Schweizerische Eidgenossenschaft
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Federal Department of the
Environment, Traffic, Energy and Communications DETEC

Swiss Federal Office of Energy

Final report 26.11.2014

Swiss Hydrogen & Fuel Cell Activities

Opportunities, barriers and public support

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SFOE Contract number: SI/500952

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Opportunities, barriers and public support

E4tech
For the Swiss Federal Office of Energy
October 2014

Title	Swiss hydrogen and fuel cell activities – Opportunities, barriers and public support
Client	Swiss Federal Office of Energy (SFOE)
Date	October 2014
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Reviewer	Prof. David Hart
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Executive Summary

Switzerland has a small but internationally recognised set of competences and actors in fuel cells and hydrogen, from fundamental research to technology and product development. Swiss organisations are prominent in a number of research partnerships, and some have either major international co-operation or are partly or fully owned by overseas companies.

However, the sector in Switzerland remains somewhat fragmented, with many actors pursuing their own niches and relatively little cross-fertilisation or co-ordination. While companies can and do work directly with research organisations, the sector (and possibly the country) have not proven large enough to build or support more connected value or supply chains.

The Swiss Federal Office of Energy, in conjunction with other Swiss support organisations, provides funding for both research and development, and some for demonstration projects. It is generally well regarded and considered flexible and simple to deal with. It does not itself have a grand vision for how the sector could or should develop, typically being responsive to project suggestions. Such a vision is not necessarily part of its remit, but does seem to reflect a broader absence of strategic perspective regarding the fuel cell and hydrogen sector in Swiss energy policy and energy debate.

This project set out to understand the state of the fuel cell and hydrogen sector in Switzerland, primarily through interviews with relevant players, and put it into the context of global developments, through E4tech's industry knowledge and further research. An additional goal was to identify any major gaps or barriers to sector development, and to suggest options for closing the gaps or removing the barriers.

The assessment showed that financial support for the sector within Switzerland is generally judged to be appropriate and satisfactory. While some more could be done with greater funding, this was not considered to be a major constraint. However, the lack of overarching vision and context, and the highly fragmented nature of Swiss local markets, were seen as significant weaknesses. The lack of a co-ordinated approach to regulations, codes and standards has also hampered projects, as in some cases it is unclear where responsibility for these lies.

Our analysis suggests that Swiss fuel cell and hydrogen technologies and organisations could be valuably additionally supported by non-financial means in several ways. Most important amongst those were felt to be by:

- Analysing existing regulations, codes and standards relevant to a representative majority of fuel cell and hydrogen projects, ensuring they are maintained in a single location or understood by a single owner for ease of viewing, and streamlining them wherever possible (e.g. by harmonising across cantons or communes wherever relevant).
- Enabling *all* of the existing actors and support organisations to come together for frequent constructive meetings, with concrete outcomes, that can be acted upon to move the sector forward. These meetings may need to be facilitated and fit within a greater plan or vision.
- Developing such a greater strategic plan or vision, by enabling debate of the role of fuel cells and hydrogen in the local, regional or national energy mix and following it with structured analysis. This should lead to a clearer understanding of the roles that these technologies *could* play in Switzerland, and hence feed into the Energy Strategy for 2050.

While other, smaller, measures are also described, those laid out above were considered to be very important in enabling the actors within the Swiss fuel cell and hydrogen sector to create local markets and clusters, increase valuable interactions, and generate greater value.

1 Introduction

1.1 Context and rationale

Fuel cell (FC) and hydrogen (H2) products are emerging in several market segments, with a few applications already fully commercial, and many others at the pre-commercial stage.

Switzerland has a strong history in fuel cell and hydrogen (FCH2) research dating back to its earliest days, and some industrial presence. However, academic and industrial research and development has historically been somewhat *ad-hoc*, rather than taking the form of a directed or strategic programme. This has been – and may continue to be – an appropriate approach to supporting the sector, but the potential for FCH2 to play an important role within Switzerland or as an export market has changed over the recent past.

While the government is supportive of FCH2, with some dedicated budgets, funds are inevitably limited and should thus be apportioned as effectively as possible. In addition, as commercial products emerge, the need for non-financial support by the Confederation for the FCH2 sector has increased. Such support has so far been limited, as specific needs have not been identified.

A review of the scientific and industrial capabilities of the industry, and the barriers it faces with regard to these developing market trends, should enable a mapping of opportunities and an identification of potential opportunities for intervention.

This study therefore lays out the evolving status and prospects of the fuel cell and hydrogen sectors as regards the market, analyses the opportunities and barriers facing the community, and suggests options for decision makers regarding future support from the Swiss Confederation.

1.2 Objectives of the study

The overarching goal of this study is to provide evidence and suggest options to the Swiss Federal Office of Energy (SFOE) on where limited Swiss resources and non-financial support could be best directed to usefully support fuel cell and hydrogen research and industrial activities in the country. To achieve this, this report:

- provides a mapping of the Swiss ecosystem of activities in the fuel cell and hydrogen sectors;
- evaluates both the individual and collective capabilities of existing industrial and research activities in the field of Hydrogen and Fuel Cell (FCH2) technologies within Switzerland;
- identifies specific market opportunities at a high level, and over different time scales;
- assesses which R&D and pilot activities are most pertinent;
- identifies barriers to development or deployment of technologies and products;
- suggests support mechanisms which could help overcome these barriers.

1.3 Scope

The scope of the study is defined by its geographical reach, value chain coverage, and timing. While we have tried to inventory as much Swiss activity as possible with the resources available, it is inevitable that we will have missed some relevant actors, particularly in fields that are supportive of FCH but not necessarily part of the sector. We apologise to any organisations we have failed to include.

1.3.1 Geography

The study is focused on FCH2 activities that take place in Switzerland. However, these take place in a global context and when it comes to analysing the market opportunities for Swiss technologies and products, we also of course consider the export potential. The study also evaluates the international collaborations of the Swiss actors as part of the Swiss capability assessment.

1.3.2 Value chain

We consider the entire technology value chain, spanning materials to system integration. Further downstream, we also consider service providers with dedicated FCH2 knowledge such as technology-informed consultancies and specialised conference organisers. In mapping the activities, we use generic steps along the value chain (Figure 1), so that the same chain can be used to characterise all three sectors considered: fuel cells, hydrogen production and hydrogen storage.

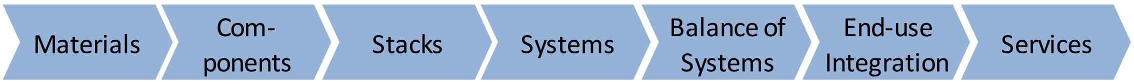

Figure 1 – Generic value chain used for the mapping of Swiss activities in the FCH2 sectors

Gas or power utilities are not included in the value chain if they act only as end users, but are included if they contribute to technology development and/or to the commercialisation of FCH2 products. We include both R&D centres and companies (material suppliers, equipment suppliers, manufacturers, system integrators, technology developers), as well as relevant associations.

1.3.3 Time scale

The focus of this report is today (2014), in the sense that it looks at measures that the Swiss Federal Office of Energy (SFOE) and other government bodies could take right now to support the development of the Swiss fuel cell and hydrogen sectors.

In fact the report considers mainly government actions that would *need* to be taken today to help the Swiss industry exploit market opportunities for commercial and early commercial applications of emerging hydrogen and fuel cell technologies. The relevant time-scale of this report is thus from today to about 2020.

Longer term options, represented by technologies that are currently still in the laboratories, are nonetheless discussed, in less depth, as appropriate.

1.3.4 Terminology – "FCH2" sector

Although recognising that the fuel cell and hydrogen activities cover many applications, based on a wide range of technologies, and addressing a number of market segments, we refer to all these activities as the "FCH2 sector" for simplicity.

2 Structure and trends of sectors

2.1 Introduction

This report covers hydrogen and fuel cell activities. The FCH2 sector is complex and broad, with inevitable crossover between certain technologies and applications. For the sake of structuring the information and the discussion we have chosen to split it into three sub-sectors. These in a sense represent three main steps along the full value chain of hydrogen as an energy carrier, from generation to use: hydrogen production, hydrogen storage and fuel cells.

To provide the relevant framework and context we first review some key features of current hydrogen markets, before discussing the market for hydrogen storage and fuel cells. The current hydrogen production and storage markets are primarily industrial, and heavily dominated by mature technologies with very well established providers. Fuel cells are very much an emerging technology. Thus the main opportunities across the board lie in the emerging applications and technologies. The current and emerging applications in each sector are reviewed in turn.

2.2 Current global hydrogen markets

Estimates of the value and size of the global hydrogen market vary widely within the range of 37 to 65 Mt of hydrogen annually, with a total value in the order of $100–150 bn per year. Refining and ammonia production dominate, representing 80-90% of total hydrogen demand, while the chemical industry, mainly methanol production, is the third largest market. All three of these large markets use almost exclusively so-called “captive” hydrogen, produced on-site for use in the same plant. This fact contributes significantly to the uncertainty in the total market volume estimates, as captive hydrogen use is typically not publicly reported and is thus challenging to quantify. The remaining 5–6% of the global hydrogen market serves other industries such as metallurgy, food, electronics, float glass, and generator cooling. Broadly speaking, these other industries make up the so-called “merchant” hydrogen market (although even in these industries, some users produce their own hydrogen on-site).

Almost half of global hydrogen production is from the reforming of natural gas. The other two main sources are the recycling of process off-gases and the gasification of coal. About 4% of global hydrogen is produced through electrolysis (Figure 2).

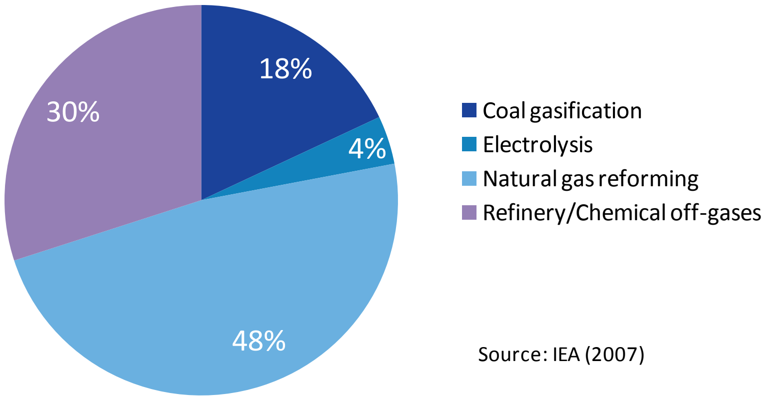

Figure 2 – Market share of hydrogen production technologies

While growth in some of the captive markets, such as refining, is expected to be significant, these markets will continue to be served by current production methods for a long time, and thus present limited opportunities for the introduction of new technology or for new entrants. Some opportunity for renewable hydrogen is almost inevitable, but it will only be competitive in the near term under very specific conditions.

2.3 Emerging hydrogen applications

Other than growth in the large, conventional and heavily conservative sectors above, a number of potential applications are emerging. These are related to the use of hydrogen as an energy vector rather than as a chemical feedstock. The two most significant are in hydrogen production for refuelling of fuel cell electric vehicles (FCEV), and in the use of water electrolysis in so-called "power to gas" applications – more broadly in providing services to the electricity grid.

Light duty vehicles and buses powered by fuel cells (FCs) are considered very important in meeting both climate and air quality regulations. These are not yet fully commercial, but a number of automobile manufacturers, including Honda, Toyota, Daimler, and Hyundai, have announced plans for commercial sales of FCEV cars in 2015–2017. Buses are increasingly being deployed in supported programmes in cities across Europe and elsewhere. Similarly, about 120 hydrogen refuelling points of varying public accessibility exist across Europe (EC, 2013) and there are plans (e.g. the H2Mobility programmes in various European countries) to deploy hundreds of public hydrogen refuelling stations between now and 2030. Hydrogen for these stations will either be produced in centralised reforming plants and delivered logistically or by pipeline, or produced using more localised methods such as electrolysis. In some aggressive scenarios such as developed in the *Portfolio of Powertrains for Europe* study, as many as 35 million FCEV cars could be on the road globally by 2030. Such a fleet would require on the order of 3 Mt of hydrogen per year, roughly equivalent to the size of the current merchant hydrogen market.

Another possibly significant opportunity is related to the increased proportion of intermittent renewable electricity generation on electricity grids, expected due to efforts to decarbonise electricity production. While there is no unanimity on the issue, some expect that the increased fraction of intermittent generation capacity will require the addition of significant storage capacity to help absorb some of the fluctuations in electricity production and demand. In this context, hydrogen is seen as potentially one of the lower cost solutions to providing large scale energy storage.

2.4 Hydrogen production: Emerging technologies and markets

2.4.1 Water electrolysis

Water electrolysis, used for industrial hydrogen production for over a century, was once the preferred method for hydrogen production. Over time it has been largely displaced by lower cost methods such as the steam reforming of natural gas. Nonetheless, a number of different water electrolysis technologies are available commercially, primarily serving the metallurgy, food, electronics, and float glass industries as well as being used for generator cooling and in laboratories.

