6 hours but may be as long as 12 hours depending on power connection and state of battery charge. Under ideal conditions

with no space constraints, stations may allow several plug-ins. Under typical urban conditions, one plug at the charging stations may only be shared by a maximum of two vehicles each. The utmost of vehicles will however be operated over the day and charged at night so that in reality almost each vehicle would need one station. The sheer number of stations and the space that would be necessary for a large share of the vehicle population specifically in inner city areas seem paradox.
In many places, additional investment for grid upgrade will be needed and is not even considered in this scenario. In case of smart metering and smart grid operation, the investment may however be limited.[6] Charging of PHEVs can basically be provided by a home station but is likely to need grid upgrade and related investments while providing little benefit to the majority of users.

In contrast, operational patterns and space requirements of hydrogen filling stations will be similar to conventional stations and can be integrated in the existing infrastructure. Recognizing the critical user constraints of BEVs and PHEVs it is more than likely that their market spread will be limited to mainly urban and fleet operation while FCEVs have the properties to establish the future mainstream solution over the other options. From an industrial, economic and market perspective, it thus seems rather doubtful that a large scale infrastructure will be built for all three options recognizing the inherent risks for their final market success and volume growth.

The European Clean Fuel Strategy is proposing a variety of “technology neutral” clean fuel options however without determining their future market potential and the likewise shares in the transportation system.[7] The portfolio offers policy options but can in no way be interpreted as the likely-to-come mix of transportation technologies for Europe. It is therefore not directed and not particularly suited to provide rationale for choosing certain options. High rank representatives of Toyota and Daimler have only recently calmed down expectations with regard to a fast growing future role of BEVs for vehicle electrification. [8] [9] They are joined by the German Federal Government conceding that the established target of 1 million BEVs by 2020 may not be reached by then.[10] FCEVs can therefore play a key role to comply with future emission legislation particularly in the larger passenger car segments and for commercial vehicles operated in urban drive cycle, including special vehicles. This would ideally combine with the particular benefits of BEVs for smaller cars and shorter distance.

FCEV Commercialization Plans

After more than a decade of technology and product development, fuel cell propulsion systems have reached technological maturity for commercial market introduction. Key technical challenges such as introduction of 700 bar onboard storage, cold start ability, improved fuel cell stack durability and robustness were addressed in recent years. Today, FCEVs are providing full functionality comparable with conventional vehicles. Cost assessments suggest that automotive cost targets can be reached when achieving the typical economies of scale of automotive production.

In 2010, a coalition of more than 30 automotive OEMs, utilities, oil companies, industrial gas companies, system suppliers, governmental and non-governmental organizations therefore concluded that the technology is ready for commercial deployment.

> With more than 500 passenger cars – both large and small – covering over 15 million kilometres and undergoing 90,000 refuellings,[23] FCEVs are therefore now considered to have been comprehensively tested in a customer environment. The result: the focus has now shifted from demonstration to commercial deployment so that FCEVs, like all technologies, may benefit from mass production and the economies of scale.

Since 2010, the number of FCEVs has further increased. The U.S. only report about 325 FCEVs in operation by 2012, with about 10 % being fuel cell buses.[12] In Japan and Korea, 600 FCEVs were operated in 2011.[13] Though no official numbers are available, the number of FCEVs operated in Germany is certainly at a level of 200 vehicles. The total number of FCEVs in operation may therefore be in the range of 1300 to 1500, globally. Several international automotive OEMs, including Daimler, Honda, Hyundai, Nissan and Toyota as well as Shanghai Automotive Industry Corporation (SAIC) announced schedules for commercial deployment of FCEV beginning from 2014/15 through 2016/17.

The 2012 Auto Show in Paris has seen several announcements with regard to fuel cell commercialization. Daimler has disclosed plans to collaborate with Nissan and Ford for the development and production of fuel cells. On January 24, 2013 BMW and Toyota Motor Corporation have signed a contract on joint development and production of fuel cells. [14] Toyota confirmed plans to launch an FCEV limousine for the price of € 42 000 from 2015.[15]

The increasing level of activity clearly signals that OEMs prepare for the next step towards FCEV commercialization. With closer proximity to market, collaborative approaches to share investment and jointly manage economic risks of FCEV market introduction receive more attendance. In particular, these co-operations shall accelerate and facilitate beneficial economies of scale to drastically reduce cost form early on. Despite this, it cannot be entirely excluded that slow infrastructure development and cooperation requirements between OEMs may still happen to slow down and delay the one or other schedule.

Commercialization plans indicate that by 2020 several hundred thousands of FCEVs may be operated, globally. Drivers of the global development are Japan, Korea, Germany and California. The European and global transport system has begun to move towards sustainability with FCEVs as a key element.
Switzerland with its central position in Europe has manifold ties and relationships with its neighbor countries and beyond. Its role as an attractive touristic and transit area, its advanced industrial structure, its high standard of living and its political commitment to environmental protection and clean energy are establishing a vital interest to participate in the conversion process. Supporting the market launch of clean vehicles and infrastructure will benefit its future economic and societal development, contribute to the Energy Strategy 2050 and strengthen competitiveness.

Global Initiatives

With the background of technology readiness and OEM commercialization plans, multiple activities and initiatives were started around the world to facilitate the market launch of FCEVs recognizing the great challenges of the associated change process. Establishment of the required hydrogen refueling infrastructure (HRS) as one of the major challenges for the introduction and finally the commercial success of FCEVs is a key element in all these activities. It is shared by the European Clean Fuel Strategy of the EC emphasizing the importance of alternative fuel infrastructure for achieving the need for the required change[16].

In Germany, a National Innovation Program was launched in 2008 and will finally provide total investments of € 1.2 billion for research, development and commercialization of fuel cells, until 2016. More than one third of the total budget is supporting transport applications. In addition, between 50 and 60 million € are spent annually for fuel cell research by other programs.[17] By the end of 2012, 20 hydrogen refueling stations were in operation.

Until 2015, H_2-Mobility supported by NOW, the national program office, will be investing 40 million € in H_2- infrastructure to expand to 50 hydrogen refueling stations. By 2015, 5000 FCEVs are expected to be on the road. The vehicle number shall reach 150 000 units by 2020 with 400 HRS in place.[18]

In January 2011, the Japanese government and OEMs jointly announced the launch of FCEVs and fueling stations in the Japanese market from 2015. Deployment will start in 4 major metropolitan areas. More than hundred fueling stations shall be established until 2015. [19] In 2012, ~ 38 million $ were spent for H_2 infrastructure and vehicle demonstration.[20] Japanese fuel cell research budget managed by the NEDO is in the order of 60 million €, annually.[21] Japanese commercialization plans are not substantially affected by impact of the Tsunami in March 2011.

The US has key research and demonstration activities under the umbrella of the Department of Energy since many years. The annual fuel cell research budget is in the order of US-$. 50 – 55 million. Until today, more than 180 fuel cell vehicles were launched under the DoE umbrella and 25 hydrogen refueling stations are in operation. [22] While there is no comparable national deployment program yet, California has launched its zero emission initiative in 1990 already and is gradually ramping up vehicles and infrastructure since then. It has deployed more than 300 FCEVs by this year and plans deployment of approx. 4000 by 2015 and 50 000 by 2017. In 2009, 26 fueling stations were in operation.

The planned commercial launch of fuel cell electric vehicles by some automakers in 2015 would require 68 hydrogen fueling stations in California. They shall be in place by the end of 2015 in order to serve adequately the first approximately 20,000 FCEVs. The total cost to expand to 68 stations is estimated at $65 million. With an expected 53,000 vehicles on the road in the 2017 timeframe, more than 100 stations would be necessary to ensure the capacity for these additional vehicles. Building additional stations or completing station upgrades to meet market demands will likely be necessary by the end 2017 to serve the expected FCEV population. “In total, ARB and CEC have provided $ 31 million in cost share funding…with $ 29.7 million allocated for future stations.”[23]

South-Korea has launched an overall of 500 FCEVs in Korea and other countries by end of 2012 and plans to have 500 hydrogen fueling stations and 50 000 vehicles in operation by 2020. [24] Korea is partnering with Denmark in the so-called “hydrogen town pilot project”.
China has established an EV Technology Innovation Strategic Alliance in January 2012. It is including FCEVs and hydrogen fueling stations.

H_2-Mobility UK – was launched in January 2012 as collaboration between 3 ministries and 13 companies. The consortium will consider the actions needed to secure the UK’s global role in the manufacture and use of hydrogen fuel cell vehicles, ahead of an anticipated rollout to consumers in 2014/15.[25] Activities will include the development of a “Low Carbon Vehicle Roadmap” and include a new 400 million £ government fuel cell project facilitating the launch of fuel cell vehicles and infrastructure.[26]

H_2moves - Scandinavia – is a European lighthouse project and was started in November 2011. The purpose of the project is to operate 17 fuel cell vehicles and gradually building up hydrogen refueling infrastructure in Scandinavia. On October 9, 2012, car manufacturers Toyota, Nissan, Honda, Hyundai and organizations of the Nordic Countries signed a Memorandum of Understanding on market introduction of fuel cell vehicles and hydrogen infrastructure in the period 2014-2017.[27]

In France, key actors from industry and government are currently driving discussions on a common roadmap for H_2 mobility. It is expected that decisions on concrete steps may be taken in the foreseeable future.

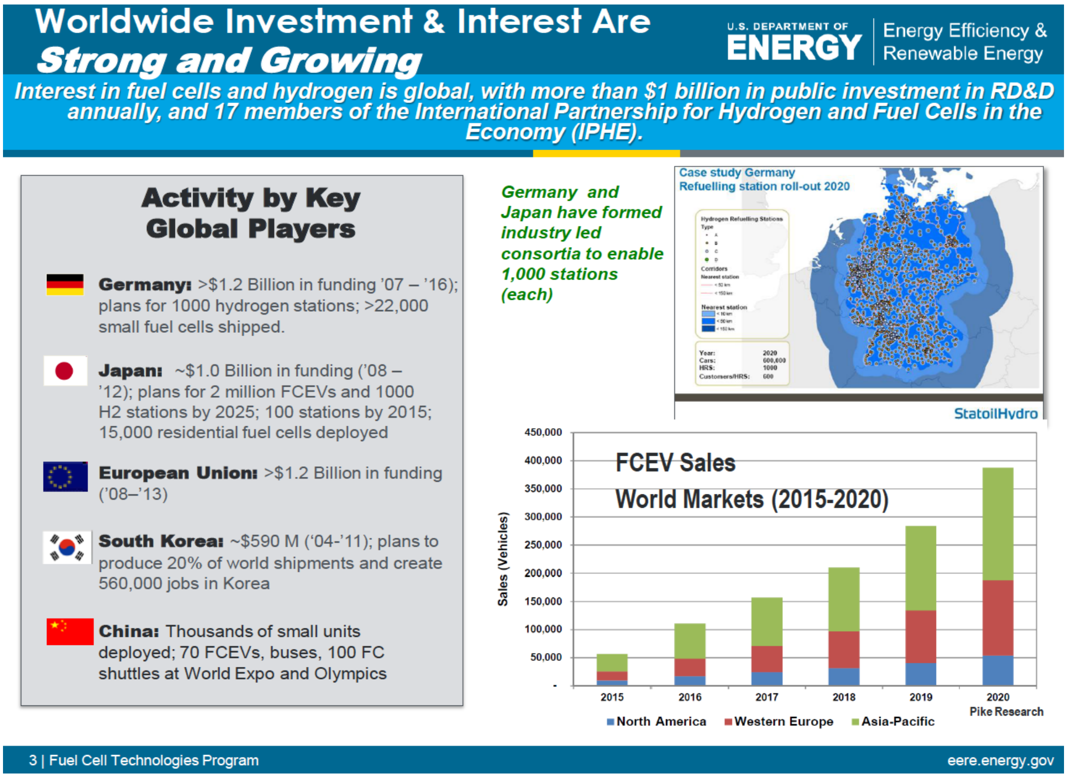

Figure 5: DoE - overview of global FCEV and HRS activity[28]

Large launch programs for FCEVs and HRS are planned in Japan, Korea, Germany and California.

Year	Japan		Germany		U.S./California		S. Korea	
	FCEVS	HRS	FCEVS	HRS	FCEVS	HRS	FCEVS	HRS
2013	300-400	25	200	20	300	25	500	11
2015	1000s	100	5000	50	4000	68	1000	n. a.
2017	n. a.	n. a.	n. a.	n. a.	50000	100	n. a.	n. a.
2020	n. a.	n. a.	150000	400	n. a.	n. a.	50000	500
2025	2000000	1000	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.

Figure 6: Overview of commercialization plans of key regions

4. The objectives of H_2-Mobility Swiss

Key objective of the H_2-Mobility Swiss - Project is the establishment of the required initial hydrogen refueling infrastructure for the launch of fuel cell vehicles in Switzerland. Main urban centers of Switzerland shall be equipped and connected with a reasonable number of hydrogen fueling stations while location and distance between the stations shall ensure sufficiently convenient access for customers, a critical mass of area coverage as well as mobility to neighbor countries. The project is directed towards supporting broad industrial commercialization of fuel cell technology in transport applications and thus providing the foundations for a self-sustaining market growth.

Today's transport markets are international as are propulsion technologies. This is specifically true for Europe. No country will be able to address the associated challenges alone. Infrastructure needs collaboration and interfaces between one country and another. Coordination of technical and economic aspects between the individual initiatives shall therefore address alignment of concepts and thus develop consistent industrial solutions applicable in all countries. At the same time, each individual country needs to develop a rollout plan under its specific political, economic and technical conditions, including establishment of a favorable political framework to accelerate learning curves and facilitate economies of scale.

In previous years, focus of activities was on demonstrating technology feasibility. The ongoing CHIC fuel cell bus project with its location in Brugg and PostAuto as public transit agency is a second generation technology demonstration project to prove full operational functionality, efficiency benefits and customer acceptance of fuel cell buses and hydrogen refueling stations. Neither the buses nor the stations are fully mature industrial products according to the standards of the vehicle industry nor industrially mass-produced. They are therefore one step prior to commercial products.

The objective of H_2-Mobility Swiss is now commercial market introduction of industrial fuel cells and hydrogen to the Swiss transport system based on OEM vehicle and HRS commercialization plans. It shall position Switzerland amongst those countries pioneering the introduction of hydrogen and fuel cells to the transport system in Europe and beyond. The transition from fossil fuels to sustainable clean fuels is mandatory to achieve future emission targets for greenhouse gases based on low well to wheel emissions. By 2020, emission target is expected to be as low as 95g/km CO_2 in average of new vehicle fleets referring to NEDC.
This target cannot any longer be achieved by further improvement of ICE drive trains but will require introduction of new alternative propulsion technologies. Alternatives will include hydrogen or electricity as well as natural gas for particular segments and markets.

H_2 as energy carrier can be produced from a large variety of primary energy sources and is particularly efficient when produced from renewable energy sources. Utilization of H_2 and fuel cells in the transport system can thus reduce und step by step minimize dependence of transport from crude oil and is therefore fully consistent with the Swiss Energy Strategy. The shift to FCEVs is an attractive option to substantially increase vehicle efficiency compared to diesel and gasoline ICEs.[29]

Introduction of FCEVs in Switzerland can therefore deliver the following contributions to achieving the objectives of the Energy Strategy 2050:

+ Development of a realistic, fact based e-mobility concept against the background of technical and economic disadvantages of BEVs for automobile mass markets
+ Fulfillment of CO_2 fleet targets under particular observation of the expected 95g/km limit from 2020 or other potential future limits
+ Achievement of radical efficiency improvements by superior overall efficiency from energy source over fuel production to wheel
+ Support of sustainability targets by production of hydrogen from renewable sources, including utilization of available chemical by-product
+ Contribution to the development of renewable electricity production and grid integration by storage of fluctuating energy via hydrogen, including utilization as fuel
+ Internalization of external cost as well as avoiding or at least minimizing of consequential social cost.