Water electrolysis technologies are distinguished by their chemistry. Alkaline electrolysis is the historic technology that uses an alkaline liquid electrolyte as the medium for the electrochemistry. The other main technology, PEM, or polymer electrolyte membrane, uses a typically acidic solid polymer electrolyte. Both of these technologies are available commercially in system sizes ranging from less than 1 kW of electrical input to several MW.

Our internal analysis suggests that the global electrolyser industry is very fragmented with about 30 SME players, including a number of new entrants, sharing a global market worth about 100–200 million USD annually. The ten largest players take up about half that market but electrolyser manufacturers predominantly serve niche, local, markets.

Water electrolysis can produce high purity hydrogen for use in fuel cells, and if renewable electricity is used then this can also have a very low carbon footprint. Low-carbon hydrogen is seen as a possible key ingredient in the decarbonisation of light duty vehicle road transportation, and so distributed hydrogen production for the refuelling of fuel cell electric vehicles (FCEV) is seen as a major potential growth opportunity.

Another significant potential opportunity is for water electrolysers to be used to provide energy storage or services to the electricity grid. Here, electrolysers could be used as sheddable loads or to absorb excess electricity. One example is so-called “power to gas” where electrolysers convert excess electricity into hydrogen which is then injected into the natural gas grid.

2.4.2 Small scale reforming

Reforming of natural gas and other hydrocarbons to produce hydrogen is the primary means of production. The technology is mature, but almost exclusively requires large scale process equipment. Applications such as small-scale fuel cell CHP, distributed backup power generation and distributed hydrogen production for FCEV refuelling could benefit from smaller-scale reforming. A number of technology developers are working on technology solutions that are cost effective at small scales. Some of these markets are close-coupled with the end-use technologies, such as in the Japanese residential fuel cell CHP units, while others are only now starting to emerge, such as refuelling stations for materials handling vehicles.

2.4.3 Other emerging technologies

Other, more esoteric options are being considered for hydrogen production. These include very high temperature processes where thermal energy is the main contributor to splitting the hydrogen-oxygen bonds in water; direct photoelectrochemical steps, where sunlight is used to directly liberate hydrogen from water without using a separate electrolyser; and biological routes using respiring algae. These are generally some way from commercial competitiveness but are nonetheless interesting in the long term.

2.5 Hydrogen storage: Current and emerging technologies and markets

Traditionally hydrogen has been stored using relatively low pressure vessels (gas cylinders, tube trailers) or in liquid form. However, the emerging applications for hydrogen discussed in Section 2.3 have different technical requirements, so new solutions are being developed.

For transport applications, key technical requirements are safety, and high volumetric and gravimetric energy densities. Following considerable research, the automotive companies have standardised around high pressure (70MPa) gas cylinders for cars, though some other vehicles use 35MPa tanks. These very high pressure vessels made light weight by using advanced materials such as composites, with either metal or polymer liners. They are available commercially in a limited manner.

Other applications may also use low or high pressure cylinders, but can accept other approaches. The second main approach is the use of metal hydride materials that can adsorb or desorb large quantities of hydrogen through the removal or addition of heat. These are typically heavier than compressed gas tanks for the same amount of hydrogen stored, but store more per unit of volume, which can be advantageous for ground storage systems. While some metal hydride storage systems are available commercially; more advanced and esoteric hydrides are still in the development stage. For energy storage applications, the emphasis will be on very large storage volumes. The primary options discussed in this context are injection into the natural gas grid, such that the existing natural gas grid infrastructure acts as the storage vessel, and storage in underground caverns.

2.6 Fuel cells

Fuel cells are beginning to be deployed in a number of both stationary and mobile applications. Several different types of fuel cell exist, of which two – the molten carbonate (MCFC) and alkaline (AFC) – are gaining some commercial traction but are not being pursued in Switzerland. Of the others, the most relevant are the polymer electrolyte membrane fuel cell or PEMFC, and the solid oxide fuel cell or SOFC. The former operates at low temperature, usually on pure hydrogen, and is deployed in transport and some stationary applications, while the latter is particularly suited for heat and power generation. The key aspects and drivers of the most significant markets are summarised below.

2.6.1 Current applications

Materials handling: Fuel cell powered materials handling vehicles in warehouses are the main market where fuel cell systems are currently commercially viable without policy support. In these applications, the FC lifts replace battery powered vehicles and, by eliminating productivity losses and costs associated with battery charging and switch over, can result in substantially lower operating costs. The materials handling market is undergoing significant growth: in 2012, US companies ordered about 2,000 FC materials handling vehicles, and orders at this level are being sustained. The materials handling market is dominated by PlugPower, with more than 80 percent market share. PlugPower currently sources its fuel cells from Ballard and integrates them into forklift systems.

Prime power: In prime power applications, FC systems are used as distributed power plants that can replace a grid connection, provide grid stability or reinforcement. Most prime power FC installations are in the United States and South Korea, where favourable policy conditions provide sufficient support for the systems to be commercially viable. This market has been dominated by three players: Bloom Energy, using SOFC systems, ClearEdge Power, which recently ceased activity but whose assets have been acquired by Korean company Doosan, and FuelCell Energy, which is the only company in the world to have a near-commercial MCFC.

Residential CHP: The residential FC CHP market is dominated by the ENE-FARM initiative in Japan. This initiative, supported by a tapering government subsidy, had deployed about 70,000 units in Japanese homes as of early 2014. The units, manufactured by consortia led by Toshiba and Panasonic and including Tokyo Gas and Osaka Gas, are integrated systems that run off natural gas, LPG or kerosene. They are primarily PEM-based systems with an electrical output of 700 W – 1kW and a large hot water storage tank and back-up boiler, though some SOFC units are also being sold, and this is expected to increase. The two technologies have different characteristics, with PEM the more mature and considered by some companies to be more robust. SOFC however offers higher-grade heat output and a possibly cheaper system. With strong support for each option it is very likely that they will continue to coexist and fill slightly different niches within the CHP market.

The rate of deployment in Japan has increased rapidly in recent years, with almost 20,000 units deployed in 2013. Korea has also had a major government-supported programme, but lags the Japanese by several years.

The Japanese companies mentioned above, in addition to others such as JX Nippon, are also moving into Europe in partnership with local corporations, including Viessmann, Vaillant, and Buderus. Other fuel cell companies, such as Baxi Innotech, Ceres Power, Hexis, SOFCPower and CFCL are trialling residential FC CHP units in Europe, the US and Australia, but none have reached anywhere near the level of Japanese deployment.

Back-up and remote power: The other significant market where FC systems are deployed commercially, i.e. mainly without policy support, is in the provision of back-up power, primarily for the telecommunications industry. The base transceiver stations (BTS) that provide mobile phone coverage typically require an uninterruptible power supply (UPS). Traditionally this has been accomplished with lead acid batteries and/or diesel gensets in areas where the grid is absent or unreliable. However, FC systems can offer a lower total cost of ownership, particularly in harsh environments and remote locations. Significant growth is expected in this market as the rate of BTS deployment, particularly in developing countries with poor electricity provision, is accelerating (in 2013, 65,000 BTS were installed in India alone). This market represents an opportunity for fuel cell systems and hydrogen storage systems as well as potentially for hydrogen production systems, as a number of integrated electrolyser plus fuel cell systems are being developed and deployed.

The main players selling units for telecoms back-up include Plug Power (now also including ReliOn), Altergy, Ballard, Dantherm, Horizon Fuel Cells, Hydrogenics, and Electro Power Systems.

Portable and auxiliary power: Portable power FC systems range in size from less than 10 W to about 300 W and are typically currently fuelled from 'cartridges' using methanol, compressed or hydride hydrogen, or chemical hydrides. The most successful segment of the portable power market is for military applications where players such as Protonex, Ultracell and Adaptive Materials (part of Ultra Electronics) have all engaged in developing rugged FC systems to replace military field batteries. Horizon Energy Systems and Protonex have also been developing systems designed for use in unmanned aerial vehicles (UAVs). On the civilian side SFC Energy has a successful line of methanol fuelled systems designed to provide auxiliary power to recreational vehicles and boats, having shipped over 20,000 units by 2013[1]. Battery chargers for portable electronics are manufactured by MyFC, Horizon, and Intelligent Energy.

2.6.2 Emerging applications

The transportation sector is one of the "big prize" sectors for fuel cells and has strongly influenced technology development in PEM FC systems. Like battery electric vehicles (BEVs), fuel cell electric vehicles can use renewable (including zero-carbon) fuels and have zero emissions at point of use, thus also helping improve air quality. Also like BEVs, FECVs will require a new fuelling infrastructure and are currently more expensive than their conventional counterparts. However, FCEVs are strongly supported by many automotive companies because they can be rapidly refuelled (in 3-5 minutes) and have good autonomy (the best FCEVs can do up to 800km on a single fuelling). It is widely expected that they will coexist with BEVs and that each will offer the consumer a different set of advantages.

As mentioned in Section 2.3, many major automotive OEMs have announced their intention to launch commercial FCEVs between 2015 and 2017, though these will not be fully mature or cost-competitive. In contrast to similar announcements in the 1990s, however, the conditions seem more favourable for these launches to take place. For instance, a recent report by the California Air Resources Board indicates that automakers expect almost 6,000 FCEVs on the road in 2015 in California and that about 17,000 by 2016 (CARB, 2012). Similarly, the UKH2Mobility study suggested that annual sales of FCEVs in the UK of about 10,000 per year might be expected by 2020, and 300,000 units per year by 2030 (UK Mobility, 2013). In these markets, and in others such as Germany, programs exist or are being put in place to deploy hydrogen refuelling infrastructure. For instance, by 2015, Japan expects to have a network of 100 refuelling stations, California 68 and Germany 50 (Fuel Cell Today, 2012a), consistent with the expected FCEV fleets in those markets. The convergence of commercial vehicle launches, deployment of hydrogen refuelling infrastructure and policy support strongly suggests that FCEV market entry will indeed take place between now and 2020.

[1] E4tech estimate based on press releases and other data

3 Swiss capabilities

3.1 Objective

In this chapter we build an overview of the Swiss FCH2 landscape, focusing on understanding the strengths and weaknesses of the local industry. We use this as the starting point to identify opportunities, and barriers to their exploitation, for which appropriate interventions may be needed.

This overarching objective can be broken down into three sub-tasks:

- Inventory Swiss actors in the FCH2 sector
- Map these actors along the FCH2 value chain
- Assess the Swiss capabilities in the FCH2 sector

The approach taken to meet these objectives is described in section 3.2, while the analysis is detailed in sections 3.3 to 3.4 below.

3.2 Approach

3.2.1 Inventory

The actors involved in the FCH2 sector in Switzerland are identified based on a combination of in-house knowledge, literature review, interviews, desktop search and review by leading actors. The scope of this inventory is defined above.

3.2.2 Mapping

The Swiss actors identified are then mapped along the value chains defined in Figure 1. Colour codes differentiate specific characteristics (type of actor, size, etc.). This provides a view of how Swiss capabilities in the FCH2 sectors are distributed along the different relevant value chains, and further serves for the assessment of collective capabilities below.

3.2.3 Capability assessment

Here we have focused on assessing collective rather than individual capabilities. We cautiously compare Swiss capabilities against those of the global FCH2 industry landscape by considering and weighting the following criteria as appropriate:

Specific area(s) of expertise
Local and international linkages
Critical mass
Potential competitiveness
International recognition
Strength of IP
Technology game-changer potential

Capital intensity
Technical risk
Existing key partners
Ability to ramp volume
Track record in business development
Presence in key geographies

It should be stressed that it is not the purpose of this study to judge the strength of the individual FCH2 actors, although actors with particularly strong capabilities are mentioned, as they may play the role of catalyst for the wider industry.

3.3 Capability landscape

3.3.1 Hydrogen production

The mapping of the Swiss activities along the value chain of hydrogen production is presented in Figure 3, grouped by type of organisation. We inventoried 41 actors, comprising:

- 24 industry players
- 13 academic organisations (within which are 29 research institutes or labs)
- 3 service providers
- 1 association

The total number of employees within these 41 organisations who have full- or part-time activities related to hydrogen production is estimated at 460, but most of these are part-time. The actors are well spread geographically with activities in 11 cantons and the three main linguistic regions.