In order to achieve these objectives, H_2-Mobility Swiss shall collaborate with other initiatives in Europe and elsewhere. Due to the advanced activities and expertise, geographical proximity, similar technical standards and market gravity, Germany and specifically the State of Baden-Württemberg shall play a central role for coordination of technical and economic activities of the project.

5. Situation Analysis - Assessment Results

5.1. FCEVs - Status and Commercialization Plans

Carmakers have invested billions of Dollars in the technical development of FCEVs and components. The cost of FCEVS will however still be higher than conventional vehicles in early years due to the lack of economies of scale and early state of technology. Even more importantly, infrastructure investments are to be provided to allow FCEV introduction to the market. Political targets for emission reductions and energy efficiency essentially triggered the technology development. Policy shall therefore also take a key role for the establishment of favorable framework conditions for their market introduction. It is a common OEM view, that the ease for owning such an FCEV for the customer or in simple terms the existence of a hydrogen infrastructure and efficient incentive schemes are key factors in their decision, if, when and where to launch FCEVs first.[30]

A coordinated launch of hydrogen refueling infrastructure and fuel cell vehicles will be essential to limit the economic risk exposure for the involved players. Assuming establishment of up to 15 HRS – see details in section 5.2.1 - as initial infrastructure in Switzerland, a total number of approximately 5000 vehicles is considered necessary to allow sufficient utilization of stations and create the required momentum for market growth.

H_2-Mobility Swiss shall therefore focus on establishing a sufficient hydrogen refueling infrastructure and mitigating initial economic gaps in terms of vehicle, fuel and station cost by effective political instruments, industrial commitment and stakeholder cooperation.

5.1.1. Technical status of FCEVs

The technical status of FCEVs was concluded from data delivered under a confidential request for information by the following automotive companies: Daimler, General Motors, Honda, Hyundai, Nissan, Toyota and Smith Electric Vehicles.

Vehicle functionality

FCEVs of today can be driven like conventional vehicles. Fuel cell systems supported by energy management provide comparable dynamic behavior and performance as state-of-the-art internal combustion engines. The electric motor provides maximum torque and thus faster acceleration from zero speed. FCEVs therefore feature superior driving behaviors related to an equally powered ICE vehicle. The most critical technical hurdle of the past, cold start at freeze conditions, was addressed by all OEMs in recent years. OEMs declare cold start capability of vehicles from -20°C to -30 ° C which basically allows operation of vehicles under all major climate conditions. The achieved power density of the fuel cell system and the onboard hydrogen storage eliminate vehicle packaging constraints to the passenger compartment or the vehicle trunk. There are no safety limitations for operation of the vehicles on public roads, in tunnels or for parking them in garages.

Hydrogen quality, onboard storage and refueling interface

Currently, OEMs require industrial grade 5.0 H_2 quality being the industrially available hydrogen quality best complying with the future SAE J2719 specification. Alternatively, SAE J 2719 working documents are used as reference until completion of a final H_2 quality SAE standard that will then be accepted and applied by all OEMs. Introduction of the standard is expected in the foreseeable future. Over recent years, compressed H_2 with 700 bar onboard storage and refueling systems were introduced and proven. They establish the mainstream solution for fuel cell cars of almost all OEMs. The only current exception is Honda with 350 bar onboard storage for the FCX Clarity. They however indicated to change to 700 bars for their next generation vehicles, too.

The refueling interface is standardized in SAE J 2799 thus providing a universal solution for the fueling nozzle. Hydrogen tank size is in the range of 4 to 5 kg H_2 mass. Refueling of vehicles can be completed within <3 min. per fill. H_2 quality, onboard storage and refueling interface thus allow uniform infrastructure solutions and full compliance with customer expectations in terms of handling and refueling time. Onboard H_2 storage for buses is typically 350 bar pressure level. This is due to fewer space limitations of the buses in combination with a maximum range requirement of 300 km for urban transport operation. All other requirements are identical with cars.

Vehicle range and fuel efficiency

State-of-the-art benchmark of fuel economy for compact cars is as low as 0.8 kg H_2/100 km. Though not all OEMs have achieved this yet, at least comparable fuel economies are expected for all next generation vehicles. With 4 to 5kg H_2 mass onboard vehicles, FCEVs can typically achieve a range between 500 and 600km. Expected efficiency improvements will further expand this range in the future. State-of-the-art FCEVs have therefore an almost comparable driving range with conventional gasoline or diesel vehicles. Translated into diesel equivalent this would be equal to a consumption of 2.7 l diesel/100km for a compact car under the NEDC drive cycle. The pure number gives an impression of the potential fuel savings that can be generated by the introduction of FCEV.

Fuel efficiency of buses cannot be predicted in the same way as for cars since there is no commonly accepted drive cycle under which fuel consumption of buses is measured and benchmarked. The main reason being that buses will be operated on specific routes only, which typically differ in terms of geographical profile, traffic flow, climatic and road conditions. Common cycles will therefore not deliver much practical benefit and in fact not reflect the specific operational requirements of individual sites. Several assessments of fuel cell bus demonstrations in recent years have however shown that typical fuel cell bus range is >300 km and that efficiency improvements between 20% and 30% can be achieved under urban drive conditions.

One vehicle manufacturer, Smith Electric Vehicles, offers a battery electric midi truck (7.5-12.0 t) with a fuel cell range extender. The vehicle features extended electric driving range of up to 300 km and is therefore well suited for fleet operation in mainly delivery or public transport services. It has a 350 bar onboard hydrogen storage and will therefore be compatible with bus refueling requirements.

EMPA, PSI and Bucher Schörling developed a hydrogen driven fuel cell road sweeper vehicle and tested it during 3 years in four Swiss cities. Road sweepers are in a daily 7-8 hour operation and could, if available, help increase hydrogen demand and HRS utilization.

Vehicle reliability and durability, after market support

Expected reliability of the vehicles is typically stated by the OEMs with >99% referring to operating when requested. Vehicle reliability for personal cars and buses will comply with the automotive product standard requesting operation under all circumstances and environmental conditions. It includes sophisticated technical risk management methodologies to minimize technical failure and ultimately avoid large field interventions and liability issues. In the case of special vehicles a sufficiently solid data base is still missing.

Most OEMs have expressively stated that their vehicles will not require specific aftermarket support but can be handled like conventional vehicles. Standard aftermarket support services will be provided by the OEM dealership along common templates. This will of course require and include training and education of staff with regard to H_2 handling and safety, high voltage systems and power electronics.

Vehicle certification

The EC has issued regulation no.79/2009 on January 14, 2009 on Type Approval of Hydrogen powered Motor Vehicles, effective from February 24, 2011. With this, a European standard certification procedure exists which was adopted by the European Parliament and the Council. The OEMs will certify their fuel cell vehicles along this regulation at their place of operation in Europe.

According to the ASTRA (Bundesamt für Strassen), the EC regulation is adopted and can be applied in Switzerland. This does allow acknowledgement of the Type Approval without further administrative effort and thus removes a critical administrative burden for the market introduction of FCEVs.

5.1.2. Target customers

General Observations

Development and introduction of FCEVs respond to political objectives in terms of greenhouse gas reduction, energy security and energy efficiency. FCEVs deliver an instrument for conversion to a clean and sustainable transport system. These societal values and benefits need to be utilized when marketing FCEVS. Economic constraints with regard to the total cost of operation of FCEVs will however require incentives and regulation to compensate initial cost penalties. Existing limitations of the initial refueling infrastructure in terms of number and distance between stations are to be considered.

Until 2020, OEM commercialization focus will be on passenger cars, including SUVs and urban or commuter buses. A few delivery vans and probably special vehicles such as road sweepers may complement the vehicle portfolio. Vehicle sales and marketing therefore need to be centered on these vehicle categories.

The ideal customer should either appreciate or (directly) benefit from the (societal) benefits of FCEVs and thus reflect them in its procurement decisions. Vehicle operation patterns shall match infrastructure limitations and as much as possible support high utilization rates of refueling stations. Financial strength is one more element that will allow a rather long-term commitment to clean innovations.

Role model of federal institutions

The Energy Strategy 2050 is requesting a role model of federal institutions, in particular for public vehicle fleets, as well as substantial improvement of energy efficiency with internalization of external cost as a key instrument.[31] For the same purpose, the EU has implemented directive 2009/33/EC – "Promotion of clean and energy efficient road transport vehicles"[32] by the end of 2010 which is meanwhile effective in all EU countries but is not yet adopted in Switzerland. It delivers the regulatory framework and methodology to facilitate procurement of clean vehicles in public fleets.

For this, three calculation schemes are delivered:

- Lifetime cost of energy consumption
  Total Mileage x Energy Consumption/km x cost per unit of energy
- Lifetime cost of CO_2 emissions
  Total Mileage x CO_2 emissions/km x cost/kg CO_2 (averaged EU values acc. to table 2 of directive) see **table 1.**
- Lifetime cost of pollutant emissions
  Total Mileage x emissions g/km x cost/g (averaged EU values acc. to table 2 of directive) see **table 1**.

Averaged values for total mileage of major vehicle categories are contained in table 3 of the directive and shall be applied. They may be substituted by higher cost based on real local/national values, but shall not be higher than twofold of the averaged values.

A help desk was established under http://www.sustainable-procurement.org/index.php for organizations and authorities who intend to work with the directive. The help desk shall provide information and advice in support of implementation and interpretation of the directive.

Table 2: Cost for emissions in road transport (in 2007 prices)

CO_2	NO_x	NMHC	Particulate matter
0,03-0,04 EUR/kg	0,0044 EUR/g	0,001 EUR/g	0,087 EUR/g

Table 3: Lifetime mileage of road transport vehicles

Vehicle category (M and N categories as defined in Directive 2007/46/EC)	Lifetime mileage
Passenger cars (M_1)	200 000 km
Light commercial vehicles (N_1)	250 000 km
Heavy goods vehicles (N_2, N_3)	1 000 000 km
Buses (M_2, M_3)	800 000 km

Table 1: Averaged values for cost of emissions and total mileage of major vehicle categories

The directive delivers an instrument and the methodology for internalization of external cost in public fleets. It is suited to reduce the financial gap for FCEVs and thus support procurement decisions in favor of clean transport solutions.

Table 2 on next page displays a specific case analysis for diesel and fc buses operated by PostAuto AG, the largest public transport agency in Switzerland and a key stakeholder of the H_2-Mobility Swiss initiative. PostAuto are intending to support the project in terms of FCEV (Bus) procurement and HRS launch in the context of their transportation services.

The calculation demonstrates the effect of internalizing external cost by establishing a cost penalty of CHF 247 380 for the diesel bus. In essence, it would more or less double the price tag of the conventional diesel bus to a total of +/- CHF 500 000. This cost penalty would have to be considered as part of the overall TLCC of the bus when taking procurement decisions. In effect, the cost difference between fuel cell buses and diesel buses is shrinking substantially.

	Case PostAuto[i]	Diesel Bus	Fuel Cell Hybrid
1.	Fuel Consumption /100 km[ii]	38 l	7.5 kg = 25.5 l diesel equivalent
2.	Fuel efficiency improvement	-	ca. 33 %
3.	Lifetime cost of energy consumption - CHF[iii]	562.400	377.400
4.	TLC CO_2 emission - kg[iv]	802.560	0
5.	External cost of CO_2 emissions - CHF[v]	32.102	0
6.	TLC NO_x emission - kg[vi]	5.512	0
7.	External cost of NOx emission - CHF[vii]	29.214	0
8.	TLC PM emission - g[viii]	10.640	0
9.	External cost of PM emissions - CHF[ix]	1.064	0
10.	TLC external cost - CHF	624.780	377.400
11.	Ext. cost penalty diesel vs. FC Hybrid - CHF	**247.380**	

Table 2: Calculation of external cost diesel vs. FC Hybrid – case PostAuto AG

i. The calculation is based on the methodology provided in the EU directive 2009/33/EC - Promotion of clean and energy efficient road transport vehicles, tables 2 and 3, on a tank-to-wheel basis. The comparison was made between a CITARO FC Hybrid as operated in the CHIC-project and a Euro 5 diesel CITARO, emission level EEV, with emission after treatment and particulate matter filter.
ii. Data delivered by PostAuto are to some extent compromised as consumption is not averaged over the year, drive cycle, external temperature and altitude are not entirely identical for the measured values. Moreover, mass flow measurements for hydrogen refueling are not fully precise due to deficiencies of current measurement methods/devices. The comparison therefore may incorporate certain deviations but is still sufficiently precise to demonstrate the methodology. Values in € were calculated using an exchange rate of 1.2 to CHF.
iii. Lifetime mileage is assumed with 800 000 km and cost per liter diesel with CHF 1.85.
iv. Specific CO_2 emission is 2.64 kg/l diesel, tank-to-wheel.
v. External cost was calculated with CHF 0.04/kg CO2 – see directive.
vi. Specific NO_x emission is given with 689g/100km.
vii. External cost of NO_x is calculated with CHF 0.0053/g – see directive.
viii. Specific PM emission is given with 1.33g/100 km.
ix. External cost of PM emission was calculated with CHF 0.10/g.

Private Vehicle Fleets

Private vehicle fleets are very often engaged in delivery and transport services in urban areas. They can therefore massively benefit from environmental advantages of FCEVs, improve their public image as well as their economic performance. Like public fleets, they will often be able to establish and operate their own infrastructure in line with their typical operational patterns. Therefore, it would be very helpful if a number of these private fleet owners will be motivated to support FCEV market introduction, increase vehicle outreach and accelerate volume ramp-up. Information exchange with the Swiss Association of Vehicle Fleet Owners (sffv) shall be established to gain and consolidate private interest of fleet owners for FCEV procurement. Selected members of the sffv are displayed in **table 3**.[33]

Sffv Fleet Members		
ABB Schweiz AG Allianz Suisse Axpo Power AG Coop Genossenschaft Credit Suisse Fleetmanagement AG Eidgenössische Zollverwaltung Emil Frey AG IKEA AG	Kantonspolizei Aargau, Bern, Graubünden, Schwyz, Zürich Logistikbasis der Armee Mercedes-Benz Financial Services Schweiz AG Migrol AG Migros Genossenschaft Luzern Mobility CarSharing Schweiz Nestlé Suisse S.A.	NOVA-TAXI AG Siemens Schweiz AG Strasseninspektorat der Stadt St. Gallen Strassenverkehrsamt Kt. Zürich Swisscom Immobilien AG Zürich Versicherungs-Gesellschaft AG

Table 3: Selected SFFV Members

In order to facilitate procurement decisions in favor of clean propulsion technologies, it should be considered to extend the principles of the directive 209/33/EG beyond public procurements and recommend its adaptation for private fleets.

Individual customers

Sale to private vehicle users is the backbone of the long-term mass market. The existing economic and infrastructure constraints in the beginning of FCEV market launch will however rather limit volume growth of this segment. Sales need to concentrate on opinion leaders, innovation and environmentally caring individuals or groups. HRS location will be a key aspect. Sales shall therefore concentrate on customers living near fleet locations with available refueling infrastructure. The lessons learned from introduction of CNG vehicles, where successful, shall be considered for the overall marketing strategy.

5.1.3. Vehicle sales price and funding requirements

General considerations

Information delivered by the OEMs in the RfI is indicating that cost of current FCEVs is between 3.5 to 6.0 times higher than the cost of conventional vehicles, i.e. CHF 100 000 – 150 000. The numbers vary depending from the specific OEM vehicle concept and production numbers. The most critical factor for the high vehicle cost is lack of economies of scale of the fuel cell and system components. Design to cost is an additional factor, which typically matures with progressing industrialization of the technology.

These cost symptoms are typical for all new technologies and not specific to fuel cells or FCEVs. They shall therefore not be considered as objections or specific constraints for the commercialization of FCEVs (**figure 7**). The common OEM view presented in the coalition study is expecting that due to "steep decrease in the cost of fuel cell systems, BEV components and hydrogen as a result of higher utilization and economies of scale, the TCO of all the power-trains converge after 2025". [34]

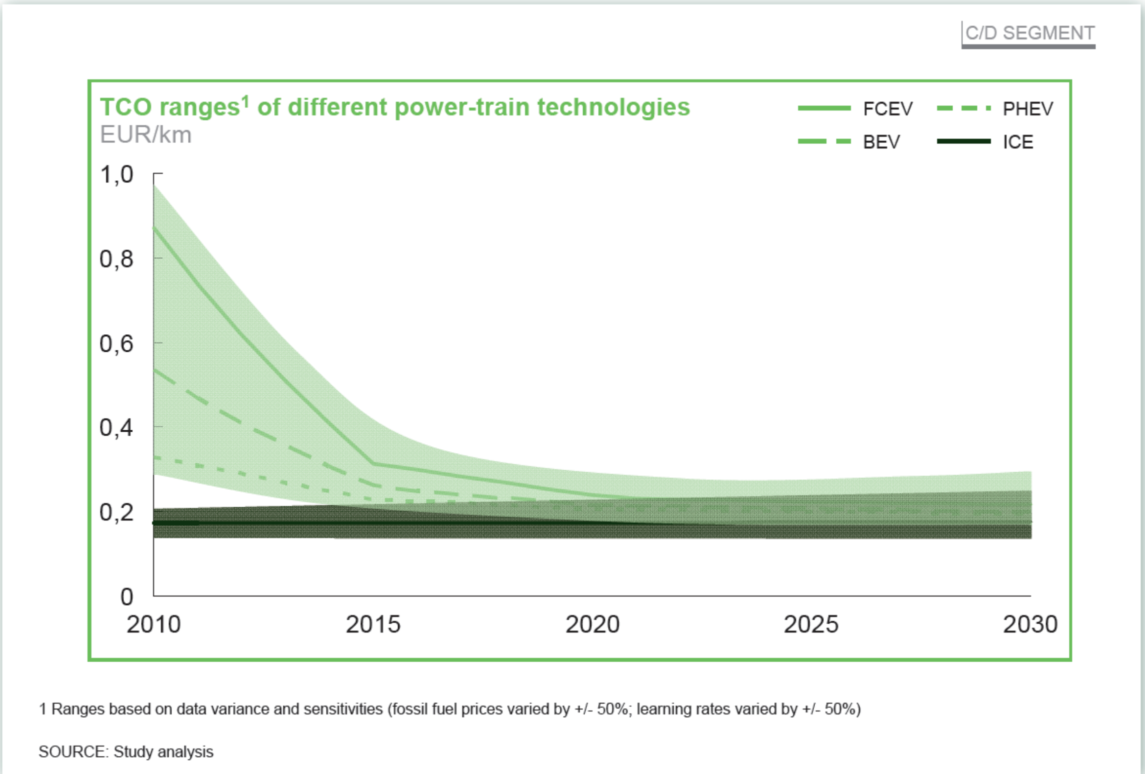

Figure 7: TCO Learning Curves of FCEV, BEV, PHEV and ICE[35]

FCEVs, as other alternative powertrains, will therefore require initial support and incentive schemes for both, OEMs and customers, to bridge economic gaps of the early years. The automotive OEMs spent a combined amount of several billions of € for the technology development over the last 10 years. The drivers of the development are political objectives in terms of sustainability and more specifically emission reduction, energy security and energy efficiency targets. This investment now needs to be complemented by establishment of a sufficient initial hydrogen infrastructure and a beneficial political framework to support market launch of the vehicles in line with political and societal ambitions.

The same study concludes from the analysis of the different alternative powertrains that: "By 2050, all electric vehicles are cost-competitive with ICEs, FCEVs are the lowest-cost solution for larger cars (J segment)".[36] **Figure 8** below from the same study is suggesting that the TCO advantage for long distances does not only apply to the heavy car but to all car segments and it starts already at short distance at least for heavy cars. It then only extends with longer distance to the other car segments.

Given that conversion of the powertrain cost is expected from 2025 and comparing to other technology innovations, it also appears that the 2050 time frame seems very far off for this scenario, i.e. there is reason to expect these TCO benefits rather earlier than later.

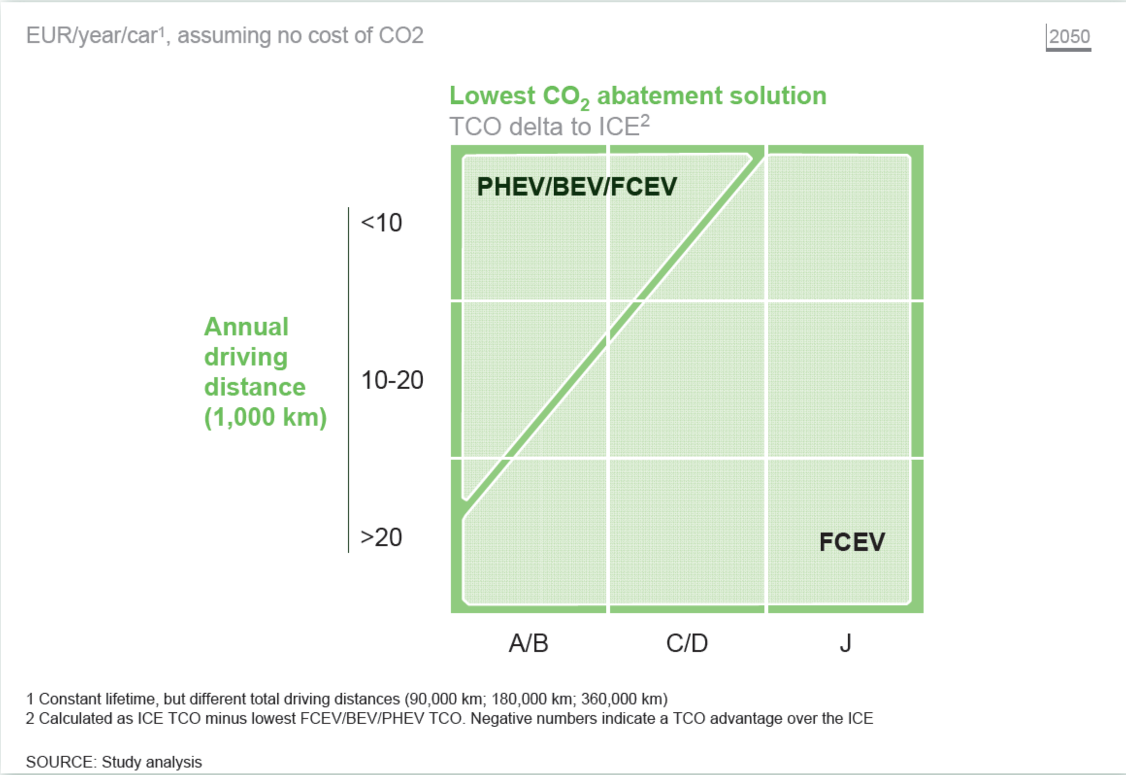

Figure 8: TCO of FCEVs, BEVs and PHEVS in the heavy/long-distance car segments[37]

Besides the sales price of the vehicle, its operational cost will massively impact customer attractiveness. Given that no particular other elements are identified which massively differ from conventional vehicles, operational costs are more or less determined by the cost/price of hydrogen fuel at the HRS (**table 4**). It is therefore essential to address the cost of hydrogen as a key factor for customer attractiveness. The following table delivers a benchmark for competitive hydrogen pricing based on fuel efficiency in diesel equivalent and current market pricing of diesel assuming a reduction of fuel consumption for FCEVs between 20…40% compared to conventional vehicles.

Description	CHF
Current market price of diesel/l incl. tax at HRS	1.85
Diesel equivalent of 1 kg hydrogen = 3.33 l	6.16
FCEV consumption = 20% improvement = factor 0.8	7.70
FCEV consumption = 30% improvement = factor 0.7	8.80
FCEV consumption = 40% improvement = factor 0.6	10.26

Table 4: Benchmark for Competitive Hydrogen Pricing per kg H_2

Ultimately, fuel economy of FCEVs as for other vehicles will depend on the drive cycle and their specific consumption rate. Consumption reductions of diesel or gasoline hybrids versus conventional ICEs are limited to urban areas. Moreover, these propulsion systems only make up a minority of current vehicle population. It may therefore be concluded that reduction of fuel consumption by FCEVs can be averaged with 30%. Taken this assumption, competitive H_2 pricing at the station shall be CHF<9.00/kg based on current diesel pricing. The benchmark displays another key aspect of FCEV competitiveness in terms of its operational costs. It needs to be observed when establishing the hydrogen supply chain. Details and further considerations will be delivered in section 5.3 below.

OEM Vehicle Pricing Strategy

Information delivered by the OEMs for cars is suggesting that there is no consistent approach established yet towards market pricing for FCEVs. Several OEMs have explicitly stated that their pricing strategy is not yet fixed. While some tend to establish market pricing with acceptable mark ups versus conventional models in the order of 10 - 15% others seem to prefer pricing vehicles near to cost levels. It appears however that the latter concept is rather associated with low vehicle numbers for large demonstrations or limited production numbers as supposed to commercial sales of vehicles.

In order to develop a reasonable scenario with regard to required financial incentives for FCEV (car) sales, therefore the following assumptions are established:

- Increasing production numbers from 2016 will leverage OEM pricing strategies to follow the mark-up/premium price concept to address commercial market requirements and be competitive with other manufacturers.
- Though, the absolute level of this mark-up cannot be predicted with certainty, analysis of the Toyota Prius market launch suggests that the corridor for premium pricing may be between 10…20% mark-up compared to conventional models.[38]
- This mark-up will however be only paid by customers if the vehicles will be associated with environmental friendliness while delivering comparable or better performance.
- The recent announcement of Toyota – see page 12 – with regard to a sales price of € 42 000 for their 2015 FCEV launch is supporting the assumptions.

While these seem to be reasonable considerations for cars and for mass-produced vans given the size and financial strength of large automotive OEMs, pricing policy for buses may differ from this template. The major reason for the expected difference is the much smaller size and lack of financial power of bus manufacturers who are not in a position to withstand significant financial loss associated with the sale of their products. Pricing policy of bus manufacturers may rather tend to cost pricing and will therefore need different incentive tools.

The price of current fuel cell hybrid buses is in the order of 1.8 Mio. € per unit. Prices include substantial safety margins for warranty due to lack of reasonable warranty statistics. Experience with bus reliability in the current CHIC-Project and other bus projects are encouraging and may allow reducing safety margins in future. It is expected that next generation buses will be priced at the level of current trolley buses.[39] One option to further mitigate the economic gap compared to diesel buses is delivered with the EU directive 2009/33 which is described on page 18. Assuming internalization of external cost according to this methodology, the anticipated price of next generation fuel cell buses of CHF 800 000 would compare to a cost tag of CHF 500 000 for a diesel bus.

Financial Incentives for Car Sales

In the early commercialization phase, OEMs will apply premium pricing to FCEVs. It means that customers shall pay some of the additional cost (reasonable premium) of the new drive train while the vehicle manufacturer will subsidize another portion of the cost as long as the necessary economies of scale are not achieved yet.

Given that the introduction of FCEVs will contribute to the Swiss energy strategy in terms of CO_2 reduction, energy security and efficiency, a beneficial political framework shall be established to facilitate the market launch of FCEVs. Incentive schemes need to address both, acceptance of the vehicle procurement for the customer and acceptable economies for the OEMs to support vehicle deliveries thus sharing the initial burden between all players. Incentive schemes need to deliver a longer-term perspective with clear and consistent rules for the initial period of 5-10 years. Analysis of existing regulation and incentive schemes in Switzerland has identified the following options that may be utilized in support of commercial FCEV launch:

- The expected enforcement of fleet targets to 95g/km CO_2 aligned with introduction in the EU 27 from 2020 will establish a strong driver for introduction of new propulsion systems as this target cannot any longer be achieved by conventional vehicles.
- Electric vehicles are except from import tax of 4% of the vehicle import price. The regulation is most likely applicable to FCEVs.
- Most cantons apply reductions of motor vehicle tax for electric vehicles between 30% and 100% with the average in the area of 50% for a period of 3 to 5 years. Typical tax rates are between CHF 300 and 600/year for a compact mid class vehicle. These rules will most likely be applicable for FCEVs.

Vehicle Insurance Tariffs – Allianz Suisse

Conversations were held with Allianz Suisse in regard to potential support for FCEV commercialization in the framework of H_2-Mobility Swiss. Allianz being the largest global vehicle insurance company consider FCEVs and hydrogen as a promising pathway to address risks of future energy supply and environmental impacts of the transport system. They are therefore prepared to support the H_2-Mobility initiative with their instruments.

Specifically, Allianz has committed to grant reduced insurance tariffs for comprehensive collision coverage of FCEVs. Benefits will be at a level of 25% reduction which is equivalent to CHF 400/year assuming a standard tariff of CHF 1500/year. This attitude of a major insurance company is a key achievement and cannot be valued high enough for a company dealing with the business of risk analysis and management.

Non-Financial Incentives

Some European countries have implemented effective incentive schemes that deliver templates for non-financial supportive action in favor of FCEV market introduction. For example in Oslo/Norway, BEVs are allowed to use highway shoulder lanes in case of traffic jam, bus lanes in inner city areas and are privileged for inner city parking. Oslo has achieved a population of more than 7000 battery vehicles operating, the highest all over Europe, due to these non-financial incentives. These results suggest that such incentives may play a complementary role for supporting the market launch of FCEVs. While privileged parking is a specific requirement in the context of charging stations for BEVs such instrument may not be necessary and effective for FCEVs and thus would not establish further constraints in term of limited public parking areas.

Preliminary calculation of potential financial benefits for FCEVs

The accumulated financial benefit that may be available by existing or upcoming regulation and insurance tariffs in favor of FCEVs is summarized in the following calculation (**table 5**) for the lifetime of a mid-class compact car with an assumed import price of CHF 35 000.

Financial Incentive	Financial Benefit CHF
Exemption from import tax – 4% once	1 400
Exemption from cantonal motor vehicle tax – medium; 3-5 years by 50%	1 000
Reduction of insurance tariffs – 10 years	4 000
Total Financial Benefit	**6 400**

Table 5: Averaged financial benefit for the life cycle of a typical mid-class compact car

As is obvious from the numbers, the combined benefits can deliver a massive incentive for FCEV procurement assuming initial mark-ups of up to 20% on vehicle price compared to conventional models. It shall be further supported and improved by competitive hydrogen pricing.

Role model of public institutions

The Energy Strategy 2050 is requesting a role model of federal institutions for energy efficiency. This does include public vehicle fleets. Incentives shall be prepared to support energy efficiency and internalization of external cost. The EU directive 2009/33/EC – see page 18 of the report – is fully in line with this requirement and can establish an instrument for implementation of the role model.