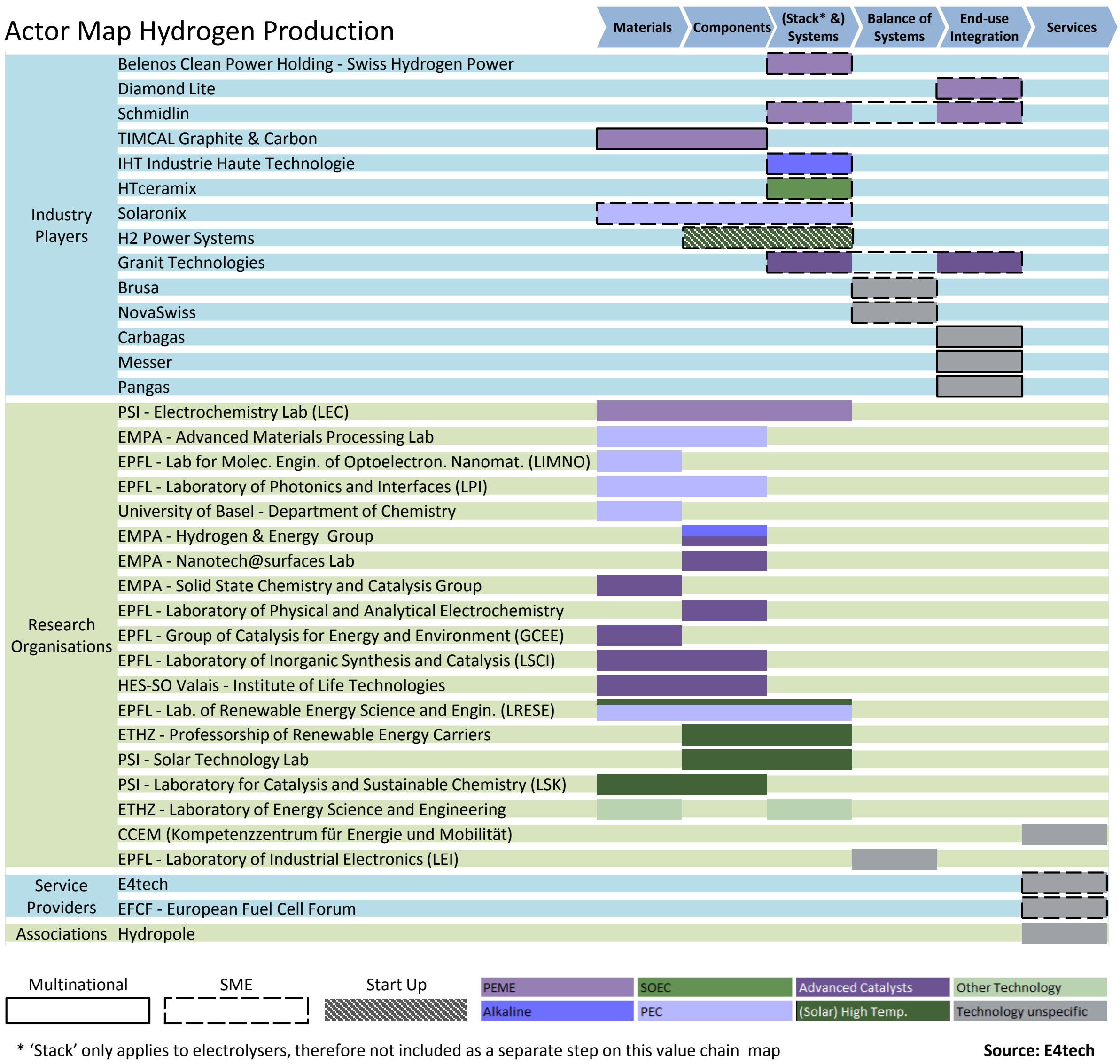

Figure 3 – Mapping of Swiss actors in the sector of hydrogen production along the value chain

3.3.2 Capability assessment

Industrial capabilities: In spite of the apparently large number of actors, the Swiss ecosystem of hydrogen production activities is highly heterogeneous. We could identify neither a collective core competence in terms of technology focus, nor a particular strength in terms of positioning along the value chain (see Figure 1).

Analysing the industry suggests that out of the 15 industry actors inventoried:

- Only 4 can be considered operating or wishing to operate as 'pure' hydrogen energy players (IHT, HTceramix, H2 Power Systems[2], Swiss Hydrogen Power), with the others running their hydrogen energy activities either ad-hoc (e.g. industrial gas companies), or as one market segment amongst several (e.g. material and BoP[3] suppliers). In addition, the 2 suppliers of balance of system solutions are all working in completely different technology areas, so the know-how generated is broad but diffuse.
- 6 are developing or supply proprietary system technologies, but again each is working on a different technology type (proton exchange membrane electrolyser (PEME), solid oxide electrolyser cell (SOEC), alkaline electrolyser, photo-electrochemical cell (PEC), advanced catalysis and high temperature water splitting.
- 4 actors are working on PEM electrolysis, but these activities are unconnected and thus cannot be said to represent a collective competence:
    - Schmidlin manufactures a PEM electrolyser for laboratory scale hydrogen supply which is sold worldwide under different brands
    - Belenos is developing a PEM electrolyser
    - Diamond Lite is not a technology developer, but distributes a US PEM Electrolyser product under licence, with little development activity in Switzerland;
    - TIMCAL is a generic supplier of carbon black materials, though it serves the fuel cell industry[4] with dedicated products for components.

Overall, few industry actors demonstrate obvious world-leading capabilities and none (apart from TIMCAL) appear to have the resources to penetrate the market on their own. It appears that most actors will therefore require some form of strategic partnership with larger industry players. In this regard, the presence in the value chain of industrial gas companies with international outreach including Air Liquide, The Linde Group and Messer (Carbagas is a subsidiary of Air Liquide, Pangas of The Linde Group) might potentially offer a pathway to the market for certain products. The majority of their current hydrogen activities are however largely disconnected from those of the other hydrogen actors inventoried. However, when collaborative opportunities with common strategic alignment have emerged, the gas companies have usually been participative. Hydrogen refuelling stations or power-to-gas projects are examples of such joint alignment.

Research capabilities: The research landscape is somewhat less dispersed than the industry ecosystem, both in positioning along the value chain, which shows a clear upstream clustering (the focus is on research and development of materials and components), as well as in research activities. These focus on 3 main topics:

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[2] Currently in stasis following the entry into receivership of the parent company

[3] BoP stands for Balance of Plant. In a fuel cell system BoP includes components such as fuel processors, chillers, system control and others, but not the actual stack

[4] Carbon black is used as support material for catalyst in PEM fuel cells.

- 7 labs from 3 institutions are working on advanced catalysts, potentially relevant to FCH2 technologies
- 4 labs from 3 institutions are working on photo-electrochemical cells (PEC)
- 4 groups from 3 institutions are active in high temperature water splitting

However, these competences appear to have limited connection with the existing industry activities further downstream in the value chain. Out of the 19 above-mentioned laboratories, only 3 have developed any formal relationship with an industry player, to the best of our knowledge.

In terms of individual capabilities, a majority of the laboratories inventoried are small entities with fewer than 6 people working on hydrogen topics. Although these mostly carry out valuable research with relevant IP generation potential, they offer limited exploitation opportunities in the short term. They are thus relatively far from directly generating commercial solutions that could address an emerging market within a 5 year horizon. This does not of course mean that any IP they develop might not be exploited more rapidly through licencing or other mechanisms by more advanced players, potentially outside Switzerland.

In addition to these small labs, a couple of research groups are much larger (>15 persons working on hydrogen topics), are well-established, and thus potentially have stronger R&D capabilities. Amongst these are the Electrochemistry Lab (LEC) and Solar Technology lab at PSI, the Professorship of Renewable Energy Carriers at ETHZ, and EPFL's Laboratory of Photonics and Interfaces (LPI).

Sector-wide capabilities: The hydrogen production sector in Switzerland clearly does have valuable academic and industrial capabilities, but these are very heterogeneous, with the consequence that the sector does not offer any obvious 'cluster' competences. Broadly it seems that the sector:

- does not have critical mass in any given technology;
- lacks a large and motivated industrial actor that could potentially play the role of gateway to the market for novel technologies, although the industrial gas companies present could potentially offer some opportunities;
- is characterised by limited (usually bilateral) relationships between complementary actors within the ecosystem, i.e. industry actors and labs. This in turn implies that
    - The (mostly upstream) R&D carried out in labs is largely disconnected from the (mostly downstream) industrial activity;
    - No network-type exploitation mechanism has been developed, although the Hydropole Association offers some networking links;

Because the overall Swiss capabilities in hydrogen production appear as isolated 'islets', no portion of the value chain has higher concentrations of capabilities which might represent a focus for development opportunities for Switzerland, and thus more possibilities for systemic intervention.

3.3.3 Hydrogen Storage

The Swiss ecosystem around hydrogen storage is composed of 14 actors, including (Figure 4):

- 8 industry players
- 4 public research institutes
- 2 service providers with specific FC&H2 knowledge
- 1 association

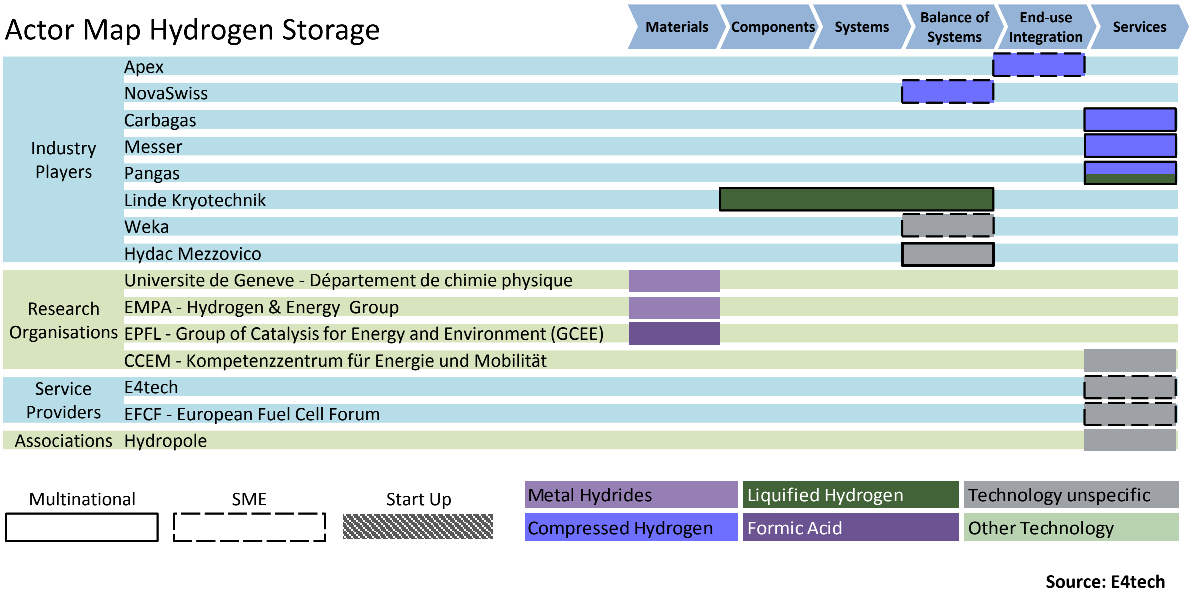


Figure 4 – Mapping of Swiss actors in the sector of hydrogen storage along the value chain

3.3.4 Capability assessment

The Swiss hydrogen storage sector is far less developed than that of hydrogen production, both in terms of number of people employed and number of actors involved. We estimate that around 100 people are active in the sector (one third of that in hydrogen production), though again the majority is only working part-time on hydrogen storage activities.

In addition to the small size of the sector, it is very dispersed in terms of technology focus and positioning along the value chain (see Figure 4), resulting again in limited collective competences in any given area.

In terms of individual competences, it is worth highlighting that:

- the research activities at EMPA on metal hydrides have generated many significant scientific publications and some relevant patents, and the experts have strong connections with the worldwide hydrogen solid state storage community, but has not yet yielded any commercial activities (spin-off or licensing);
- Linde Kryotechnik has strong specialised capabilities in hydrogen liquefaction, but is part of a large industrial group that require no specific public support and which is not necessarily likely to develop further strong industrial activities within Switzerland.
- Hydac Mezzovico is a supplier of specialised gas coolers and part of the Hydac group that has developed a tool which monitors particulate contamination in hydrogen flows. This is highly relevant to hydrogen refuelling stations; however, it is unclear which competences are available in the Swiss branch of this international player.

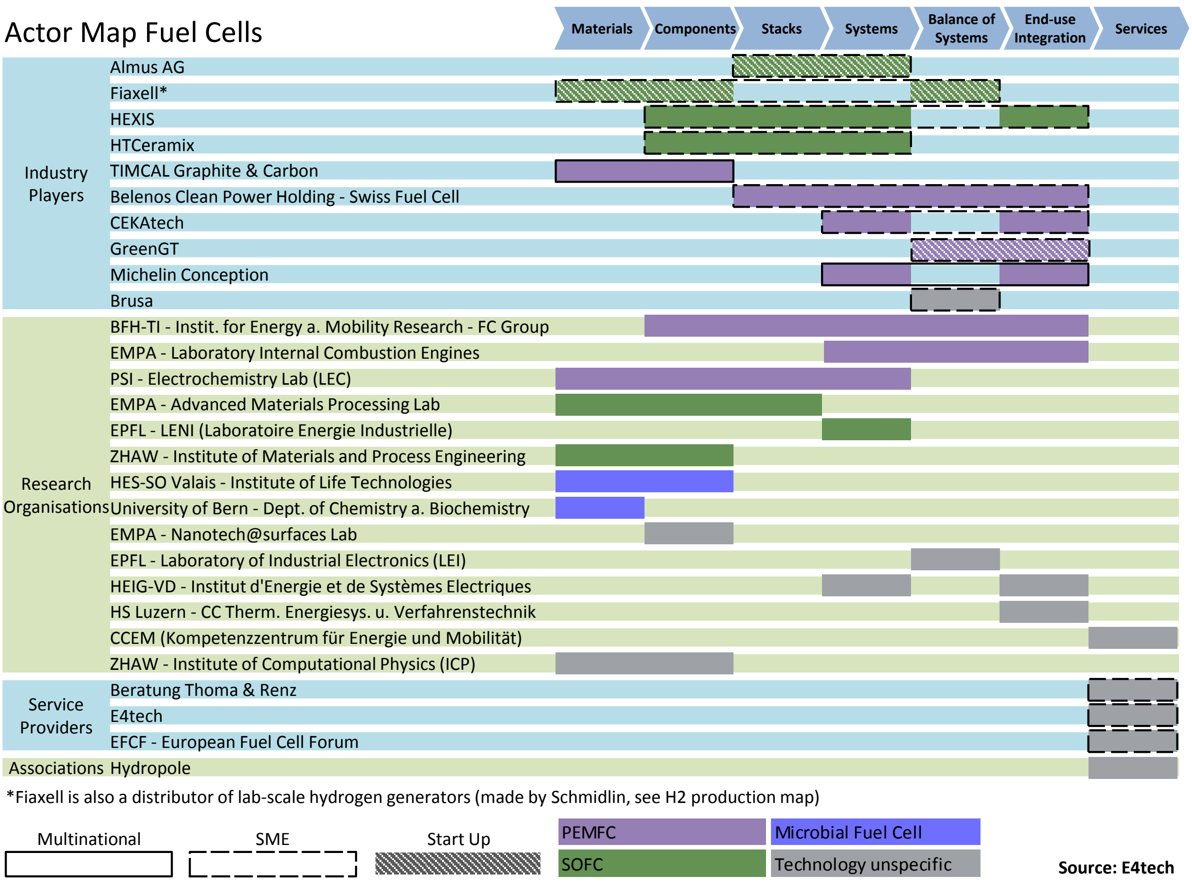
All in all, the sector offers relevant individual capabilities. However, the very heterogeneous landscape is thought unlikely to generate market opportunities based on collective competences, though advances in hydrogen storage technologies continue to be sought worldwide by those commercialising hydrogen energy applications.

3.3.5 Fuel cells

The Swiss fuel cell ecosystem, composed of 28 actors, is presented in Figure 5. The breakdown is as follows:

- 10 industry players
- 14 public research institutes
- 3 service providers with specific FC&H2 knowledge
- 1 association

The actors are well spread geographically with activities in 11 cantons and all three linguistic regions.



NB the LENI lab may soon be renamed JVH lab

Figure 5 – Mapping of Swiss actors in the sector of fuel cells along the value chain

3.3.6 Capability assessment

With a clear focus from both industry and academic actors on two technologies, the proton exchange membrane fuel cell (PEMFC) and the solid oxide fuel cell (SOFC), the fuel cell landscape appears less heterogeneous and somewhat more vertically integrated than those of hydrogen production and storage. In addition, the majority of the industry actors do have a product ready that addresses specific early commercial market segments.

In spite of this apparent clustering of competences, a closer analysis nonetheless suggests that these activities are actually quite heterogeneous in nature.

SOFC activities

SOFC activities are led by industry players Hexis and HTceramix[5], which together employ some 35 people, and which both develop micro-CHP systems for building applications. However, their respective design approaches differ widely and they are thus likely to address different market sub-segments. The SOFC sector also includes the two smaller actors Fiaxell and Almus:

- Fiaxell is a 3-person start-up which develops SOFC materials, components and subsystems, both addressing specific gaps they observe in the industry and responding opportunistically to openings.
- Almus also develops specific SOFC technology but sells mainly educational SOFC kits, and does not appear to have strong growth ambitions.

The activities of these four actors are not currently linked, but some benefit might be gained from collaborative work.

Swiss academic capabilities in SOFC are strong but limited to a few people and organisations. They can be considered as mostly complementary in terms of positioning along the value chain. However, this complementarity does not appear to be exploited through strong collaboration between the labs.

The industry-academic relationship is relatively straightforward. EPFL's Industrial Energy Systems Laboratory and EMPA's Advanced Material Processing Laboratory carry out their own research and provide support to HTceramix and Hexis respectively. The institute of Material Process Engineering at the Zurich University of Applied Sciences (ZHAW) also conducts fundamental research, much of which is linked to the Hexis design, and Hexis also collaborates with FHNW[6]. A strong and direct link has existed between PSI and Belenos for several years.

PEMFC activities

Belenos and Michelin Conception are the most visible industry players in the Swiss PEMFC landscape. They have both historically been involved in mobility applications, although Belenos is also targeting stationary applications, in part based on an O2/H2 fuel cell. Both companies have strong in-house R&D capabilities and significant resources, and have developed their own IP. However, neither has an advertised commercial product and their respective business development strategies are not communicated publicly in any detail.

The landscape of system developers is complemented by CEKAtech and GreenGT who both carry out system development and integration, While CEKATech has its own stack technology, GreenGT integrates stacks from others. Both are focused on near-term commercial opportunities, and both are close to selling products:

[5] HTceramix is 100% owned by Italian-based company SOFC Power, but conducts all of its R&D in Switzerland.
[6] the University of Applied Sciences and Arts Northwestern Switzerland

- CEKAtech is a long-established industrial company active in a range of sectors, although its fuel cell activity is much more recent. It has developed a FC-powered train coffee trolley for elvetino, which has now reached an early commercial stage. CEKAtech has the potential to tackle other portable applications with its technology, but has currently very limited resources dedicated to its fuel cell activities.
- GreenGT is dedicated to the development of fuel cell racing cars and other high power specialist mobile applications. They have a first homologated prototype vehicle and some industrial projects.

In addition to the above actors, TIMCAL is a leading industry player that supplies carbon black to the fuel cell industry, as it does to PEM electrolyser developers. TIMCAL also seems to be moving slightly downstream in the fuel cell value chain with some early R&D activities dedicated to the fuel cell sector.

Swiss academic capabilities in PEM are qualitatively strong but limited to relatively few people and organisations, as with SOFC. PSI's Electrochemistry Lab focuses mainly, though not exclusively, on sub-stack level work, BFH-TI is looking into system engineering and EMPA's Internal Combustion Engine Lab is active in system integration and demonstration. These three key PEMFC actors in Switzerland complement each other well. They are also very well linked and cooperate on specific projects.

- The Electrochemistry Lab at the PSI has strong competences in both low temperature and high temperature PEM fuel cells. The focus is on applied research and development at the membrane and cell level, while stack and system engineering would typically be conducted by a third party. The EMPA lab has partnered with industry (e.g. CEKAtec, Belenos) to jointly develop and commercialise products. The electrochemistry lab also has strong capabilities in material analysis and cell level diagnostics, for instance used in durability measurements of MEAs[7].
- The capabilities of the Fuel Cell research group at the BFH-TI[8] are concentrated around endurance testing of fuel cell stacks and systems. In addition, the group has worked closely with CEKAtec on the commercialisation of PEMFC systems.
- The Internal Combustion Engine Lab at EMPA has integrated PEM fuel cells into a municipal utility vehicle and led the corresponding demonstration project, conducted in collaboration with industrial and academic partners, including the Electrochemistry Lab at PSI.

Other fuel cell activities

A few Swiss actors do not specifically target fuel cells, but do supply certain components for use in fuel cell systems: Brusa is specialised in highly efficient power electronics, DC/DC converters, electric motors and other components required in electric vehicles, including fuel cell electric vehicles. On the academic side, some research on microbial fuel cells is ongoing, which is a long-term research topic worldwide.

[7] Membrane Electrode Assembly
[8] Berner Fachhochschule Technik und Informatik

Sector-wide capabilities. Although there is a clear focus on two overarching fuel cell chemistries (SOFC and PEMFC), the specific underlying technologies developed differ widely. The industry players are developing different products, and addressing different market segments and applications. As a consequence, there is limited collaboration between the different industry players, and limited interaction between the academics and the industry, though the sector is small enough that all of the actors know each other to some degree. Of course, some collaborative projects have taken place, and others are ongoing, but the Swiss fuel cell landscape can appear to some extent as a patchwork of individual actors. Although some of the individual capabilities are relatively strong, with ongoing IP generation, the exploitation opportunities are not always fully clear.

3.4 Conclusion on Swiss FCH2 capabilities

3.4.1 Individual capabilities

Overall, academic laboratories do good science and industry players do good R&D with strong technology understanding. For both the academia and the industry, the individual R&D capabilities are relatively well reflected by the actual size of the teams involved in labs and companies. The industrial ecosystem is exclusively constituted of small players, with teams of fewer than 25 individuals working on FCH2 aspects[9]. The majority are in fact small actors, as 19 out of 24 industry players have fewer than 10 individuals involved full- or part-time in FCH2 activities.

This suggests that most industry actors lack the critical mass to ramp-up production and to develop channels to market on their own. Partnering with strategic players is thus likely to prove essential for most players who reach the commercial phase. Currently most players are at the demonstration or early commercial phase, and few yet benefit from strong partnerships or strong market access.

However, the interviews we have conducted suggest that the industry players have a sound understanding of the market needs for the applications they target. The situation is somewhat different in the academic world. We have observed, and this has also been confirmed to us by several of the industry players interviewed, that laboratories sometimes lack a sound understanding of market needs and techno-economic performance requirements for technologies to reach competitiveness.

Although it is beyond the scope of the study to assess in detail the quality of the intellectual property (IP), we estimate from both the interviews conducted and observation of the products developed that the sector has developed some strong IP. It is however uncertain whether this IP is currently exploited to its full potential.

3.4.2 Collective capabilities

The Swiss FCH2 ecosystem comprises 41 actors, of which 13 are academic (broken down into 29 different institutes or labs on the above maps), 24 industry players, 3 service providers and one association. An upper bound suggests that the sector ‘employs’ close to 460 people, though many are active only part-time on FCH2 topics. This figure should thus be interpreted as the number of people involved in FCH2 activities, and not as an estimate of the full time jobs in the sector, which is likely to be significantly lower.

Overall, the effort is somewhat stronger on hydrogen activities than on fuel cells. The counting is however rendered difficult by the fact that some actors work on both fuel cells and hydrogen,

[9] For non-pure players, we have only counted those individuals actually involved in FCH2 activities within the organisation.

leading to some double counting (Table 1). It is also interesting to note that the academia and industry are comparable in size.

However, the positioning of the academics differs from that of industry players. While the laboratories are largely and unsurprisingly positioned on the upstream end of the value chain (materials, components), the industry players are more concentrated downstream (system, integration, BoP, services) with relatively limited overall vertical integration. This is particularly visible for the hydrogen activities (see actor maps Figure 3 and Figure 4 above), although somewhat less marked for the fuel cell sectors, for which a higher correlation between academic and industry activities can be observed (Figure 5 above).

Table 1 – Estimate of the number of employees working in the FCH2 sector in Switzerland

	Fuel cells	H2 storage	H2 production	Across the three sectors *
In companies (incl. consultancies)	140	80	130	270
In academia and associations	100	20	150	190
Total	**240**	**100**	**280**	**460**

*the numbers per sector do not add up to the total across the three sectors, as some individuals are involved in more than one sector

Source: E4tech

Overall the FCH2 landscape appears highly heterogeneous both in terms of technology and applications targeted than in terms of positioning along the value chain. This implies that there is no strong area of collective competences, which suggests that there is no collective driving force through clustering of competences. Equally, there is no *collective* critical mass in any area that might offset the lack of *individual* critical mass already observed. It should however be noted that this is not atypical for an emerging sector with few commercial applications, with little or no consolidation. The structure of the FCH2 sector in other countries looks similar, with many smaller players active on many different topics and technologies.

There is clear lack of both a full value chain and supply chain within Switzerland. Although the latter might be considered a weakness for developing industry activities, in practice it is not plausible to imagine that all components and competences could be found in Switzerland, nor that they would be the best available. On the value chain side, in contrast, the limited number of leading industry players to act as channels to market, at least for certain applications, is a concern. In practice for some applications only a very few companies (e.g. ABB, Alstom) could play this role, for instance as an end-use integrator for uninterrupted power supply systems (UPS). To the best of our knowledge they are not currently heavily involved. International industrial gas companies, such as Pangas (Linde), Carbagas (Air Liquide) or Messer could also play useful roles, but have limited interaction with CH industry at this point.

Finally, relatively limited networking and collaborative activities take place between the FCH2 actors, compared to what can be observed in some other energy sectors, such as building physics. Some (mostly bilateral) collaborations exist between given laboratories and industry players and occasional networking events do take place, but these tend to be sporadic and no collaborative momentum is maintained in the sector.

However, it is not clear if there has ever been a need or driver for the sector to become more collaborative. Ccompanies pursuing FCH2 solutions in Switzerland have come into being for very different reasons: Hexis was originally a step-out development activity for Sulzer; HTceramix was a spin-off from EPFL; Belenos was the vision of a wealthy entrepreneur; IHT was producing on-site industrial hydrogen for Djeva; while Michelin Conception is akin to a 'skunk works' for a big corporation. These companies did not come into being due to any Swiss structural 'pull' for FCH2 development and so have not necessarily needed to develop in a collegiate manner.

3.4.3 International outreach

Swiss organisations have wide interactions internationally and some also have some influence in international committees, for example. Many of the academic institutions and individuals are recognised as having world-class capability, and are engaged in projects throughout Europe and further afield, on an individual basis or in consortia as part of e.g. FCHJU projects.