5.1.4. Vehicle volumes and ramp-up scenario

General view and outlook

Commercialization plans of OEMs suggest commercial launch of FCEVs from 2014/2015. Most OEMs will however still limit production numbers for their vehicles until and including 2015. Volume growth can be expected from 2016 with at least several thousands of vehicles per year. From 2017, most OEMs state that production will follow market demand assuming that any number of vehicles, at least in the order of 10 000s, can be produced by then. A few key markets such as Japan, Germany and California will be mandatory for early FCEV deliveries from OEM perspective due to market size, regulation and existing framework for vehicle launch in terms of infrastructure and incentive schemes. Further vehicle deliveries to other countries will be directed by availability of a sufficient initial hydrogen infrastructure and incentive schemes that help bridge initial economic disadvantages in terms of FCEV and hydrogen price as well as HRS investment and utilization rates.

H_2-Mobility Swiss is targeting to establish a beneficial political, technical and economic framework for the market introduction of FCEVs in Switzerland with particular focus on establishing the initial H_2 refueling infrastructure. Assuming availability of such beneficial framework, it can be expected that FCEVs will contribute to vehicle sales in Switzerland from 2016. The planned production schedules and capacities of OEMs as well as parallel introduction in several countries will support stepwise ramp-up of vehicle numbers. Observing these factors, a possible ramp-up scenario for Switzerland may look as follows:

Year	Annual Sales – Volume Range	Total FCEV Population	Share of FCEV Sales %/year	Av. No. FCEV Refueling	Total H_2 Demand/Year kg
2016	500… 1 500	1 500	0.4	750	135 000
2017	3 000… 4 000	5 500	1.0	3 500	630 000
2018	6 000… 8 000	13 500	2.0	9 500	1 710 000
2019	10 000…12 000	25 500	3.0	19 500	3 510 000
2020	15 000…18 000	43 500	4.5	34 500	6 210 000

Assumptions:

1. 50% of annual FCEV sales contribute to hydrogen demand,;
2. 15000 km/year, consumption 0.8kg/100km, 120kg/year/vehicle individual users with 50% share of total population;
3. 30000 km/year, consumption 0.8kg/100km, 240kg/year/fleet vehicles with 50% share of total population

Table 6: Possible vehicle ramp-up scenario and hydrogen demand for Switzerland

In this scenario, FCEVs would contribute with > 4% to new vehicle registrations in Switzerland by 2020. The forecast is in line with extrapolations of other countries and similar initiatives. Germany for example forecasts 150 000 FCEVs by then. Given the different market size, it would be about the same ratio of total vehicle sales.

After 2020, a much faster growth rate can be expected as cost of fuel cell propulsion systems will significantly drop (-90%) based on improved economies of scale and further technology progress. Cost disadvantages versus conventional drive trains are expected to basically disappear by 2025.[40]
By the same time, the cost of hydrogen will be reduced by 70% compared to 2010 levels.[41]

5.2. Hydrogen refueling infrastructure

5.2.1. Rationale of approach

The commercial launch of fuel cell vehicles requires a dedicated refueling infrastructure with sufficient area coverage. Customers need to be able to access fueling stations within acceptable distance and time. Urban centers will therefore play a key role as initial locations. Moreover, transit and cross border transportation needs to be considered for the positioning of stations to ensure mobility across Switzerland and within Europe.

Analysis suggests that a total number of 15 fueling stations in highly populated areas and key transit corridors will be sufficient for Switzerland to address initial HRS requirements (**figure 9**). In this scenario, the largest distance from station to station would be roughly 100 km with an average of 50 km or less. The planning and micro location of the specific sites for establishment of the hydrogen infrastructure shall be addressed in the Phase 1 – Project, including construction of up to three HRS for proof of concept and demonstration.

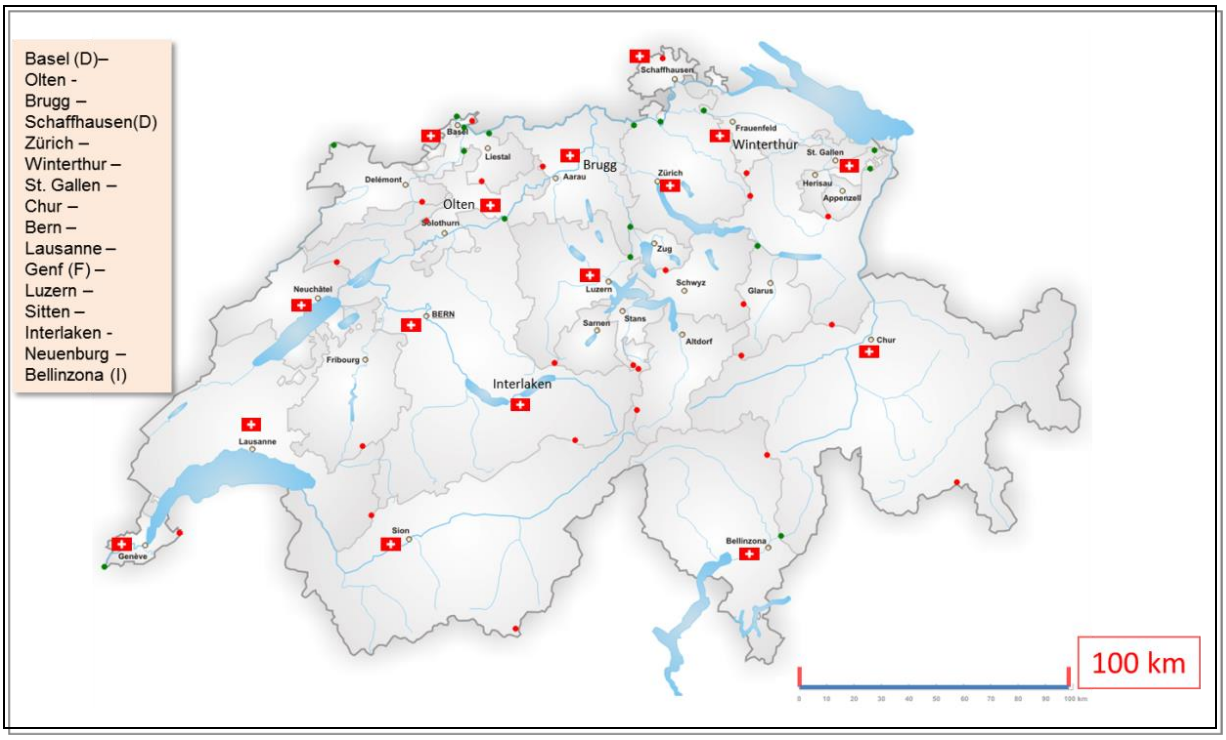

Figure 9: Preliminary HRS Network Plan for Switzerland

The cost of hydrogen refueling stations is still high due to low production numbers, lack of reasonable benchmarks and market competition. In addition, only a small number of component suppliers deliver key components that determine great part of the cost. Different safety requirements in individual countries may establish further cost penalties. It is therefore critical to align safety rules at least within Europe. Utilization of the stations will need time to grow to acceptable levels thus posing economic risks to the station operators typically referred to as “first mover disadvantage”.

The main driver for the development of alternative power trains is CO_2 emission regulation, which is mainly a duty of the automotive industry while fossil fuel production and infrastructure are lacking CO_2 related regulation. The oil industry is therefore rather in an observer position than an actor role. Therefore, investment needs to be stimulated and scale effects need to be generated to reduce the HRS cost.

Permission of sites and certification of fueling stations will be a critical element for the establishment of fueling stations. It has to follow specific standards and requires special expertise. The overall process needs to be established and managed in a coordinated way throughout Switzerland to facilitate the launch activities. Essential documentation needs to be pooled for easy access and shared by the participating authorities and users. Training of staff will be necessary and has to be supported.

The launch of an initial H_2 infrastructure thus is a complex technical, administrative, economic and political issue and the most critical requirement for commercial introduction of FCEVs. It cannot be executed by a single or a few companies only but needs synchronization with international standards and procedures (mainly Germany) and coordinated action between all stakeholders to establish a favorable political framework, including required regulation and incentive schemes.

Therefore, a limited number of early HRS locations shall be selected, established and operated to develop, test and consolidate the permission and certification process, prove technical HRS concept and collect operational experience. Establishing of the sites should include FCEV users, the corresponding cantonal energy departments and the involved energy suppliers. Other interested regions should observe and support the activities to share experience, disseminate expertise and thus prepare extension of the HRS network in the second phase. For HRS procurement, tenders including definition of the relevant legal and safety aspects as well as uniform specification parameters shall be used.

5.2.2. Technical options and status of fueling equipment

An overview of technical options are discussed in this report. Basically, two options will be needed, i.e. 700 bar for cars and other LD-vehicles and 350 bar for buses. Furthermore, HRS may be based on trucked in hydrogen from central production or onsite electrolysis. Onsite electrolysis could include supply to other stations thus to increase demand and improve the economics of onsite production. Trucked in hydrogen may be supplied from dedicated existing hydrogen production sites where it is produced as chemical by-product with very low CO_2 footprint – see also section 5.3.

The fueling technology is proven by several demonstrations but will need industrialization and more development specifically with regard to accurate metering of the H_2 dispensers. The refueling interfaces are standardized in SAE J 2799 and the refueling process in SAE J 2601(700bar) and SAE J 2600 (350bar).

5.2.3. TCO (CAPEX and OPEX) of Hydrogen Refueling Stations

Information delivered by the fueling station manufacturers in the framework of the RfI indicates that Capital Expenditure (CAPEX) is one of two key challenges for the business model of station operators. The prices were requested for a 160 kg/day HRS capacity. The price span delivered for stations with onsite electrolysis excluding onsite construction works is from CHF 1.1 Mio. to CHF 2.5 Mio. Prices for H_2 dispensers vary between CHF 1.05 Mio. and 1.2 Mio. Expert advice from the automotive industry is suggesting that the dispenser price shall be <CHF 1.0 Mio. today. The California Fuel Cell Partnership has developed baseline cost assumptions displayed in the next table and basically confirming the same level of capital cost. Though no numbers available publicly, indication was given by NOW that this is in line with the experience in Germany.

Station Timing and Size	Capital Cost	Annual Operating Expenses	
Station Built in 2014		No Load	Max load
100-170 kg/day	\$0.9M	\$75k	\$100k
250 kg/day	\$1.4M	\$80k	\$117k
Stations Built 2015-2017			
250 kg/day	\$0.9M	\$75k[15]	\$112k
400-500 kg/day	\$1.5M-\$2.0M	\$81k	\$167k

Table 7: Hydrogen Station baseline cost assumptions CAFCP[42]

Due to conceptual differences in terms of specific HRS capacity, storage and pressure level, cost information is hardly comparable and will need more analysis and negotiation.

The CAPEX can be influenced by the following factors:

- Economies of scale by larger HRS production volumes
- Containerized solutions with integrated safety system and easy to install interfaces
- Integrated dispensers w/o local construction and piping effort
- Integrated storage w/o local construction and piping effort
- Capacity demand and modular scalability of stations to adjust to demand levels
- Standardized grid integration of electrolyzers
- Integration of electrolyzers in power-to gas concepts of utilities.

In the framework of the H_2-Mobility Project, suitable technical concepts shall be selected. The selection process needs to include further cost analysis to determine, negotiate and agree reasonable station pricing in line with capacity requirements, procurement volumes and market aspects.

Operational expense (OPEX) of fueling stations is mainly determined by the following cost elements: depreciation, energy demand, cost of personnel and rental cost of real estate. Numbers delivered by Migrol allow the following rough estimation of annual OPEX for an average HRS:

Depreciation	CHF	80.000	(station price of CHF 800 k for a 160 kg/day, 10 year write down scheme)
Energy cost	CHF	3.000	
Cost of personnel	CHF	10.000	
Cost of real estate	CHF	4.000	
Total annual cost	**CHF**	**97.000**	

These numbers are in line with the CAFCP information as contained in Table 7 above.

Typical gross margins for conventional fuels / fueling stations are at a level of 9% per liter fuel based on the total cost of operation. Assuming the same gross margin for hydrogen fuel, one station should sell 120 000 kg H_2/year to achieve breakeven. This is impossible with a 160 kg/day station.

Current HRS concepts are suited to support initial market introduction technically but need substantial cost reduction of CAPEX – along the analyzed factors above. Evenly important is the generation of economies of scale by clustering HRS demand. Initially, increase of margin can help address the economic gap but is limited by the hydrogen production cost on the one side and the competitive benchmark to conventional fuels on the other side.

5.2.4. Permission of sites and certification of equipment

Permission and certification aspects are crucial for the installation of H_2 fueling stations and may establish cost issues. Currently, some Swiss safety rules such as with regard to hydrogen tight fittings or dimensioning of EX-zones around the fuelling nozzle differ from those of other European countries, especially Germany. Also, very little experience is available with the Swiss public authorities in regard to permitting HRS sites and certifying HRS equipment. The technical and safety aspects as explosion and fire prevention therefore need to be assessed and proper approaches are to be established with all involved stakeholders. In particular the SUVA, the SVGW and the KFV have to be involved in the technical specification for HRS to be able to integrate the hydrogen dispensers into existing fueling stations together with all other fuels.

A comprehensive guideline for permission and certification of HRS shall be established addressing the construction permit as well as the operational approval (Plangenehmigungsverfahren) for each HRS. The required technical information and safety aspects for both, the construction permit as well as the operational approval, shall be summarized for the involved cantons. The safety and technical requirements of the cantons should be aligned with state-of-the-art approaches as applied in Germany to avoid over engineering and cost penalties for design modifications. Based on this analysis, a Swiss approval procedure for H_2 fueling stations as described above shall be drafted in cooperation with all involved agencies.

Best practice

In the H_2-Mobility project in Germany, a group of relevant stakeholders from industry and authorities has developed a guideline for HRS permission establishing a uniform approach across the country.

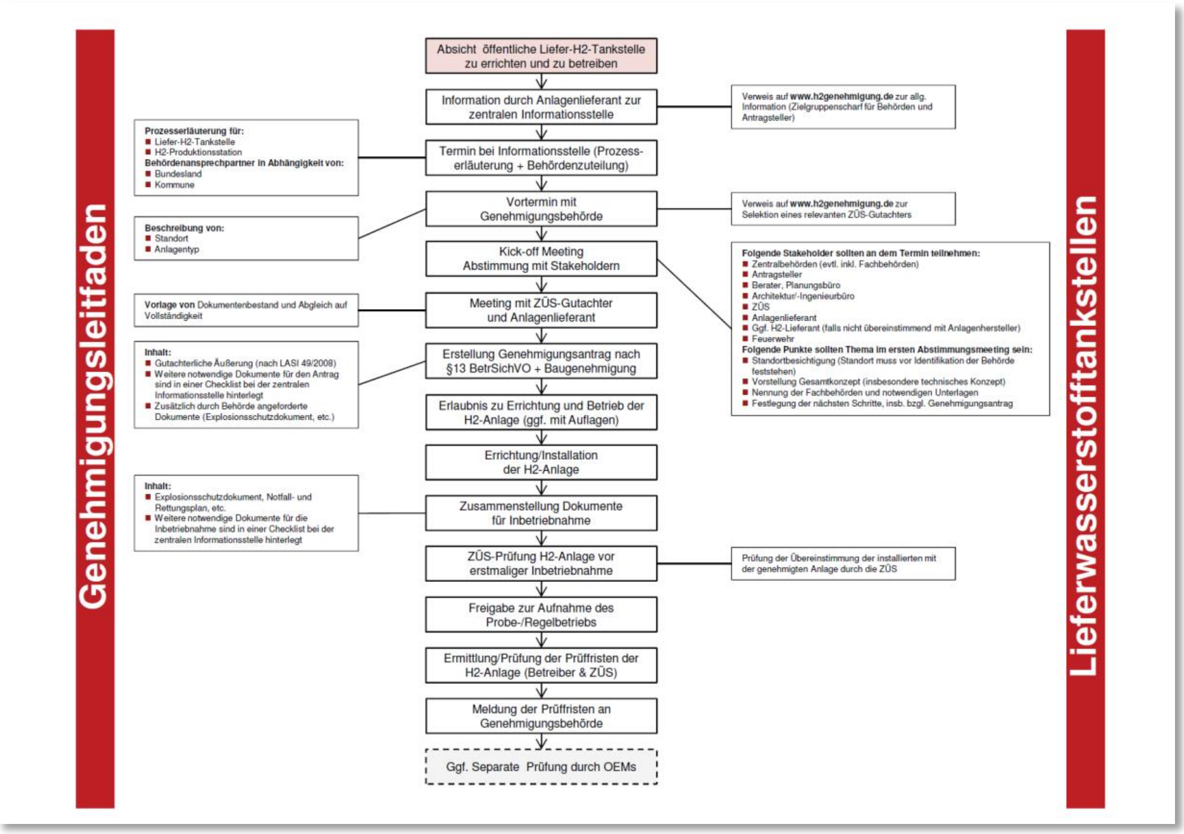

Figure 10: German guideline for the HRS permission process

The guideline reflects the necessary steps observing German legislation, safety standards and administrative responsibilities. As a matter of fact, the permission process in Germany is like in Switzerland with the local authorities and may therefore provide a reasonable platform to shape a guideline for Switzerland. Collaboration with Germany and the State of Baden-Württemberg will be critical to align safety aspects, establish consistent technical and safety requirements for HRS equipment and sites and thus control station cost. NOW and e-mobility Baden-Württemberg are willing to provide support, share information and invite Swiss representatives to relevant meetings to help establish the guideline.