For companies the picture varies. Hexis and HTceramix are perhaps the most internationally active, participating in multiple funded projects in addition to their international ownership structures (HTceramix by SOFCPower, and Hexis with its investment from Viessmann). Other relationships are inevitably confidential, such as when overseas organisations require consulting support or partnership on technology development. Some of the smaller company activities (e.g. that of CEKAtech) are primarily within Switzerland and their international ambition is currently limited.

Switzerland is also actively involved in some international activities, such as the IEA Hydrogen Implementing Agreement and in FCHJU Committees. The SFOE publishes yearly report on FC and H2 activities, including a summary of national activities, and Hydropole publishes summaries of Swiss activity in different sectors, available for download by anyone who wishes, and has historically represented Switzerland at some hydrogen and fuel cell events, though this activity has diminished. E4tech publishes an annual high level Review of the Fuel Cell Industry[10]. The annual European Fuel Cell Forum in Lucerne is an important international outreach event, as well as an information and knowledge exchange opportunity. Further specific international activity takes place, for example, through the ModVal Symposia for *Fuel Cell and Battery Modeling and Experimental Validation*.

While these activities are valuable in their own right, and essential to bringing increased external understanding and exposure, they do not necessarily appear strategically co-ordinated. It is not clear that there is any structured mechanism for information flow within the entire FCH community, nor systematic representation and outreach. While Swiss influence is significant on some FCHJU committees, for example, no structured representation or reporting out across the FCH community is apparent. It may be that increasing Swiss visibility and creating or exploiting additional opportunities could come about through a more targeted approach.

[10] www.FuelCellIndustryReview.com

4 Opportunities and barriers for Swiss FCH2 capabilities

4.1 Objective and approach

In this chapter we identify opportunity areas for Swiss industry, including those where players might develop a high added value or distinctive capability in emerging FCH2 markets. The relevance of Swiss capabilities is then assessed by mapping the Swiss collective capabilities assessed in Chapter 3 onto the market trend maps discussed in Chapter 2. We have considered both possible competitive advantage in export markets, and how this global opportunity might be reflected or initiated at Swiss level. The analysis is focused on applications currently being targeted by Swiss industry, but also assesses opportunities for Swiss actors to address other applications for which their technologies may demonstrate a high added value.

The focus is on industrial activities, but we also discuss the longer term potential for early-stage technologies still in laboratories.

Finally, we identify capability gaps and barriers to deployment that may prevent identified opportunities from being exploited. These may include:

- A mismatch between technical capabilities and technology needs;
- a mismatch between product offering and market needs;

Barriers are identified both through in-house expertise, and on the basis of the interviews conducted with a large number of stakeholders.

4.2 Opportunities for Swiss industry

We have mapped the majority of applications targeted by Swiss FCH2 suppliers onto the market trend map shown in (Figure 6). This provides an overview of the matching of Swiss activities with regard to short and medium term market demand.

Only those activities addressing clear and specific applications have been mapped. Opportunities for upstream technology developers and suppliers (material, component, generic BoP suppliers, suppliers of technical services such as modelling or testing), who can supply system developers more or less irrespective of the application they target, do not appear, because they are potentially relevant to such a wide range of applications and actors that they dominate the map. Instead they are discussed below.

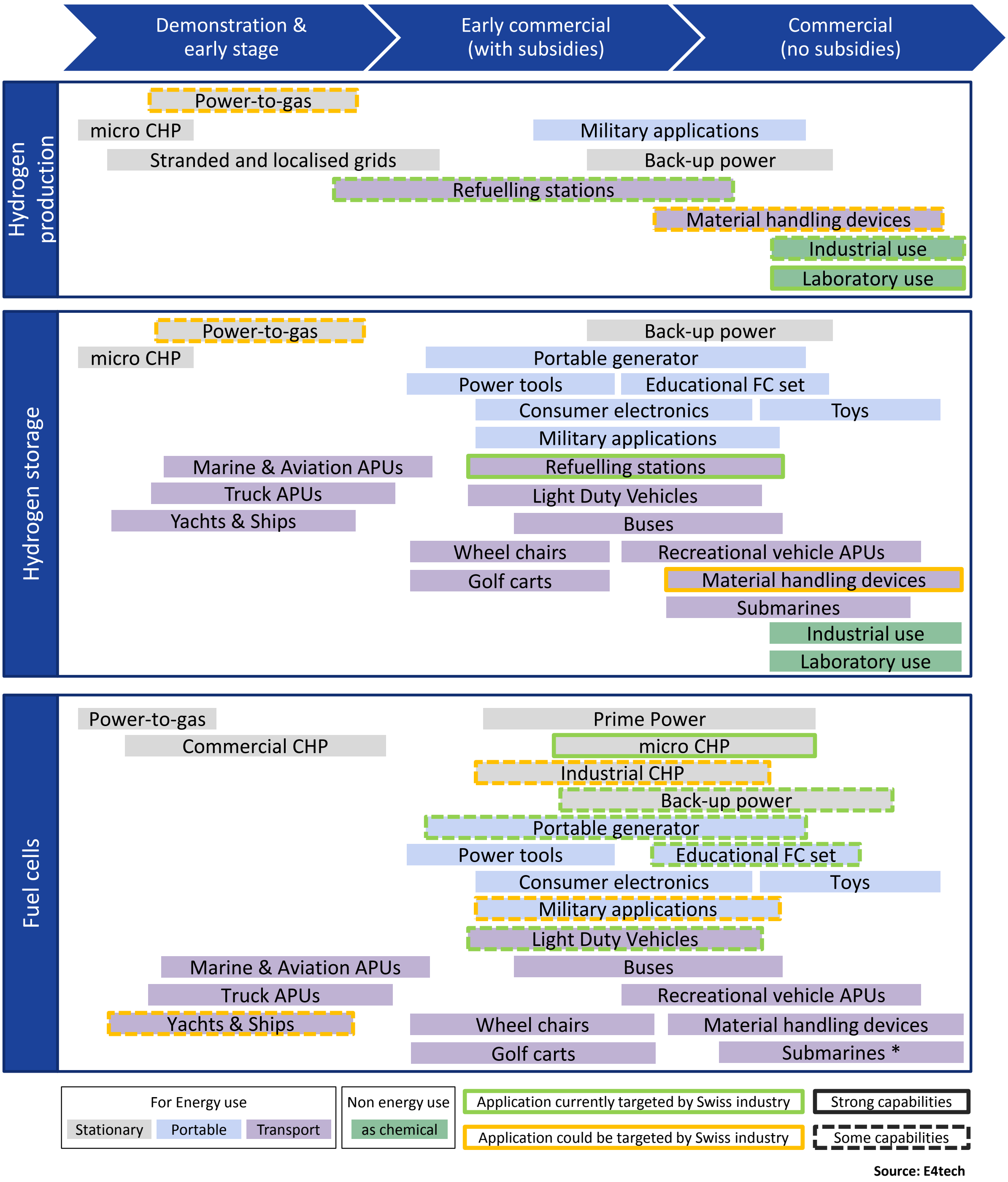


Figure 6 – Swiss capabilities in the FCH sectors with regard to global market trends

It is important to note that Figure 6 refers to applications and not technologies, and in some cases uses current common terminology which is perhaps not completely indicative of the scope of the application. For example 'power-to-gas' refers typically to a wide range of applications which include the production of hydrogen and its direct feed into the natural gas grid, but also local hydrogen storage and re-electrification through a fuel cell, and potentially its use for refuelling vehicles. This explains why it appears in each of the boxes above, which is perhaps not intuitive.

By inspection of Figure 6, we can see that the applications currently targeted by the Swiss FCH2 industry are well aligned with current market trends. Swiss industry players seem to have particularly relevant capabilities with regard to market needs in the following three segments:

- Industrial hydrogen;
- Transport applications, including vehicles and infrastructure;
- Micro-cogeneration.

Given this match, these three areas do in principle represent opportunities. These are discussed in more detail below.

4.2.1 Industrial hydrogen

A few players in Switzerland already target industrial hydrogen markets. The market for delivered hydrogen for industrial applications in Switzerland is largely covered by the global industrial gas companies through their Swiss branches Carbagas (Air Liquide), Pangas (The Linde Group) and Messer. These companies are also active in onsite hydrogen generation. Diamond Lite, by contrast, is a smaller player dedicated to onsite gas generation solutions including hydrogen, initially for industrial markets but which are also relevant in hydrogen energy.

While the markets for industrial hydrogen are not expected to grow significantly – neither globally nor in Switzerland – they provide the baseload income for many players to develop businesses in more speculative areas. One specific player is Linde Kryotechnik, a Swiss-based subsidiary of The Linde Group which is a global leader in gas liquefaction technology, focused on exports. Even without significant growth in industrial hydrogen volumes, Linde Kryotechnik may benefit from a trend in certain world regions to more liquefaction (as opposed to compressed gas) in industrial gas distribution. In addition, suppliers such as WEKA, who provide BoP components such as valves, measuring systems and cryogenic components, are also involved in the liquid gas business.

4.2.2 Fuel cell vehicles

Belenos, Michelin Conception and GreenGT have activities related to the development of fuel cell vehicles. While all three actors are system integrators, only Green GT is currently developing actual vehicles – race cars – as a commercial product, while the business focus of Belenos and Michelin Conception appears to be mainly on the development of components, stacks and systems.

GreenGT is developing products for niche high power markets, co-operating with suppliers and end-users as necessary. It intends to find its own pathway to the market. The Belenos and Michelin approaches appear more in competition with automotive companies – they are not especially well placed to act as Tier 1 suppliers, nor is this an easy route to take. If they wished to enter automotive markets on their own, however, they would need either to be very well-funded (hundreds of millions of CHF per year) or have a very sophisticated step-wise niche market entry strategy.

Although becoming part of the supply chain of the most advanced players like Toyota or Hyundai is unlikely without a game-changing product, opportunities may exist with those OEMs that are still building their supply chains (e.g. VW, BMW) provided the technologies offered can demonstrate a suitable value proposition.

Judging whether this might lead to an industry opportunity for Switzerland is hard:

1. The actual performance of the technologies developed by Belenos and Michelin is not public, though neither are any existing relationships they have with automotive OEMs (other than Belenos' arms-length purchases of Fiat vehicle bodies) nor detailed performance characteristics of current OEM technologies.
2. Neither Belenos or Michelin Conception (or their respective mother companies) have clearly communicated a strategy regarding which technology they might commercialise, nor whether they intend to further attack these potential market opportunities.
3. The potential (direct or indirect) economic benefit for Switzerland is unclear, should either of the above players make a commercial move, as it would in part depend on the level of supply chain development and industrialisation in Switzerland.

In addition to these system suppliers, it is worth mentioning Brusa, which develops and manufactures highly efficient power electronics, DC/DC converters, electric motors and other components for electric vehicles. They are recognised internationally for their high performance products and are already integrated into a number of FC development vehicles, for example. Given the right motivation, they might have the capacity to access opportunities in broader or other emerging commercial markets.

4.2.3 Refuelling infrastructure

Both Belenos (through its subsidiary Swiss Hydrogen Power) and Diamond Lite are active in decentralised hydrogen production, based on PEM electrolysers. While Belenos is developing its own system, Diamond Lite is an integrator and reseller using Proton Onsite's US technology, with exclusive distribution agreements for Europe. The future client base for refuelling stations, one of the emerging applications, is likely to be diverse and geographically segmented (mainly by country), which may make local market access easier than for component suppliers for fuel cell vehicles. However, many other companies, including the industrial gas majors, are positioning themselves specifically for this market, increasing competition. Although there have been announcements that several hundred hydrogen refuelling stations may be deployed throughout Europe in the coming decade, exploiting this mid-term opportunity will require continued presence in the currently rather small market, and a non-trivial investment in participation in relevant individual country and European activities such as H2Mobility.

Switzerland might possibly be able to offer an early market for refuelling stations, if heavy duty vehicle (HDV) and other specialised fleet operators decide to play the role of early adopters. PostAuto is currently running a bus trial, though wider bus adoption is unlikely to happen in the coming years without significant public initiatives or direct subsidy schemes. However hydrogen-fuelled delivery fleets could be an interesting option for improving the sustainability of some Swiss corporations.

Much of the value in a refuelling system is in the local economy in terms of gas supply logistics, personnel, etc. So although limited capability exists to deliver whole refuelling station solutions, the capabilities of Belenos and Diamond Lite are directly relevant. While the extent to which Switzerland would actually benefit economically from supporting this early market is not immediately clear, it could be carefully assessed.

In addition to the above, three suppliers, WEKA, NovaSwiss and Hydac Mezzovico develop and manufacture relevant BoP components in Switzerland. They produce liquid hydrogen valves, high pressure compressors, and gas coolers respectively. WEKA's valves are used globally in refuelling stations, while the others are potentially directly relevant for hydrogen refuelling and other hydrogen supply systems. These companies could therefore also benefit from such refuelling station roll-outs, whether or not in Switzerland, but need to be part of the ongoing European or global discussions.

4.2.4 Micro-cogeneration (CHP)

HTceramix and Hexis are both developing SOFC-based micro-cogeneration units, in good alignment with the early micro-CHP market that is emerging in Europe, with Germany and the UK looking to be early adopters. The two companies' technologies and respective value propositions differ significantly, as may their respective opportunities. So far Hexis and HTceramix have played the role of technology developers. Each company is partly or fully owned by an industry player outside Switzerland (Viessmann and SOFCpower respectively), and it is highly unlikely that all industrialisation activities would take place in Switzerland if this market takes off. However, R&D activities, in addition to high value engineering and design, could certainly remain and so value should be created for the Swiss FCH2 sector.

The systems are each applicable to slightly different commercial settings, but in principle could be well suited to providing cogeneration within Switzerland and contributing to wider energy and climate objectives. In order for this to take place a combination of strategic support and barrier removal would almost certainly be required.

HTceramix' technology may also potentially be suitable for industrial-scale CHP, which may represent an interesting medium term opportunity.

4.2.5 Other opportunity areas

In addition to the above three areas of opportunity, further market segments may offer interesting prospects:

- **Off-grid and back-up power**: the H2/O2 fuel cell system in development by Belenos may offer competitive advantage for UPS applications, though it is as yet unclear what specific opportunity this may represent for the Swiss FCH2 industry.
- **Portable generators**: CEKAtech may be able to tackle various (niche) applications with its portable fuel cell generator, benefiting from a longer autonomy and able to deliver higher power than incumbent batteries. They will certainly primarily build on their powered trolley, which has reached early commercial status, and may co-operate with elvetino in commercialising the trolley in other geographical markets.
- **Power-to-gas**: although no Swiss hydrogen player is currently developing power-to-gas systems in Switzerland, some of the competences available in Switzerland (system integration of onsite hydrogen generation, BoP components for hydrogen systems) may be suitable for this application. This may offer longer term opportunities, as any power-to-gas market would only emerge at scale in the next 5-10 years). It is also worth noting that Swissgas and Erdgas Zürich are active in Power-to-Gas demo plants in Germany and Denmark, respectively.

4.3 Opportunity for technical support and consulting services

Both technical (e.g. modelling, validation, testing) and technology-informed business consulting services are offered today to various international organisations (leading industrial groups, multilateral organisations, major energy companies, national governments, etc.) by research institutes (e.g. EPFL, PSI) and private companies (e.g. E4tech). The need for such services is likely to increase significantly in the coming decade, in line with the growing market opportunities offered by emerging FCH2 technologies.

These capabilities are today typically offered individually by the players involved. There might be an opportunity to attract more consulting work from international players and grow the skills and size of the sector, by offering and promoting joint complementary consulting services from relevant players. This would not only broaden the scope of opportunities that can be addressed but increase the mutual visibility and credentials of the Swiss actors involved.

However, the volume of services is likely to remain small in comparison to that of industrial activities. Nevertheless, it is sufficient to support or part-support a certain number of small organisations, and these services may also represent an interesting catalyst for R&D activities, both by increasing the international visibility of Swiss innovation in the FCH2 sector and by exposing more organisations to more opportunities through mutual introductions.

The matchmaking services offered by EFCF during the annual Lucerne conference are a further important contributor to the visibility of Swiss actors, and may also contribute to generating opportunities.

4.4 Swiss R&D activities in a global context

A range of FCH2 technologies, at different levels of maturity and with different potential future market reach, are attracting significant attention globally. These include, *inter alia*, SOFCs, PEMFCs, PEC and metal hydrides. We have taken an informed but necessarily subjective view of the relative effort in Switzerland versus that worldwide, to help us assess Switzerland's position overall. We have considered such elements as the amount of funding into a specific topic, the number of people engaged, patents and publications, etc. It has not proved possible to rigorously map these for the specific activities, as weighting each element is in itself a subjective exercise. We therefore give a qualitative perspective on these activities, to initiate further discussion.

We estimate that the depth and breadth of Swiss academic research into PEC and metal hydrides is broadly equivalent in terms of effort and support to that at the global level, i.e. Switzerland is not putting a disproportionately small nor large effort into these areas. The research carried out overall in Switzerland is of high quality and tackles relevant issues – though it is not clear whether the full potential of the IP is or can be exploited. The attention given to SOFCs and PEMFC, although significant, is felt to be lower in comparison to efforts in the global scientific community, which is both very large and very diverse.

Conversely, we believe that solar water splitting through high temperature thermal approaches receives proportionately more attention in Switzerland (even if this is much smaller than PEM or SOCF work) in comparison to the global research trend. This technology is in their early development stage, with no obvious application or market segments identified, though it may offer interesting prospects in the medium term. The Swiss research institutes active in this area seem well positioned to tackle emerging opportunities, but will need to continue their innovation to remain so. To exploit the technologies, at some appropriate point it will be necessary to identify market segments in which they develop competitive advantage.

Other activities, such as in PEME, alkaline electrolysis, microbial fuel cells and formic acid, are somewhat 'niche' both in the global context, and in Switzerland, where they are also only pursued by a small number of Swiss researchers.

Of special interest are a number of research activities in 'advanced catalysis'. Due to their fundamental nature, these activities cannot be directly linked to individual sectors of the FCH2 space or to specific applications, though they could be very valuable in several areas.

As before, we have not separated out some of the cross-cutting areas of research, such as in modelling, nor very fundamental and generic aspects like new catalyst discovery (even earlier in the research pipeline than the 'advanced catalysis' above) that is not necessarily specific to fuel cells. These cannot easily be represented but are included in the overall view of Swiss sector strength – the ModVal symposia discussed earlier form part of the assessment of strength in PEMFC, for example.

4.5 Barriers to deployment

Understanding the barriers to technology development and product deployment is fundamental to identify the most appropriate accompanying measures and framework conditions to alleviate these barriers, and hence support development of the Swiss FCH2 industry.

In this section we discuss the financial, socio-economic, market and regulatory barriers faced by FCH2 actors along the value chains identified earlier. Although the focus is on technology suppliers, we also consider service providers and research institutes, as they belong to the same ecosystem and their difficulties may indirectly affect the development of the sector as a whole.

We have not considered technical barriers faced by individual actors, as these cannot be addressed by systemic measures. Similarly, barriers of a generic structural or macro-economic nature (e.g. the strong Swiss Franc as a barrier to export, or the current uncertainty regarding the participation of Switzerland in the EU Horizon 2020 framework programme) are not discussed, as the focus is on barriers specific to the FCH2 sector.

The barriers identified are described in Table 2 and ranked in severity as follows: (1) minor: (2) mild; (3) major; (4) severe; (5) showstopper. The severity ranking reflects the impact of the barrier on the FCH2 sector as a whole, and not the impact possibly felt by individual companies.

We have identified 11 barriers, of which 5 have been ranked as 'severe' and 2 as 'major'. Although no showstopper issues have been identified, this analysis nonetheless indicates that the sector is facing issues that strongly impede its development. Most 'severe' issues are not financial, but are of a market, socio-economic or regulatory nature.

Possible mitigation measures that could be taken by Swiss government organisations (e.g. by the SFOE) to help lower these barriers are suggested in section 5.

Table 2 – Barriers to development faced by Swiss FCH2 industry and academic actors.

Barrier category	Barrier	Comment	Severity ranking
Financial	Some financing gap seems to exist between the SNF and the SFOE programme for oriented fundamental research. Such R&D activities can be considered 'too applied' by the SNF and 'too fundamental' by the SFOE, leaving an absence of support.	Materials research is a very important element of FCH2 R&D. It also corresponds to a position along the value chain where Switzerland is particularly strong, with a large concentration of both laboratories and industry actors. However, it is felt that insufficient funding is available for bridging a gap to what has been referred to as "applied fundamental research" by several of the actors interviewed during the course of this study.	3
Financial	Although an effort has been made in recent years to increase the funding available to pilot and demonstration units, many actors commented that money is accessible until proof-of-concept stage, but beyond that stage it is progressively more difficult to find, with nothing at all available to support market entry.	The lack of a big success story so far in the Swiss FCH2 sector, in addition to some past unsuccessful cases, also contributes to making it difficult to raise finance for project and demonstration projects.	3
Financial	It has been commented (and this is not unique to the FCH2 sector) that CTI projects are sometimes disconnected from industrial and market realities because academics may not have the same understanding of industrialisation processes and constraints as companies, nor move at the same pace	The academic perspective is also very important, and may equally not be fully understood by industrial actors.	2
Financial	Some start-up companies feel it is harder for them to access RD&D funding from the national programmes (SNF, SFOE, CTI) than it is for larger established organisations.		2
Financial	Although the FCH-JU programme offers interesting opportunities and access to strategic players, the low percentage financial contribution from this programme has made it difficult for some Swiss actors to take part.	This is not exclusive to the FCH-JU but also to other EU programmes.	

Barrier category	Barrier	Comment	Severity ranking
Market (Access)	There are typically few possible industry partners in Switzerland for players developing intermediate products (materials, component, sub-system, system) that need to be integrated into the supply chain of an end product. It can be difficult for Swiss players to establish contacts with and trigger the interest of potential strategic partners abroad.	Although the issue is particularly marked for start-ups, it is also faced by established companies, as well as for academics who have not yet developed a robust network of industrial contacts.	4
Market (Access)	Smaller players, or those with FCH2 as only a part of their activity are not always well informed of relevant international activities in the sector as keeping up-to-date is not a priority use of their budgets.		3
Market (Develop-ment)	The large number of often small actors in the energy industry (e.g. 750 electricity companies) and lack of a coherent overarching FCH2 strategy in Switzerland do not help the development of Swiss markets		4
Technical	Technology is sometimes developed with Swiss circumstances in mind, which may not bring competitive advantage in a global market.	Swiss price points and technology requirements can be different from most other countries, and some of the smaller players may not always be aware of the techno-economic performance required to reach competitiveness against both incumbent technologies and FCH2 solutions proposed by competing companies abroad.	3
Social	Lack of awareness and acceptance for hydrogen technologies	This issue has recurrently emerged during the interviews. The fact that no one, outside the FCH2 community, is aware of the current deployment status of FCH2 technologies is felt as a real hurdle. Moreover, confusion (e.g. linking all hydrogen with nuclear power) and misconceptions about hydrogen are common, making the life of project developers difficult.	4

Barrier category	Barrier	Comment	Severity ranking
Economic	Most emerging FCH2 technologies are not yet competitive and require some form of support to meet a market. No market entry support currently exists in Switzerland.	Only a few emerging FCH2 applications are commercial without subsidy today (e.g. fuel cells for toys, telecommunications backup and for material handing devices; electrolysers for submarines or laboratory use). 'Early commercial' applications benefit from support schemes such as feed-in tariffs or direct purchase subsidies in countries aiming to take a leading position in FCH2 technologies (e.g. micro-CHP in Japan and Germany).	4
Regulation	Widely differing or absent regulations, codes and standards (RCS) within Switzerland, and lack of international consent on the matter impedes the installation of pilot and commercial units, directly and significantly impeding industrial development.	Installation regulation currently varies by canton and even by communes. This impacts the deployment of hydrogen refuelling stations, the connection to the grid of FC-powered micro-CHP units, the availability and cost of insurance, and many other things. It also requires considerable time to investigate the relevant regulations and regulators.	4
Regulation	Experience in other countries suggests that as yet unknown Swiss RCS issues are likely to emerge, hindering future deployment of FCH2 systems.	This is not about barriers currently faced, but an anticipation of future issues. No severity rating is thus given.	N/A
Regulation	Customs issues for companies with cross-border activities	Companies with cross-border R&D activities often have to transfer not-yet commercial systems between their different premises in Switzerland and abroad, facing import duties and an administrative burden. This however is a concern for a minority of actors.	2

4.6 Conclusion on opportunities

Several opportunity areas have been identified for the Swiss FCH2 industry. To indicate how Swiss actors are positioned with respect to these opportunities, we have mapped the most promising Swiss industry activities against their current access to an 'appropriate' market (Figure 7). An appropriate market is a somewhat subjective term, chosen to represent a market that could reasonably sustain the activity or relevant actor. Thus a small niche player may have access to a small niche market, which we therefore term 'appropriate'. Those activities on the top right of the map reflect actors with both strong capabilities and market access. Those activities that lie on the bottom portion of the map can be viewed as 'opportunities' as they have not yet achieved their potential. The actors in the areas on the bottom right may be considered of particular interest as they have comparatively strong capabilities, but the barriers that need to be overcome for any actor – strong or otherwise – to achieve better market access may be significant and hard to overcome.