5.3. Hydrogen Production and Supply

5.3.1. Sources of hydrogen

H_2 is an energy carrier that can be generated from various energy sources, input-vectors and processes. In Switzerland, several plants are already producing H_2 for various applications or as chemical by-product. The following major sources exist:

a) Large-scale electrolysis combined with high pressure storage of H_2 and O_2 for the production of synthetic crystals. Current capacity is approx. 145 kg/h, 1.000.000 kg/year of which about 25% may currently be available for external use, i.e. 250 000 kg/year.
b) Chemical by-product from production of hydro-carbon structures based on mineral oil. The potential production of H_2 available for transport application is in the range of 900 kg/h, 6 300 000 kg/year, of which 10% could be available without further changes of the process.
c) Chemical by-product from chlorine and alkaline electrolysis. The available production is approximately 45 kg/h, 315 000 kg/year.
d) Several steam reforming units are installed establishing a production volume of approximately 90 kg/h, 630 000 kg/year.

As first order of magnitude, assuming 7000 h annual operation, H_2 of varying quality is available in Switzerland in the order of 1000 kg/h or 7 200 000 kg/year, today. Based on the assumptions in table 6, page 25, of this report, this amount would allow to fuel about 50 000 cars by available H_2 sources in Switzerland. Chemical by-product hydrogen can therefore deliver an excellent option to satisfy early H_2 demand and additionally provide a significant contribution to growing hydrogen demands in future.

For sustainability evaluation of by-product H_2, three options exist: The environmental burden will be allocated to the main product only and the by-product will per se be considered as sustainable (1). The environmental burden will be equally shared between main and by-product (2) or it will be shared in line with their economic value in the production chain (3). Each of the options has benefits and disadvantages. If the environmental burden, i.e. CO_2-emissions, will be shared between main and by-product based on the actual economic values of the products (per kg end product), by-product hydrogen would be carrying only a minor fraction of the total emissions and thus be a fairly sustainable fuel.

The latest EUCAR CONCAWE well-to-wheel report is suggesting the following methodology for the use of by-product:

- All energy and emissions generated by the process are allocated to the main or desired product of that process.
- The by-product generates an energy and emission credit equal to the energy and emissions saved by not producing the material that the co-product is most likely to displace.

[43]

Whatever method will ultimately be chosen, it is obvious that by-product hydrogen can provide a beneficial contribution to the overall portfolio of hydrogen production pathways and should therefore be utilized. In addition, there are good reasons to consider utilization of chemical by-product as a sustainable pathway for hydrogen production. Following these considerations, hydrogen from chemical by-product may be subject of mineral oil tax exemption according to the Swiss Mineral Oil ordinance, articles 18 and 19, based on the agreed methodology.

The ultimate and long-term solution in terms of environmental benefits and overall energy efficiency is production of H_2 from renewable energy sources. Under Swiss conditions, this option will become relevant beyond 2020 since current share of renewable energy except for classical hydropower contributes with a few percent only to the total energy production predominantly by electrolysis. The need for large-scale energy storage with H_2 will therefore emerge much later than for example in Germany or Denmark. Electrolysis will only grow along with increasing shares of renewable energy and particularly photo voltaic but will then be needed to ensure grid stability, utilize excess electricity and leverage supply and demand.

Figure 11 below provides a view on the potential H_2 storage demand with growing amounts of renewable power generation in Switzerland. With hydropower, Switzerland is currently conveying 3.2 TWh of electrical energy from summer to winter. This is already absorbing about 90% of the existing hydro-storage capacity. If in future, more electrical power will have to be stored from renewable electricity production, additional storage capacity of at least the same order of magnitude will be required to utilize seasonal excess energy. This would require 50.000.000 kg H_2 for seasonal storage. If entirely used for transportation purposes, 10% of Swiss car population could be fed.

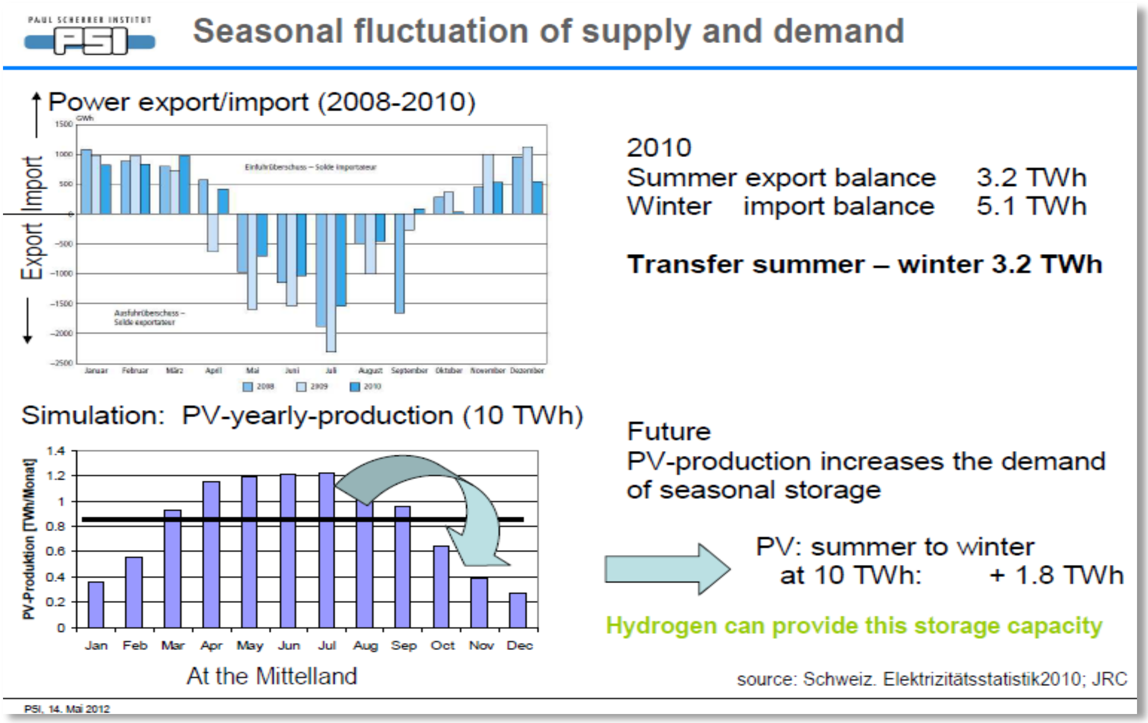

Figure 11: Future Storage requirements to ensure seasonal grid stability balance

In a number of studies modelling energy systems with massively fluctuating renewable electricity production, economically optimal shares of renewable capacity are assumed to be nearly twice as high as the expected direct energy contribution to the grid. This offers an ideal platform for the use of excess capacity hydrogen as transport fuel.[44]

Thus, analysis suggests that the H_2 demand generated by growing FCEV population could be fully saturated by existing sources until 2020. Only by the middle of the next decade, substantial volumes from other sources would be required. As these need to be developed and will need time to grow, parallel development of other H_2 production pathways is required, particularly from electrolysis based on renewable energy. Generally, the production sources and pathways of H_2 shall be selected and developed to reduce overall greenhouse gas emissions on a well to wheel basis and deliver clear benefits in terms of greenhouse gas reduction and energy efficiency compared to conventional fuels. At the same time, cost competitiveness shall be observed which will be analyzed in the next section.

5.3.2. Cost of Hydrogen

The H_2 price will be a key factor for customer acceptance and the success of FCEVs since it largely determines the operational cost of the vehicles. It is therefore a critical element of the overall commercialization effort and needs particular attendance. It is composed of production and logistic cost and includes taxation. All cost elements are to be controlled and managed to achieve the objective.

Taxation of H_2 will in future depend on energy sources for its production (renewable or not), its CO_2 footprint and its utilization as fuel or for power generation. Suitable methodologies still need to be developed. In the framework of a P+D – project, H_2 will be except from mineral oil tax.[45] The cost of H_2 will therefore only depend on the production process, scale of production and supply volumes.

Common production processes of H_2 are steam methane reforming and water electrolysis. Production can be either centralized or distributed onsite. Typical H_2 production pathways are displayed in **figure 12** on next page.

The following assumptions were used for providing the price information by the hydrogen suppliers: delivery free station, average distance for delivery 100 km, annual demand of 10 000kg, 50 000kg and 100 000kg per station.

Based on these assumptions, prices for trucked in hydrogen from central production source are indicated between CHF 4.00/kg to CHF 14.00/kg. The price (cost) difference in the case of central production is mainly determined by the production process and to a much smaller extent by the logistic cost associated with supply volumes. In the case of central production, it is moreover assumed that production scale will be near or at optimum size so that scale effects are effectively available.

The prices (cost) for onsite production of hydrogen will depend on the production process, the production rate and in the case of electrolysis on the electricity price. Price indication delivered by the suppliers based on electricity cost of 0.08 €/kWh is as follows:

10 000 kg	CHF 35.00 – 60.70
50 000 kg	CHF 6.75 – 16.50
100 000 kg	CHF 7.70 - 14.50 [46] *

Based on the vehicle ramp-up scenario developed in table 6 on page 25, a demand of 50 000 kg may be reached by individual stations in 2018. If taking the low-end cost of CHF 6.75/kg, onsite distributed electrolysis could be a viable option for hydrogen production from this production rate. In case electricity cost would double to 0.16 €/kWh, the H_2 cost for the 50 000 kg/year case would be CHF 10.35/kg H_2 and not yet establish an economically viable case.

The H_2 price sensitivity analysis developed in table 4 on page 22 suggests a H_2 price of CHF 9.00/kg to be competitive with conventional fuels. The price status delivered by the hydrogen suppliers on the other hand indicates that only part of the hydrogen can be delivered at this price. Stable and consistent H_2 pricing will however be a critical element for customer acceptance. It will therefore be a major task of the H_2-Mobility Project to assess ways and identify concepts to ensure competitive and consistent H_2 pricing assuming different production pathways and sources for its delivery. For larger demands >50 000 kg/year per station from about 2018, onsite H_2 electrolysis may complement and establish a parallel pathway that shall be developed in accordance with the overall and per station demand. This will however largely depend on the electricity price.

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*Increased cost numbers for 100 000 kg at the low end are influenced by limited capacity assumptions for onsite electrolysis, i.e. should be lower if capacity of the electrolyzer is scaled up.

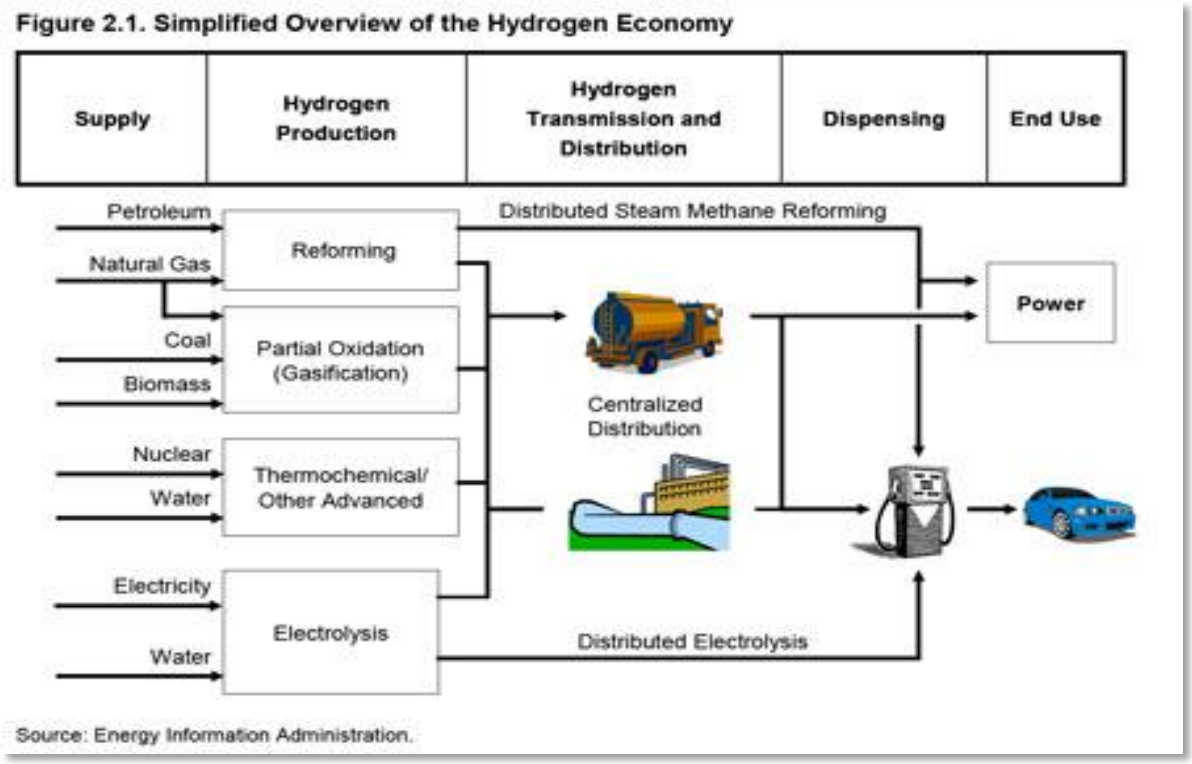

Figure 12: Typical Hydrogen Production Pathways[47]

The Swiss CO_2 law determines that from January 2013, fuel importers need to compensate part of the CO_2 emissions associated with diesel, gasoline or natural gas based fuels. Initially, the fee will be CHF 0.02/l and may be raised up to CHF 0.05/l. If the compensation will not be paid, penalties of CHF 160/t CO_2 are due to the Federation. Emission reduction certificates may be gained by projects or actions with proven CO_2 reduction. [48]

The regulation establishes a direct impact on the market price of conventional fuels and facilitates measures to reduce CO_2 emissions. It may therefore help hydrogen pricing as well as facilitate H_2 projects reducing CO_2 emissions.