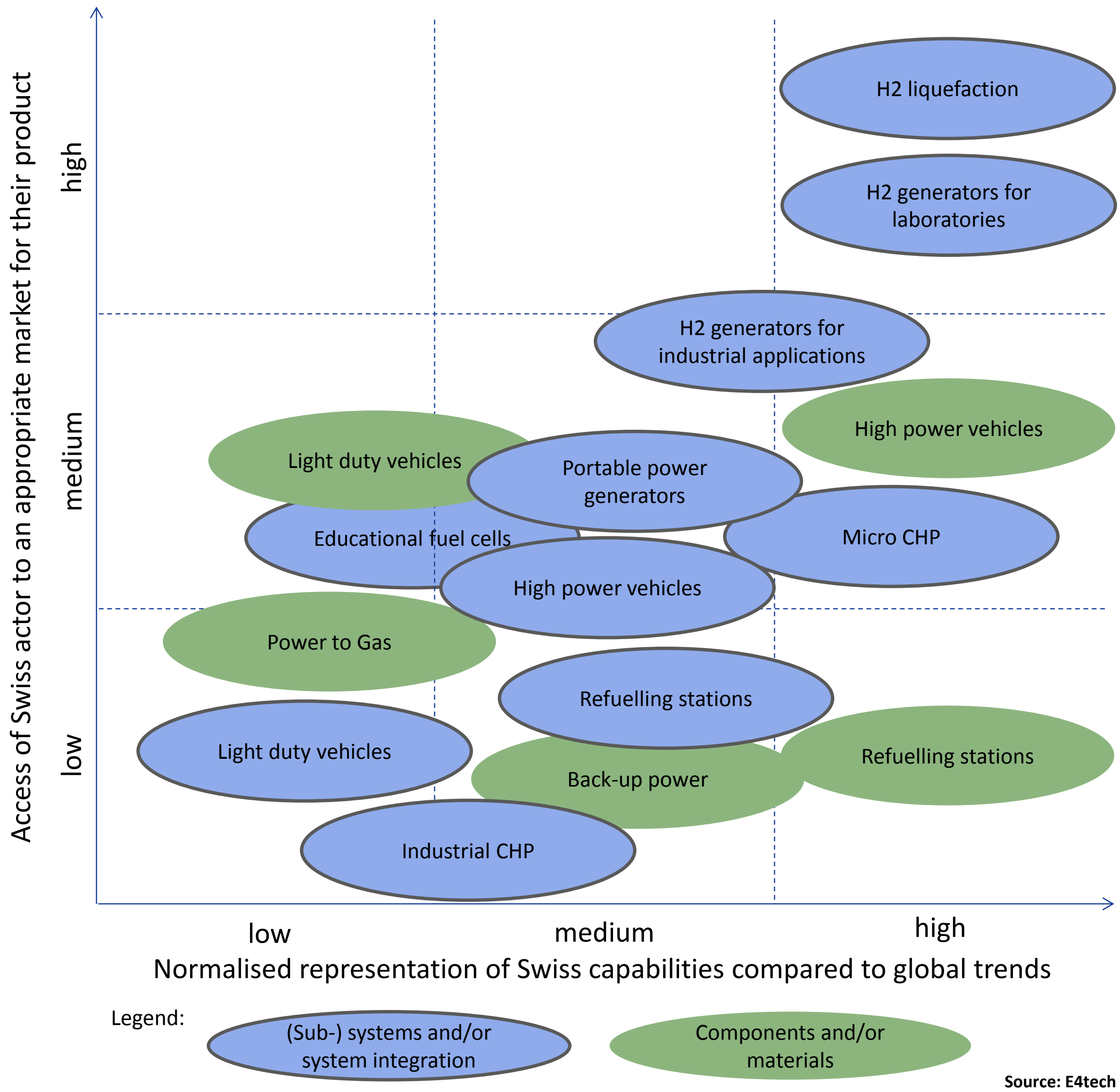


Figure 7 – Mapping of Swiss FCH2 activities considering the capabilities of the Swiss actors and their current access to an appropriate market

The access to appropriate markets is estimated by comparing the national or international reach of the organisation and the size of the market and comparing it to the size and ambition of the actor(s). The capabilities are normalised against the amount of effort/investment being committed to that market globally. e.g. Swiss actors currently have very limited access to international back-up power markets, though their intrinsic capabilities are comparable to many others globally.

All the short term opportunities are based on the capabilities of individual players, as no opportunities could be identified that require or build on collective capabilities. Certain market segments (e.g. refuelling infrastructure, micro-CHP) do offer opportunities to several actors, but each actor typically addresses opportunities alone. We previously observed that Swiss FCH2 actors tend to work with limited interaction between players active in the same area, in contrast to countries such as Denmark, Germany or the UK, where common ground is covered somewhat collaboratively and often in participation with an industry association, while competitive aspects of course remain individual. Finally, Swiss capabilities are often only relevant to a very limited portion of a given supply or value chain for each opportunity identified.

This implies that many opportunities will mostly benefit individual actors rather than the FCH2 sector as a whole, though more activity is likely to breed more suppliers and create value in other ways. The actual economic benefit for Switzerland is hard to quantify. It might be limited for most of the opportunities identified, as the supply chain including industrialisation and assembly of most end products is likely to happen abroad, though the R&D might have been carried out in Switzerland. However, this is true of many industries, and increasing sectoral strength would potentially mean that high-value R&D jobs and licencing revenues come back to Switzerland. The benefit for the country might thus be through more indirect revenues, rather than in manufacturing along the supply chains of successful commercial products.

However, while this is likely to be particularly true for downstream products (systems, end products), upstream specialised products (components, BoP) are more likely to generate some industrial activity within Switzerland. The development of local markets for FCH2 products (e.g. micro-CHP, power-to-gas, etc.) would have the largest potential multiplier effect, necessitating local skills, jobs and revenues downstream of manufacturing.

The type and size of opportunities differs significantly depending on the positioning along the value chain. Therefore, we have separately analysed the downstream players (system suppliers, integrators product and service providers) and the upstream actors (material, component, sub-system and BoP suppliers.

(Sub-) system providers / integrators

A good alignment can be observed between Swiss FCH2 industry activities and global market trends (micro-CHP, fuel cell powered portable systems, uninterruptable power supplies (UPS), fuel-cell vehicles and refuelling infrastructure). This suggests that Swiss actors are overall aware of market opportunities.

The main market development for these applications will occur mostly outside Switzerland, which implies that access to these export markets is essential. However, Switzerland could provide a local proving ground and a potentially supportive internal market due to its unusual characteristics, including a frequent willingness amongst consumers to pay for quality and to think long term.

Ease of market entry will inevitably prove more difficult in certain sectors than in others. Accessing the supply chain of individual automotive groups with a fuel cell system is certainly amongst the most challenging, while fully integrated micro-CHP units offers more diverse market opportunities, due to a wider and more heterogeneous potential customer base.

It could be a very powerful catalyst if Switzerland could offer opportunities for early markets (including pilot units), in particular for those developing proprietary technologies, as this would increase their visibility and credentials, allow them to gather data and strengthen their designs, and facilitate access to strategic players outside Switzerland. Visibility will be particularly crucial for those applications (e.g. portable applications, micro-CHP, and refuelling infrastructure) that are likely to see different national or regional markets emerge, with many players local to these markets involved in their deployment.

It should be kept in mind that while some actors carry out system integration work on imported technologies (e.g. Diamond Lite, GreenGT), they can still add value and create economic opportunity both in the sector and in their regions

Component and BoP suppliers

Some promising opportunities exist for Swiss FCH2 component and BoP suppliers (see Figure 7), as several have developed technologies with the potential to address gaps in existing supply chains. However, these actors are unlikely to find major market opportunities in Switzerland and are naturally oriented towards export. Market access, and more precisely difficulty in getting in contact with large industry players abroad, is thus amongst the principal barriers faced by these actors. In those sectors with dominant OEM players, such as the automotive industry, component providers might however face lower barriers to market entry than would system providers.

Material suppliers

There is little FCH2 material know-how in Swiss industry, although Swiss academic research in this area is relatively strong. TIMCAL is a notable exception, as it benefits from strong capabilities and access to market for its carbon-based solutions for PEM technologies.

Service providers

Current market access for organisations offering consulting services varies greatly between actors. While 'pure' consultants may have a relatively wide and varied access including a proactive approach to marketing, laboratories with technical consulting skills may be understandably and appropriately more reactive to opportunities in tune with their competences.

5 Opportunities for public support

The activities of the Swiss FCH2 industry and research institutes have been shown to be broadly aligned with global market trends, and with a generally high level of innovation (see Chapter 4). However, ease of access to markets varies considerably, and some unnecessary barriers are slowing exploitation of the techniques and products being developed. This suggests that Swiss entities could be more strongly positioned in these sectors, with the potential for regional and national economic benefits.

Switzerland is a small country and with a small FCH2 sector, but the global fuel cell industry is also far from mature. Suitable allocation of scarce Swiss resources is important, and so any significant changes in the level of support would need to be justified at a national strategic level. However, setting a positive context in which FCH2 technologies can develop should not require major interventions, and removing unnecessary barriers would contribute positively to sector growth, enabling Swiss organisations to maintain a high global standing.

Overcoming some of these 'unnecessary' barriers could in some cases be achieved through public support. Both generic and targeted public support, at levels appropriate to the size of the barriers and the potential benefit, could help Swiss organisations best exploit their potential in different sectors.

In the rest of this section, we:

- first discuss current public support and its adequacy with respect to the perceived needs of the FCH2 sector, then
- propose possible measures to enhance the impact of this support, in particular focusing on those that may contribute to lowering barriers to technology development and deployment.

We distinguish between financial and non-financial support.

5.1 Financial support

We have broken down the analysis of the financial support into five elements:

- Volume of national funding
- Coverage of innovation chain
- Allocation process
- Effectiveness of allocation strategy
- Access to international funding

5.1.1 Volume of national funding

Adequacy of current support

At federal level, three main complementary sources of public funding support FCH2 R&D across the innovation chain (see Figure 8): the Swiss National Fund for Research (SNF), the Swiss Federal Office of Energy (SFOE) and the Commission for Technology and Innovation (CTI). Additional funding at a cantonal level or from the private sector is not considered in this analysis.

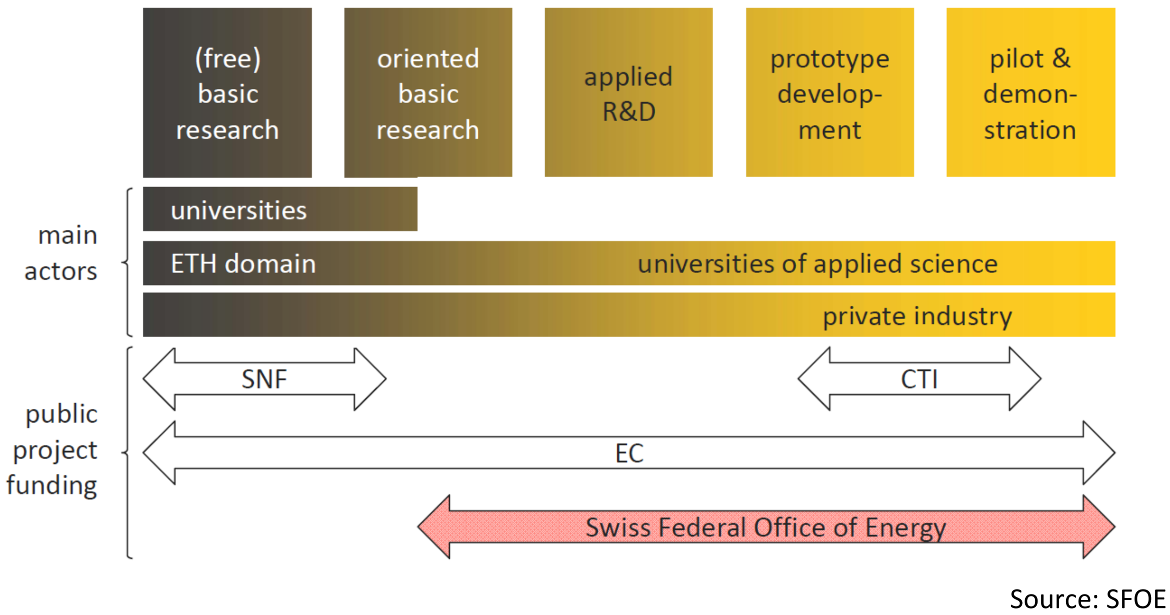


Figure 8 – Positioning along the innovation chain of the different sources of public funding available at federal and EC/EU levels to the Swiss industry and academic actors

Of these three sources of federal funding, only the SFOE currently has a programme dedicated to the support of FCH2 activities; the SNF and CTI budgets are not sector-specific and therefore not secured to FCH2 activities.

According to IEA statistics, the total government budget dedicated to FCH2 activities in 2011 was close to CHF 26 mio CHF (SFOE 2013). Switzerland's contribution to the sector is much higher than that of countries of comparable size such as Sweden (CHF 3 mio) and Austria (CHF 3 mio), but only half the budget of Denmark (CHF 34 mio), known for its strong support of FCH2 activities. Swiss funding can be considered above average by international standards.

The consensus amongst Swiss FCH2 actors, both public and private, is that the level of public funding available to the sector is adequate. It is of course claimed that more could be done should more funding be available. However, it is specifically suggested that slightly increased levels of funding would helpfully enable systematic approaches in place of less well-informed but nevertheless strategically important choices (e.g. about material or design). No strong voices suggested the funding volume was either dramatically too low or not accessible.

Possible measures

The total volume of funding available to the FCH2 sector is felt adequate to maintain a small and dispersed FCH2 sector in Switzerland, and broadly appropriate to the size of the Swiss nation. However, in absolute terms it is still small by international standards, and some actors felt that a small increase in funding might have a large benefit in terms of Swiss competitiveness.

At present, the FCH2 sector is rarely discussed at a strategic policy level in Switzerland. Given the significant advances in the industry globally, and the increasing penetration of FCH2 technologies, this may be a good time to review both the ambition that Switzerland has for its FCH2 sector, as well as the role that the Confederation sees for FCH2 technologies in the Swiss Energy Strategy 2050. Once these are more clearly defined, the appropriateness of the current funding can be reassessed. Even without any change in the amount, having a long-term view on future funding and on what it is intended to achieve is always helpful for actors to plan their developments.