To highlight the case for the substitution of gasoline vehicles by FCEVs, the reduction of CO_2-equivalent can be as high as 45% in case of H_2 from electrolysis based on Swiss electricity consumption mix. With substitution cost of 150 CHF/t CO_2, this can lead to a H_2 price of 1 CHF/kg H_2. Therefore, with such a production mix and utilizing the CO_2 law, the H_2 fuel cost could be at an equal level as gasoline. The ratio would even improve if larger fractions of excess-renewable electricity would be used - compare table 1.

5.3.3. Hydrogen value chain

The analysis in the previous chapters illustrates that the establishment of the industrial value chain for hydrogen fuel is a complex and challenging process. It has to deal with different production pathways of hydrogen, different cost levels of the produced hydrogen, establishment of the required logistics as well as investment in and operation of HRS in line with acceptable economics.

Onsite H_2 production will need to be developed and integrated using a modular approach to ramp-up production scale in relation to the demand of a specific HRS, including to supply other HRS until sufficient demand levels will be achieved. H_2 refueling equipment needs further industrialization and cost reduction in line with at least European standardization and regulation. Safety aspects are to be considered and permission of HRS shall be managed along consistent criteria and in a coordinated way. The H_2 price shall be competitive and consistent. The HRS network needs to meet customer expectations.

It is very obvious that this development needs coordination and collaboration of the involved industries, authorities and other stakeholders. The H_2-Mobility project will therefore have to establish a systematic and collaborative approach for tackling the individual issues and develop an overall concept for the establishment of the hydrogen value chain.

Hydrogen JV

In the course of the analysis, several industrial stakeholders were consulted to identify the potential for a collaborative business approach. Key stakeholders such as CarbaGas/Air Liquide, Pangas /Linde, Lonza, Migrol and PostAuto share the opinion that combining industrial efforts is more suited to address the challenges ahead and would be preferred versus competitive approaches. Such model would help sharing the required investment, mitigating associated economic risks, address supply chain issues in a coordinated way and thus unfold much more momentum.

A sequence of meetings is foreseen to discuss all related aspects, including establishment of a venture. The associated process will be part of the H_2-Mobility Phase 1 - Project. The potential scope of activity of the Hydrogen Venture is displayed in the **figure 13**. It may include the entire value chain from production source to the customer refueling interface at the HRS.

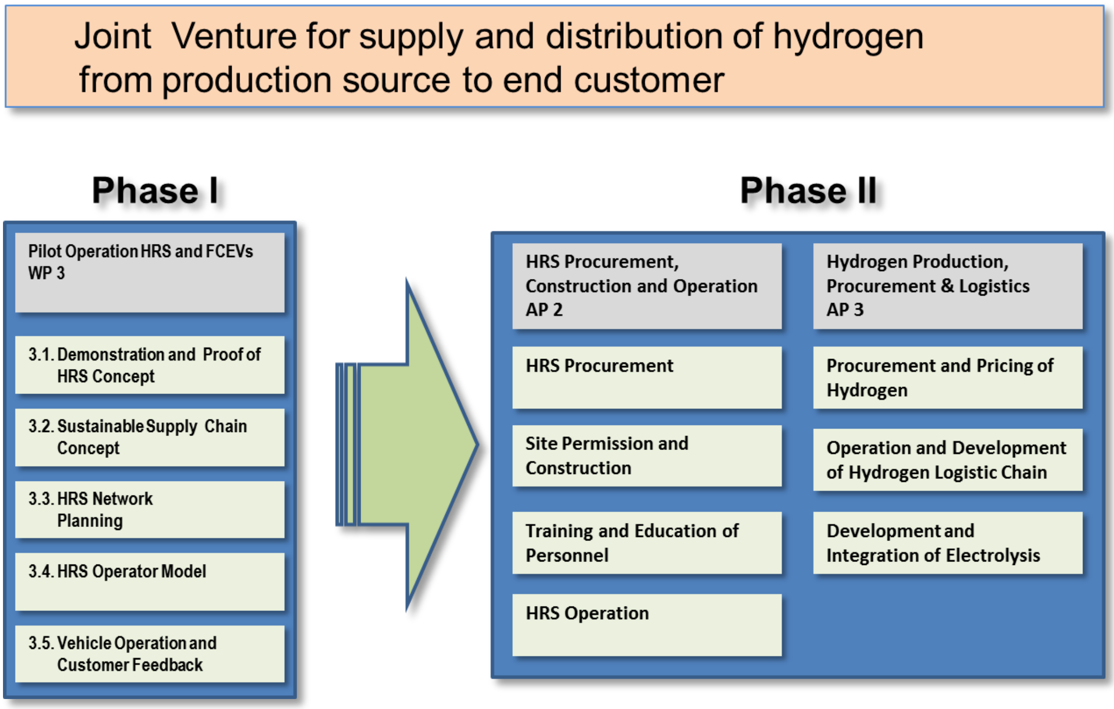

Figure 13: Potential Scope of Activity of the Hydrogen Venture

Major purpose of the venture will be coordination and facilitation of the related value chain aspects while specific operational activities will be the responsibility of individual players. Specific details of the necessary arrangements need to be determined and worked out.

6. Socio-economic Analysis – The Business Case

6.1. Economic gaps and pathway to self-sustaining business case

When concluding the analysis of previous chapters a number of critical economic gaps are identified mainly associated with the lack of scale effects and industrialization of key elements in terms of FCEVs, HRS as well as mass-produced hydrogen from electrolysis.

Table 8 on next page displays an overview of generic actions in terms of regulation, financial and non-financial incentives that may be suited to support the overall development.

These generic options were initially discussed with the BfE resulting in comments with regard to the status or probability of their introduction which can be categorized as follows: Implemented, very likely, likely, unlikely and no go. [49]

Economic gap analysis and general options for their mitigation			
	Vehicles	Hydrogen	Fueling stations
Economic Gaps	▪ Vehicle sales price ▪ Cost of operation	▪ Hydrogen cost/price ▪ Renewable H_2 pathways	▪ Investment cost/CAPEX ▪ HRS utilization/OPEX
Direct or indirect financial incentives	1. Vehicle tax exception/ reduction by cantons 2. Import tax exception/ reduction 3. VAT exception/reduction 4. Internalization of external cost for fleets – EU directive 5. Accelerated/improved write down schemes for fleets 6. FC promotion for domestic vehicle manufacturers (Hess u. a.)	11. Exception from electricity tax for electrolysis 12. Tax exception for hydrogen fuel 13. Industrial tariffs for electrolysis 14. Gratification for energy storage…grid integration based on hydrogen 15. CO_2 credits/penalties for distributors based on existing regulation 16. Use of excess electricity	18. Accelerated write down schemes 19. Tax credit for clean fuel investment/Eco tax for conventional stations
Regulative Measures	7. CO_2 penalties/credits for importers based on existing regulation 8. Zero emission mandate for fleets in urban areas 9. Exception from cantonal road traffic tax 10. CO_2 reduction targets 95g/km by 2020	17. CO_2 reduction target for distributors	20. Clean fuel mandate for all stations/distributors
Non-financial incentives	21. Use of shoulder lanes on highways in case of traffic jam 22. Use of bus and taxi lanes in inner city areas 23. Parking privileges in inner city areas 24. Access limitations/privileges to inner city areas		

Table 8: Economic gaps and generic options for their mitigation

Several economic gaps were identified in previous chapters representing challenges for the commercialization of FCEVs and hydrogen fuel. It can however reasonably be expected that these gaps will be set off by increased production volumes and improved maturity of the technology.
Several assessments, including by the U.S. DoE annual progress reports and the so-called coalition study[50] in Europe, have confirmed this expectation. At the same time it is recognized that a longer introduction phase will be necessary until optimum production rates can be achieved and cost of technology will meet ultimate cost targets. This period is critical for the market breakthrough of hydrogen and FCEVs and will require political support as was shown above.

Political support shall however be designed in a way that economic reality will be reflected and incentives will be reduced based on achievements. As market growth and economic indicators cannot precisely be predicted a kind of progress monitoring is suggested to allow adjustment. The monitoring shall be based on a number of relevant indicators such as FCEV registration in Switzerland and globally, hydrogen consumption in Switzerland and globally, number and utilization rate of HRS etc. The results should be reported to the BfE annually and provide the factual basis for political decisions on adjustment or improvement of incentive schemes.

As was shown before, the cost of different drivetrains will converge after 2025. The same applies to the economics of HRS as their number will allow optimum production numbers and sufficient utilization rates with growing vehicle population, only. Onsite electrolysis will require a certain minimum hydrogen consumption rate per station to become economically viable and will therefore come into effect from the end of the decade. Hence, a 10-year time frame shall be considered until full cost competitiveness and economic viability may be reached.

Though, all three key areas, i.e. hydrogen production, distribution and FCEVs have their specific cost constraints, it seems obvious that the most critical element of the business case is acceptance and competitiveness of FCEVs. The better the business case for fuel cell vehicles, i.e. the faster the volume ramp up will happen, the more likely is the economic success of the other elements.

6.2. Summary of required political action and support schemes

The expected introduction of FCEVs and hydrogen as alternative fuel are a result of political requirements in terms of emission reductions, energy efficiency and energy security. Their commercialization will require and ignite massive changes in terms of energy use, energy sources, energy conversion and infrastructure in the transport sector and beyond. The change process is fundamental and cannot be implemented by individual actors but will need collaboration of all stakeholders and political support both in terms of general policy and specific incentive schemes to address the associated challenges.

It appears that several legal options exist already or may be utilized in support of FCEVs and H_2 – see section 5.1.3, page 21. These measures are however addressing part of the challenges only and should be complemented by the following additional actions or improvements.
It would be beneficial, if FCEV motor vehicle tax exceptions by the cantons would follow a more common template than established for BEVs today to allow consistent vehicle pricing and thus improve market mechanisms. It would require adaptation of the "Energieetikette" (appendix 3.6 of the energy ordinance) for FCEVs to allow legislative procedures and administrative action in the cantons.

The role model of public institutions should be facilitated and supported by adopting the EC regulation 2009/33/EC – "Promotion of clean and energy efficient road transport vehicles" – see section 5.1.2, page 18. It would clearly help to direct procurement decisions towards green transport solutions by generating focus and mitigating part of the economic gaps. As fleet operators will represent a critical customer group for initial market introduction, it should be considered to extend the regulation to private fleets.

Ultimately, the value of non-financial incentives such as use of highway shoulder lanes and bus lanes in inner city areas shall be further investigated in terms of their local benefits by the relevant federal authorities, cantons or cities.

It is key for all further considerations with regard to the economics of the hydrogen value chain and the ultimate hydrogen price that exception from mineral oil tax will be officially clarified, confirmed and fixed.

For economic and availability reasons, introduction of hydrogen fuel to the transport market will require utilization of existing hydrogen production sources which are mainly chemical by-product. By the nature of their typical production pathways they will bear a much lower CO_2 footprint than conventional fuels. It will however be necessary to select and apply reasonable methodologies to identify, show and properly reward the sustainability benefits of these hydrogen sources.

In the long-term perspective past 2020, facilitation of energy storage will be necessary to manage the fluctuating availability of renewable energy sources. Such framework shall consider and include the role of electrolysis and support the most efficient utilization of hydrogen as either fuel or for generating electricity to the grid when needed.

The impact of the H_2-Mobility Project in terms of CO_2 emission reductions by proven results from FCEV operation and introduction of hydrogen fuel should be rewarded by emission reduction certificates to the relevant operators and distributors to create motivation for change.

The BfE comments are reflecting the state of discussion or implementation with regard to potential political action. As expressively declared by the BfE, they do not to any extent represent ultimate decisions. The above recommendations shall therefore be further discussed and facilitated with the relevant political authorities. The H_2-Mobility Project will deal with this topic in the framework of a dedicated work package.

6.3. Collaboration with other initiatives and projects

The largest demonstration project in Switzerland is the *European CHiC-project* with participation of PostAuto. Five fuel cell buses and a 350 bar HRS are operated in Brugg providing urban transport in the village but also commuter services in the vicinity of Brugg. The H_2 is partly trucked-in and partly delivered by an on-site electrolyser. The project began in 2012 and will run for 5 years. First results show a positive reliability of the buses and a lower consumption as was expected and promised by the supplier. PostAuto is engaged in the H_2 Mobility Swiss project and can therefore secure the link between the two projects as well as transfer lessons learned.

Another initiative is the *Hy.muve* project dealing with development of a fuel cell powertrain for a municipality vehicle, which was successfully accomplished by Bucher. The vehicle will be tested in 4 different Swiss cities. Supposed further product development, such vehicles would very nicely fit the H_2-Mobility Swiss approach and help increase the utilization level of individual HRS. EMPA is a partner in the project and supports H_2-Mobility Swiss.

THELMA is the name of a Swiss "Technology-centered electric mobility assessment" examining the profile and impact of different electric motor technologies for different markets. Findings of the project can help to detect proper market segments for specific technologies.

Since 10 years, mobility aspects play a major role within the *novatlantis - initiative* in the context of the "Pilot region Basel". In the previous phase, focus was on operation of natural-gas driven vehicles. In the new period, which just started in the beginning of 2013, hydrogen shall be explored with one HRS and a small fleet of passenger cars. This initiative is closely linked with the objectives of the H_2- Mobility Swiss project. Coordination with the project is therefore necessary and shall be established.

National activities in Switzerland need to be coordinated with neighbor countries to ensure cross border mobility in Europe. Moreover, several countries have already established similar initiatives in recent years and collected valuable experience that shall be shared and utilized by the project. The cost disadvantages of fuel cell vehicles and hydrogen stations due to the lower production numbers in the early years need to be compensated by coordinated or joint procurement activities where possible and meaningful.

Germany has established its National Program Office, NOW GmbH, for research and development of fuel cells and hydrogen, in 2008. Moreover, it has developed the first H_2-Mobility initiative globally, including car makers, utilities, oil companies and infrastructure providers aiming at establishment of a hydrogen refueling infrastructure. H_2-Mobility Swiss has already established working relationship with NOW in September 2012. Activities shall initially focus on sharing experience for the permission and certification of hydrogen fueling stations. In the second step, options for joint procurement and cooperation on public transport solutions shall be assessed and discussed.

The *State of Baden-Württemberg* in Germany is direct neighbor of Switzerland and has established its e-mobility initiative in 2010. It comprises all electro mobility options, including FCEVs and the establishment of a hydrogen infrastructure. H_2-Mobility Swiss has established contacts with e-mobility and scheduled initial discussions. Topics shall include joint procurement but also coordination of planning activities in the border regions.

Scandinavia and particularly *Denmark* and *Norway*, are very active in the field and have collected valuable experience in establishing infrastructure modules in recent years. Some of the Scandinavian results in implementing incentive schemes are very encouraging and shall be studied in more detail. H_2-Mobility Swiss shall communicate with the relevant representatives and share experience.

H_2-Mobility UK was established in the beginning of 2012 and undertakes assessments for the introduction of a hydrogen infrastructure and fuel cell vehicles in UK. As the objectives and the status are very similar with H_2-Mobility Swiss, potential collaboration shall be assessed and discussed.

The overall development of H_2 infrastructure and fuel cell vehicle commercialization is very lively and dynamic. H_2-Mobility Swiss shall therefore observe activities and actively search for collaboration opportunities as and when they may appear.

7. Overall Impact

7.1. Energy efficiency dimension

In line with the findings of this analysis, it is assumed that FCEVs will play a major role in future vehicle electrification. Other than BEVs, they provide a driving range and performance comparable to ICEs and therefore are closest to common vehicle use patterns of today. The key advantage of FCEVs vs. conventional drive trains is substantially lower fuel consumption and local or well-to-wheel zero emissions depending on the production pathway of the hydrogen fuel (well-to-tank). In **figure 14** some major production pathways and propulsion technologies are compared.

While BEVs outperform in terms of efficiency when charged with electricity from renewable energies, they are lacking two major properties, sufficient range and short refueling time. Charged with electricity from the typical European energy mix of today, batteries are just same level with ICE drive trains.

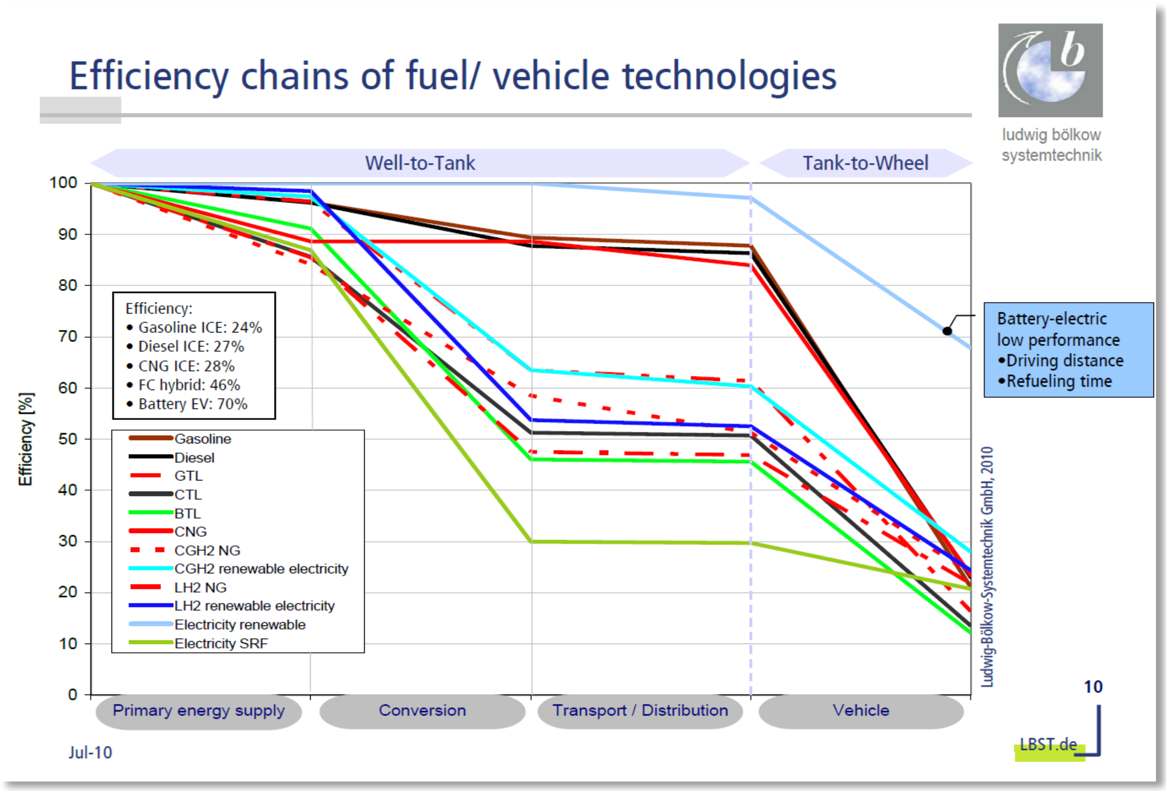

Figure 14: Efficiency chains of different fuel/vehicle propulsion systems [51]

The second best overall pathway is compressed hydrogen with FC Hybrids based on hydrogen from renewable energy sources but with all other benefits in terms of range and short refueling time. The tank-to-wheel efficiency of the CGH_2 energy chain is 46 % compared to 24 % for the gasoline ICE (factor 1.9), 27 % for diesel ICE (factor 1.7) and 28 % for CNG ICE (factor 1.6). Third rank is LH_2 from renewable energy followed by CGH_2 from natural gas. Both are still better than batteries when charged with electricity from the European energy mix of today.

Introduction of FCEVs will therefore provide transport solutions in line with customer use patterns of today while substantially reducing fuel consumption. The different production pathways of H_2 moreover contribute to energy diversity and energy security. H_2 used for energy storage will be a key element for the efficient use of increasing shares of renewable energy within the electricity sector.

7.2. Environmental dimension

Air quality and noise establish increasingly important factors for the living conditions of citizens in industrial and emerging countries. They are playing a key role for public health in terms of avoiding chronic disease and are of particular importance for Switzerland as densely populated country in its northern and central part, with its vast but sensitive natural resources, with the large number of foreign residents and as important touristic area.

FCEVs as BEVs can deliver a clean solution for public and individual transport with zero overall or at least local zero emission and massive reduction of noise levels. This cannot only create a positive social effect on living conditions but contribute to reducing the external cost of transport for society and additionally deliver positive economic effects in return. **Figure 15** delivers a well-to-wheel comparison of the CO_2 equivalent in g/km distance driven for different propulsion systems and fuel pathways.

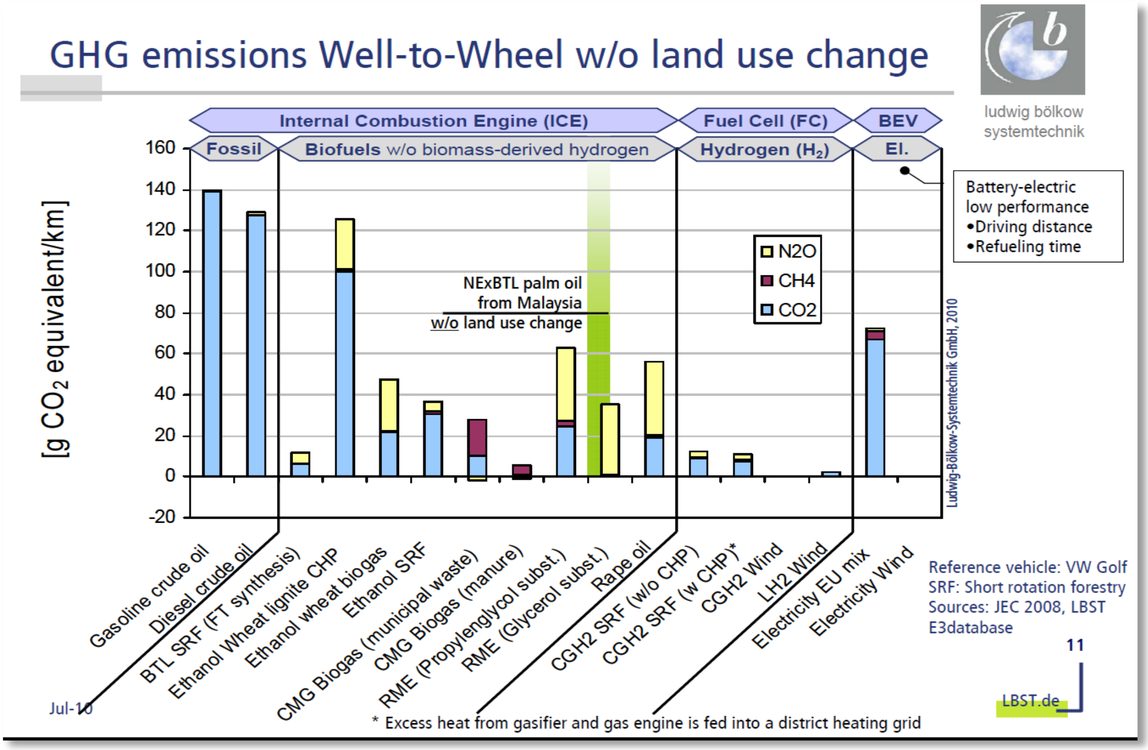

Figure 15: Well-to-Wheel CO2 Emissions by Production Pathways [52]

Both BEVs and FCEVs with CGGH$_2$ are zero emission fuel pathways when based on renewable energy. The next best option is LH$_2$ from renewable sources. Even the CGH$_2$ SRF pathways provide a massive potential for CO_2 reductions, which would particularly apply for chemical by-product bearing a fraction of the total CO_2 emissions only. **Figure 16** provides an impression on tank-to-wheel CO_2 emissions for different drive trains observing range. The desired target segment is called “low emissions and high range” (green stripes, middle to right on bottom).

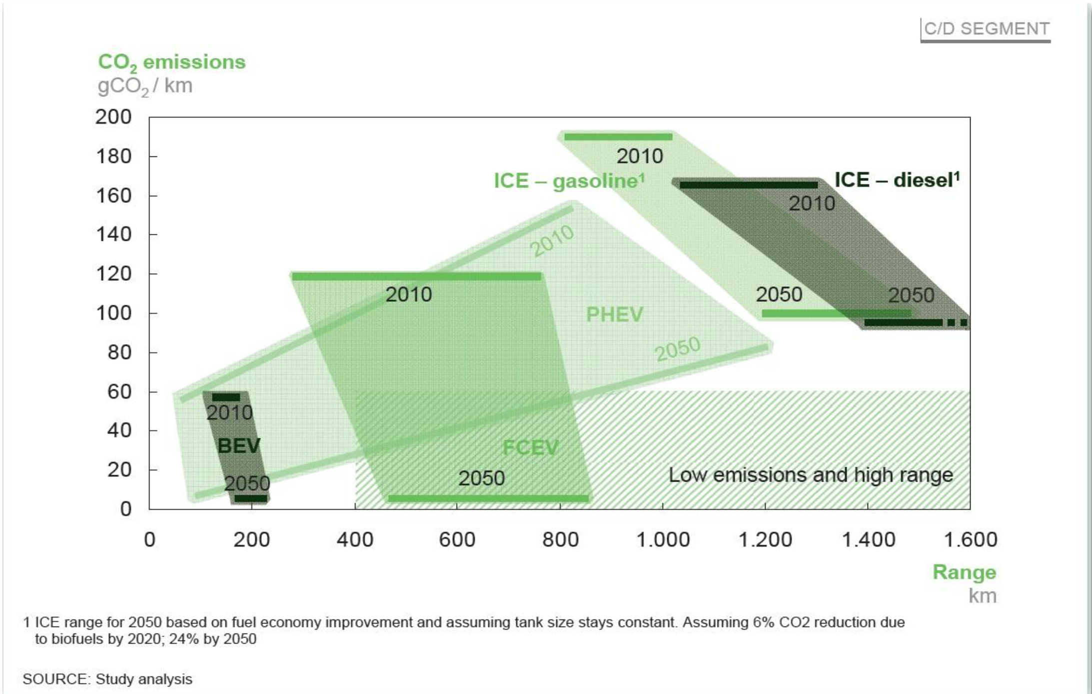

Figure 16: Comparison of CO2-emissions over range between different drive trains [53]

It is obvious that only one option, i.e. FCEVs, has the potential to fully meet the desired corridor, i.e. combination of low emissions and long range. PHEVs are scratching the corridor but by the nature of their limited electric driving capacity, with increasing emissions for long distances. BEVs are equally low emissions but stuck with ranges around max 200 km even by 2050. ICEs deliver longest distances but are limited with regard to further emission reduction potential between 90…100 g/km CO_2 by 2050. Hence, FCEVs deliver the best performance as well as the best properties in terms of environmental benefits and customer expectation.

The CO_2 life cycle analysis for Switzerland in **figure 17** on next page shows that FCEVs can reduce global warming gases for most H_2 production pathways. In particular when using the Swiss electricity mix for electrolysis, a reduction of > 45% relative to a gasoline ICE vehicle can be achieved. Also other production routes as steam reforming (SMR) from natural gas or from biomass via syngas show advantages related to ICE vehicles. Only in case of the European electricity mix, which is not particularly relevant for Switzerland, GHG emissions are higher than for ICE vehicles.

Future use of excess electricity from intermittent renewable sources can further lower GHG impact compared to SMR based hydrogen and will therefore contribute to reducing GHG from the transport sector.

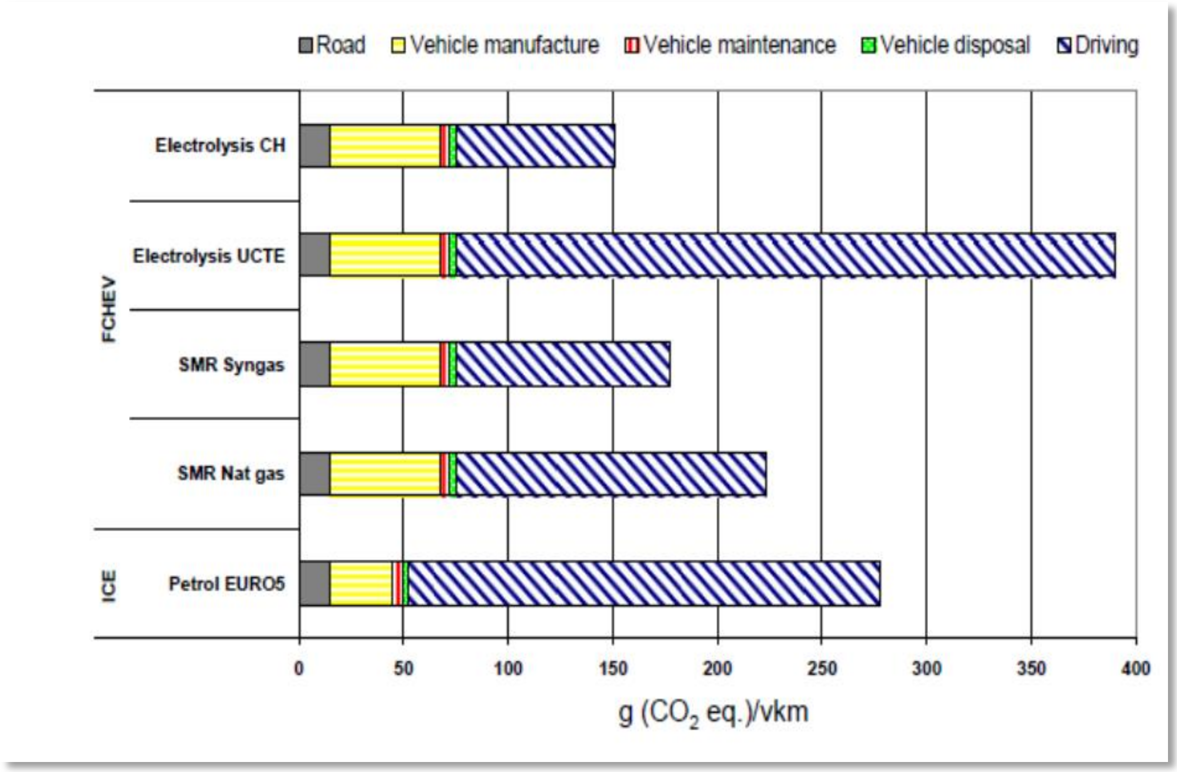

Figure 17: Total life cycle emissions of global warming gases by vehicle km in Switzerland[54]

Life cycle assessment delivers a very helpful tool to compare various value chains within the energy system. It must however be recognized that most processes are based on past or current data. Moreover, local and global factors need to be differentiated. Therefore, some assumptions have to be made when looking into the future or evaluating value chains.

This can be seen in **figure 18** on next page. The graph is based on data from 2005 without consideration of electronic conductor materials (platinum or cupper) recycling that will likely be implemented as soon as FCEV population will increase and first generation vehicles will come to end of life.

Therefore future impact of materials will decrease due to recycling effects as soon as the FC vehicle fleet is achieving a balanced share on the vehicle population. Improvements of the technology that are assumed in the presented sensitivity analysis (SA) within the next 5 years will moreover likely happen to be reality.

Furthermore, differentiation is needed between LCA categories with global vs. regional impact. In the case of regional impact, the location of the polluting source is of key importance to evaluate its real impact on the local population or biosphere. Indicators representing local or regional factors do however often not differentiate with regard to the location of such emissions and may therefore overestimate the impact on local population or biosphere. This is different in the case of global indicators where all locations contribute to the overall scenario.

7.3. Economic dimension

Electrification of propulsion systems by FCEVs requires massive investment in vehicle development and establishment of the H_2 infrastructure. It will moreover substantially change the vehicle value and supply chain. Conventional components will lose share while electric, electronic, chemical and electrochemical components will massively grow. In the medium and long-term, cost of FCEVS and H_2 will convert to common levels acceptable for customers and will therefore establish a viable alternative to conventional propulsion systems.

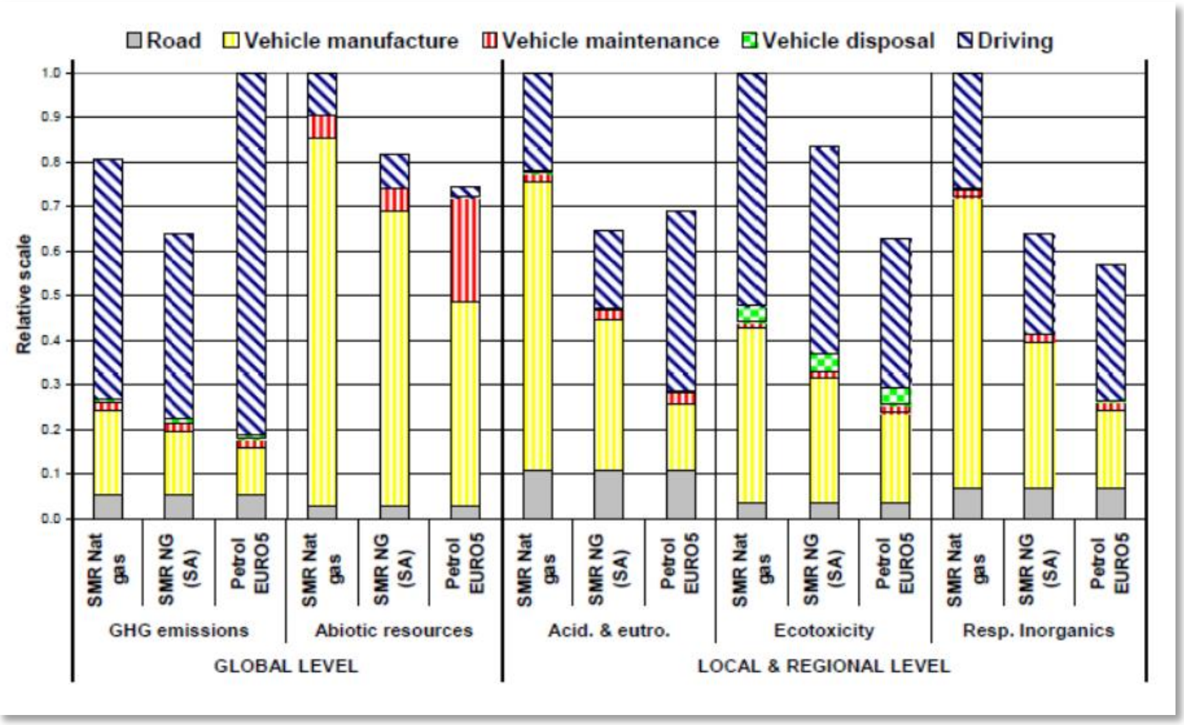

Figure 18: Results of a life cycle assessment and sensitivity analysis for FCEVs

As for all innovations, market take up is hard to predict and depends on several combined factors. The Toyota Prius provides a typical template for such a market introduction in several ways. "An examination of historic Prius sales reveals a slow and bumpy 11-year path. Reaching 1 million sales required years of production ramp-up, three generations of product development, and confronting ups and downs in the broader automotive market... This trajectory, however, did **not** require the build-out of new vehicle fueling infrastructure..."[55]

Figure 19 below provides an attempt to develop potential H_2-Mobility Swiss scenarios in comparison to the Toyota Prius take-up. These scenarios consider sensitivities with regard to the most influential factors for sales growth. While the y-axis provides vehicle sales numbers, the x-axis delivers an 11-year period that in the case of the Prius starts by the year 2000 and ends by 2011 whereas the H_2-Mobility scenarios would start by 2016 and end by 2017. The market break of the Prius between 2008 and 2010 is mainly due to the financial crisis and thus should be considered as a special effect.

When comparing the two developments, the most critical difference in the case of FCEVs is obviously the need for a hydrogen infrastructure and its accessibility. While the Prius was establishing an advanced but in its main properties still conventional market segment (no new infrastructure, no different use patterns, baseline still ICE), FCEVs are determined to replace the ICE and are therefore a disruptive innovation.

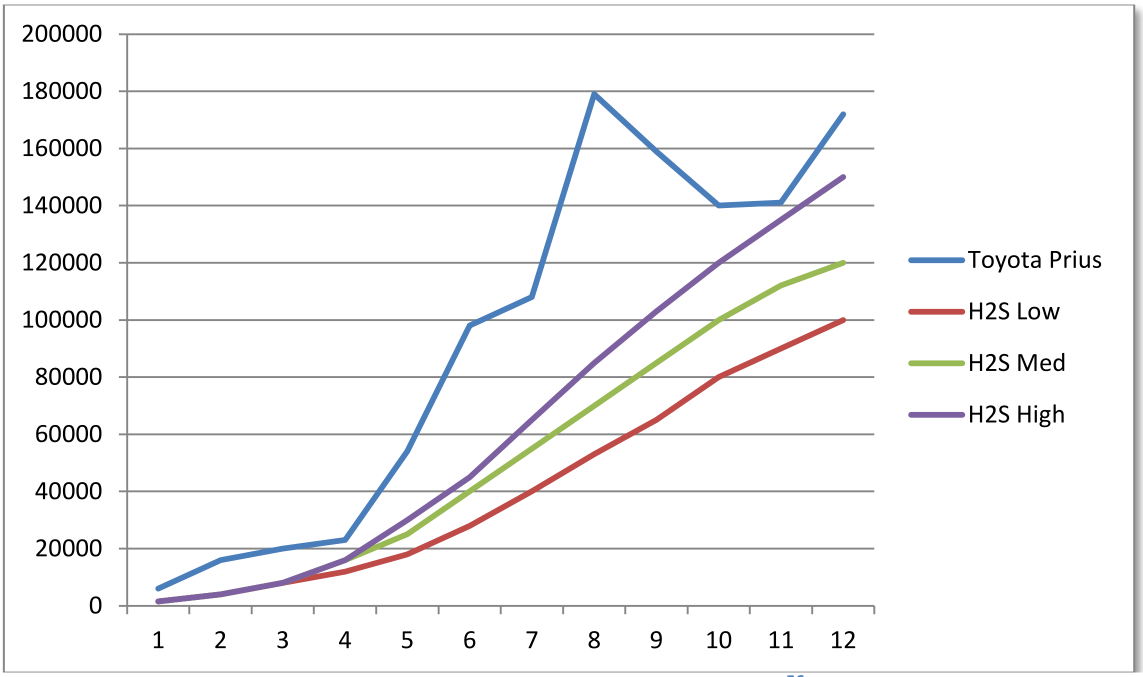

Figure 19: Potential H2-Mobility Swiss scenarios vs. Toyota Prius[56]

On the other side of the scale stands emission regulation with 95g/km fleet average from 2020 that clearly will be enforcing technological change and thus help FCEV take-up. The Prius was essentially a one-off concept of a single OEM with a few late followers. FCEVs in contrast will be supplied by at least 6 large international vehicle manufacturers from the 2016/17 timeframe with more OEMs likely joining by 2020. Different to an ICE-Hybrid as the Prius, FCEVs can play out their performance, efficiency and environmental benefits under all major driving conditions and are not limited to urban cycle.

The comparison thus suggests both, strong pros and cons for FCEV uptake. For the H_2-Mobility Swiss scenarios, a more conservative approach was chosen recognizing the disruptive nature of FCEVs and the related infrastructure build-up. Special effects of the Prius sales curve due to the financial crisis between 2008 and 2010 were eliminated. By the end of the period, a certain flattening of the growth was considered, as the FCEV share of total vehicle sales may already be fairly high.

Following these assumptions and assuming an initial minimum hydrogen infrastructure, FCEVs could contribute with approximately 4 % of total vehicle sales by 2020 (compare table 6, p.26) establishing a total fleet of ~ 40 000 vehicles. After 2020, further growth would mainly depend on infrastructure take-up leading to a low, middle and high scenario. By the end of the next decade, FCEVs may establish a population between 500 000 and 800 000 vehicles in Switzerland, correspondingly.

The dimension of the required investment in the hydrogen infrastructure is not unprecedented and can be managed in a coordinated effort of public and private investors. More importantly, it will be investment in future competitiveness and prosperity in terms of maintaining a state-of-the-art transport system providing save, energy-efficient, economic, sustainable and convenient transport services.

The necessary amount for an initial H_2 refueling infrastructure in Switzerland assuming a network of approximately 15 HRS will be ~ CHF 15 Mio. depending on the exact number of HRS, the installed capacity of individual stations and whether or not HRS will be equipped with onsite electrolysis.

Infrastructure expansion in line with growing FCEV population until 2020 (40 000 FCEVs) may require further 20 - 25 HRS representing another investment of ~ CHF 20 Mio. depending on the same factors but assuming higher share of onsite electrolysis and improved economies of scale. This would increase the total number of HRS to 35 – 40 stations with focus on densely populated areas thus reducing the distance between stations in these areas to 25 km in average or less. It can moreover be expected that operation of the HRS may then already be fairly economic and allow self-sustaining growth past 2020. The total initial investment to kick-off the hydrogen refueling infrastructure in Switzerland may therefore amount to CHF 35 Mio.

The variety of energy sources for hydrogen production, particularly when produced from renewables, provides an instrument to reduce dependence from crude oil, massively improve energy efficiency of the transport system and strengthen energy security. With further ramp-up beyond 2020, FCEVs can improve the value added in Switzerland and Europe along two axes. Firstly, powertrains need new high-tech electric or electronic components as well as new innovative electrochemical or chemical materials based on advanced expertise and know-how. Secondly, the production of hydrogen based on the fluctuating renewables will increase domestic fuel production while reducing the demand for fossil fuel due to substitution and improved efficiency.

Thus, the dimension of the change process goes beyond the transport sector. Hydrogen will play a key role for energy storage in the context of increasing shares of fluctuating renewable electricity production establishing a growing need for energy storage. Central and onsite electrolysis based on excess power will therefore provide a major pathway for hydrogen production and massively reduce production cost of hydrogen. It can then be used for either providing electricity to the grid or fuel to the transport sector thus generating a conversion between the energy and the transport system with benefits for both.

List of Abbreviations

ARB	-	Air Resources Board (California)
BEV	-	Battery Electric Vehicle
BfE	-	Federal Office of Energy
CEC	-	California Energy Commission
CAFCP	-	California Fuel Cell Partnership
CAPEX	-	Capital Expenditure
CGH2	-	Compressed Gaseous Hydrogen
DoE	-	US Department of Energy
CNG	-	Compressed Natural Gas
EC	-	European Commission
EMPA	-	Swiss Federal Laboratories for Material Science
EU	-	European Union
EV	-	Electric Vehicle
FCEV	-	Fuel Cell Electric Vehicle
GHG	-	Greenhouse Gas
H_2		Hydrogen
HEV	-	Hybrid Electric Vehicle
HRS	-	Hydrogen Refueling Station
ICE	-	Internal Combustion Engine
JV	-	Joint Venture
LCA	-	Life Cycle Assessment
LD	-	Light Duty
LH2	-	Liquid Hydrogen
KFV	-	Swiss Association of Fire Brigades
NEDC	-	New European Drive Cycle
NEDO	-	New Energy and Industrial Technology Development Organization (Japan)
NOW	-	National Organization for Hydrogen and Fuel Cells (Germany)
OEM	-	Original Equipment Manufacturer (Car Makers)
OPEX	-	Operational Expenditure
PHEV	-	Plug-in Hybrid Electric Vehicle
PSI	-	Paul Scherrer Institute
RfI	-	Request for Information
SAE	-	Society of Automotive Engineers
Sffv	-	Swiss Association of Vehicle Fleet Owners
SMR	-	Steam Methane Reforming
SRF	-	Steam Reforming
SUVA	-	Swiss Accident Insurance
SVGW	-	Swiss Association of Water and Gas Utilities
TCO	-	Total Cost of Operation
TJ	-	Terra Joule
TLCC	-	Total Life Cycle Cost
TWh	-	Terra Watt Hour
US		United State of America

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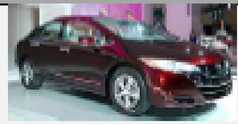
Appendix No. 1 – Overview of FC Cars of OEMs participating in H2-Moblity Swiss

	Daimler	GM/Opel	Honda	Hyundai	Toyota	Nissan
						
Roll-out strategy	Limited to 1000 vehicles until 2016, Germany, California, Japan…	No further demos, serial production delayed	Marketable FCEV by 2015	Limited to 1000 vehicles till 2015, Korea, Europe, California, after series	Vehicle launch from 2015 in Japan, Europe, California	Vehicle launch in coordination with Daimler from 2016/17
Vehicle Model	B-Class	Mid class or SUV t. b. d.	Purpose designed based on FCX clarity	iX 35 FCEV/SUV	FCEV-R - 4-door sedan	X-Trail FCEV, Nissan Terra
A Car Volumes						
2013				100	-	
2014	300			400	-	
2015	300		n. a.	500	Thousands	
2016	400	Thousands		Any volume	Thousands	n. a.
after	Thousands or higher demand driven				Goal 10000-s by 2018	
Sales conditions	Buy or lease	Buy or lease		flexible (pay down and lease)	n. a.	n. a.
H2 spec	5.0, SAE when available	SAE when available		ISO	5.0, SAE when available	
Tank pressure	700 bar	700 bar	350 bar	700 bar	700 bar	700 bar
Hydrogen mass	4 kg	~ 5 kg	< 4 kg	5.64 kg	6kg currently, reduction to 4…5kg next gen	
Vehicle range NEDC	500 km	500 km	460km	588 km	560 km Europe/780 km Japanese Cycle	800 km Japanese Cycle
Fuel efficiency NEDC	0.8 kg/100 km	1,3 kg/100 current 1,0 kg/100 next gen	0.8 kg/100km	0.96kg/100km	1.0kg/100km 0.8kg/100km next gen	
Certification	EU Type Approval	American Federal Motor Vehicle Association, by 2016 EU Type Approval		EU certificate by October 2012	TÜV currently, EU Type Approval by 2015	

Appendix No. 2 – Overview of FC Buses and Special Vehicles in H2-Mobility Swiss

	Daimler/EvoBus	VanHool	SEV
			
Roll-out strategy	Commercial sales from 2017	Limited production	Vehicle launch from middle of 2013
Vehicle Model	FC Hybrid CITARO 12 m	FC Hybrid 13 m	Midi truck Newton 7.5 – 12.0 t, BEV 8o kW with REX
Vehicle Volumes	Limited to 30 buses until 2015; after commercial volumes		> 600…2000/a 30 months after r. o. o.
Passenger Capacity	n. a.	104	-
H2 spec	5.0, SAE when available	5.0, SAE when available	SAE J 2719
Tank pressure	350 bar	350 bar	350 bar
Hydrogen mass	36 kg	38.5 kg	5 kg
Vehicle range NEDC	300…400 km	n. a.	260…300 km
Fuel efficiency NEDC	8...12kg/100km	n. a.	1.7kg/100 km
Certification	EU Type Approval	EU Type Approval	EU Type Approval