5.1.2 Coverage of innovation chain

Adequacy of current support

The stakeholders interviewed recognised that the SNF, SFOE and CTI funding schemes complement each other in a reasonably efficient way, leaving little gap in the funding process. However, three barriers are perceived by many actors (see Table 2 in section 4.5).

- It is felt that insufficient funding is available for 'oriented' fundamental research, and almost none is available to industry players, which impedes some promising materials research in particular;
- Money is accessible until proof-of-concept stage, but beyond that stage it is progressively more difficult to find, with nothing except possibly ad-hoc local funds available to support the still high-risk stage of market entry;
- No funding exists for industry players to carry out high risk research directly. While CTI funding does enable this research to be done by the academic sector in collaboration with industry, the link between CTI projects and industrial and market reality is often weak. Inevitably, not all academics have a close understanding of industrialisation processes and constraints, and research at universities is often both slower than industrial research and less results-oriented, which can lead to significant inefficiencies and frequently poor results.

Possible measures

- **Support for oriented research**. We suggest that oriented research activities could merit special attention from SFOE, as they involve high innovation and require sophisticated techniques and tools, thus potentially exploiting some of Switzerland's strong capabilities. They also have some potential to develop game-changer technologies. If possible, we suggest that the SFOE also considers funding requests from industrial actors for this type of project, as they can bring a more market-oriented perspective and often a deeper understanding due to their deep knowledge, thus focusing on solutions to specific technical issues.
- **Late stage support**. Although the share of Swiss FCH2 funding allocated to pilot and demonstration (P&D) projects went up from 3% of the budget in 2010 to 14% in 2012, it represents CHF 3.7 million (SFOE, 2013, p.8) and thus remains limited. Given these resources, and although more late-stage funding could make a big difference to the sector, SFOE could potentially make an important contribution to alleviate this financial barrier through non-financial support. For example, by supporting technology developers in identifying strategic partners who would bring co-financing, SFOE might facilitate development at limited cost. Equally, by educating some of those possible partners, of which there are very many in Switzerland, SFOE would help to ensure that all actors have a common understanding and fact base, currently not the case. Engaging with Swiss electricity and gas companies would be particularly relevant in this respect. They are the most logical partner for many emerging applications such as micro-CHP, power-to-gas, refuelling stations, etc, but are dispersed and not easily accessible for smaller actors in particular..
- **Industrial research and the CTI.** Our interpretation of this issue is that it is faced primarily by smaller companies with limited experience with CTI projects. In this sense, the issue is not a

fundamental flaw of the CTI programme, but more a question of ensuring appropriate guidance and governance between the industry actors and their academic counterparts. We therefore suggest that industrial partners newly involved in CTI projects should be supported to define the requirement specifications and the time allocation of their project in a very strict manner, and then to manage these closely, in order to reduce the risk of "academic drift".

5.1.3 Allocation process

Adequacy of current support

During our investigation, we have not found any project with high prospects of success that had to be abandoned because of a lack of funding. Funding has usually been available to actors with solid projects, irrespective of size or geographical location. It does appear that integrative projects, involving several renowned industry actors and research institutes, have a higher chance of being funded than do projects from young start-ups with no academic or industrial collaboration. This is perhaps unsurprising. However, early-stage companies do face difficulties in accessing funds, especially as they develop (see Table 2 in section 4.5). This may be due in part to a limited understanding of the conditions and “guarantees” required to obtain financial support from the Confederation, or to the organisations’ limited resources able to address them.

In addition, it has been discussed that early-stage technology-based companies are not always aware of how best to exploit opportunities to build businesses.

Possible measures

Clear communication from funders is essential: on the one hand about the criteria used to evaluate proposals, and on the other to emphasise that requests for funding in collaboration with strategic and/or academic partners have a significantly higher chance of acceptance than individual submissions. Simple proposal templates aid both those completing and those evaluating the proposals, and any specific market sectors or vision should be articulated upfront so that proposers can ensure their proposals are in alignment.

Care should nonetheless be taken not to exclude actors with potentially game-changing opportunities because of their lack of a track record. For those companies identified with high technology potential but perhaps a less systematic approach to funding applications, guidance or tutorial sessions might be of value.

Adding more specific support to entrepreneurs through links to programmes such as CTI start-ups may positively reinforce SFOE support.

5.1.4 Effectiveness of allocation strategy

Adequacy of current support

The current allocation strategy broadly reflects a straightforward risk-return assessment and may be considered an appropriate criterion for public spending on innovation.

However, the limited budget available is spread amongst many (mostly small) actors targeting a wide range of applications, based on a wide range of technologies. This is partly an issue related to a diffuse and diverse sector, but small amounts of support for many organisations brings a risk that none receives enough to become self-sufficient, and may therefore result in a lower overall return on investment than more targeted approaches.

Possible measures

A better understanding of the specific amount of funding that would make a difference is important, as a small budget increase *might* allow more organisations to move towards critical mass. If funding cannot be increased, then a more targeted strategy might bring stronger support to those opportunities with the highest success potential. It would also bring the following complications:

- Given the breadth of support offered by SFOE, from oriented research to demonstration projects, a selection criterion based on the market opportunity would rarely be applicable for early stage technologies for which no clear application can yet be identified (e.g. photoelectrochemical technologies, high temperature water splitting).
- Given the small size and heterogeneity of the Swiss FCH2 sector, supporting defined applications or technologies will implicitly mean supporting specific companies. Strong upfront justification would be needed for which applications or market segments would be supported. In some cases, justification may come from the role that specific FCH2 technologies may play in the Energy Strategy 2050.
- Non-oriented R&D may of course yield unexpected benefits, which cannot by definition be evaluated in advance.

Specific suggestions can only be made once it has been agreed what describes success. As mentioned before, the role of FCH2 technologies in Switzerland is rarely discussed, neither for their potential role in generating economic benefit, nor in the overarching policy domain, including their potential to contribute to the Energy Strategy 2050. We expand on this in the subsequent discussion.

5.1.5 Access to international funding

Adequacy of current support

Switzerland has historically been well represented in international funding programmes on fuel cells and hydrogen, with a presence in EU projects, Eureka projects, and in the FCH-JU programme.

Although the FCH-JU programme offers interesting opportunities and important access to strategic players, the financial contribution from this programme has become quite restricted. Many Swiss actors have commented on the difficulty of taking part in the programme, due to the low levels of support and difficulty of finding matching funds. It has also been mentioned that it is not always easy to know what is going on and that ongoing networking in Brussels is a major investment for each small entity.

Possible measures

Considering the importance of the FCH-JU programme, the SFOE should assess the possibility to offer a top-up on the FCH-JU funding to avoid missing opportunities (as has occasionally been done in the past). It may also be worthwhile considering appointing a dedicated neutral person or organisation to liaise between the whole of the Swiss FCH2 sector and the FCH-JU, in order to identify the potential for Swiss entities to participate in projects and other initiatives. This would not replace entities like EUresearch, nor individual representation on the various committees, but provide a specific and neutral entity dedicated to the broader Swiss cause as well as that of individual organisations.

5.2 Non-financial support

Adequacy of current support

Current non-financial public support to the FCH2 sector is very limited, and increasing it could prove particularly beneficial. The vast majority of barriers to technology deployment currently faced by Swiss actors are of a regulatory, market, socio-economic or structural nature, rather than purely financial (see section 4.5). Getting the framework conditions right for the FCH2 sector is widely recognised by the industry and academic actors as a critical prerequisite to sector development.

Given the strong views of many actors on the importance of working out the framework conditions, it is perhaps surprising that the Swiss FCH2 industry has remained surprisingly silent until now on this matter – possibly due to the lack of a regular forum for all actors to participate in and express their views, or the lack of a strong industry-driven sector association. The context of this study seems to have offered an opportunity for those views to be expressed.

Given the lack of non-financial support, we have not attempted to assess its adequacy in the same way as the financial aspects. We have instead structured our suggestions around the specific or generic barriers described.

Possible measures

We identified specific barriers to deployment in section 4.5. For each of these we propose possible mitigation measures that could be taken at a public level – importantly, this cannot be limited to the SFOE – to lower these barriers. These measures are detailed in Table 3, and are further discussed in the rest of this section.

Table 3 – Proposed measures to lower the barriers to development and deployment of FCH2 technologies

Barrier category	Barriers	Possible measures
Market (Access)	Too few possible industry partners in Switzerland; difficulty for smaller players to establish contacts with and trigger the interest of potential strategic partners abroad.	Support to establishment of international relationships with potential strategic partners. Possible measures could include: • Identification and dissemination of relevant national industry associations and events in selected countries (e.g. Germany, USA, etc.); negotiated access for Swiss players. • Strengthening of the Swiss FCH2 association • Supported participation in international events (conferences, industry shows, etc.) • Putting together a competition for SMEs whose prize is the opportunity to present at a showcase event in front of selected strategic partners[11]. Approaches requiring more resources, such as the set-up of technology accelerators, may not be warranted at this stage given the absence of a sector vision and the currently scattered industry.

[11] This can be low cost to run and quite efficient for the strategic partners, who do not have to do very much work before seeing things that have been filtered by an expert panel.

Barrier category	Barriers	Possible measures
Market (Access)	Smaller players with only a few employees, or those with FCH2 as only a part of their activity are not always well informed of relevant international activities in the sector, as keeping up-to-date is not a priority use of their budgets.	• An independent, technology-neutral representative for the Swiss FCH2 community could be tasked with understanding the specific needs of the Swiss players and the specific opportunities and activities in relevant international initiatives. They could then network and communicate between international communities (e.g. EU funding programs, FCHJU) and Switzerland. This could be cost-efficient way of triggering opportunities. • Developing specific collaborations with selected FCH2 activities in neighbouring countries (e.g. between NOW GmbH in Germany and e.g. SFOE in Switzerland) could offer valuable opportunities to Swiss players. • Specifically targeted liaison with the organisation EUresearch may contribute to raising its awareness of Swiss activities in the FCH2 sector and potentially contribute to generating opportunities for Swiss actors to participate in the EU Framework Programme Horizon 2020.
Market (Development)	There is no coherent or overarching FCH2 strategy in Switzerland, which impedes the development of many early markets as well as failing to stimulate debate on longer-term opportunities.	In the absence of any national FCH2 strategy, regional actors such as utilities or communes find it hard to understand how any local projects fit into the bigger picture, and are therefore hampered from making decisions on supporting such projects. • Systematically and clearly addressing the potential role of hydrogen and fuel cells in Switzerland in the long term, and integrating these elements into the Confederation's Energy Strategy 2050 would be very valuable in this regard. It is also widely perceived as such by FCH2 industry stakeholders. It would further help in creating a common mindset, and assist the alignment of views between policy and other decision makers at all levels (federal, cantonal, communal). Additionally, support for projects at board level within companies is made easier when the board has a clear external reference framework. Being the *only* one is quite different from being the *first* one.
Technical	Technology is sometimes developed with Swiss circumstances in mind, which may not bring competitive advantage in a global market	In some cases this is entirely appropriate and no measures are required. However, a strategic assessment of sector prospects and opportunities coupled with a venue or format for sharing perspectives may aid those organisations wishing to adopt a more international perspective.

Barrier category	Barriers	Possible measures
Regulation	No clear approach is taken within Switzerland to RCS, and no single body is tasked with understanding or harmonising the different regulations that may be applicable. This is sometimes complicated further by a lack of overlap between many Swiss and international standards.	Harmonisation of RCS at Swiss level regarding fuel cells and hydrogen use could make a significant positive difference to the sector by enabling smaller organisations, or regional or local bodies, to have a common point of contact for FCH2 projects. Even this single point of contact, maintaining an overview of the possible regulations and relevant organisations would be a positive step. SFOE could usefully support the following: • Carry out and document a detailed and comprehensive assessment of existing relevant RCS • Initiate discussions with SUVA, the organisation in charge of safety regulations, to understand the potential to harmonise RCS in this sector • Facilitate the development by SUVA (and others) of harmonised rules, looking pragmatically at examples from other countries, and working with them where appropriate. Micro-CHP, FCEVs and hydrogen infrastructure could be focus areas.
Regulation	As yet unknown RCS issues may emerge, hindering future development.	• Perhaps as part of the above, some effort should be made to investigate or anticipate future RCS barriers related to future FCH2 applications, so that mitigation measures can be taken to avoid these barriers arising.
Regulation	Customs issues for companies with cross-border activities	This issue is not FCH2 specific and hard to tackle without major reform of duties and levies as a whole
Social	Lack of awareness and acceptance for hydrogen technologies	Targeted awareness-raising, based on particular needs could be envisaged. This could for example include utilities and politicians, who have limited exposure to such issues. Measures to enhancing public acceptance for hydrogen technologies would also be valuable. Specific measures could include: • Providing publicity support to initiatives promoting field trials (such as the project Pharos12) and demonstration projects • Offer special support to projects in which local utilities are involved • Discuss with the industry association of power utilities (VSE[13]) the possibility of integrating FCH2 topics in their activities (e.g annual events, working groups). One focus could be to communicate the status of development of the global and EU markets for FCH2 technologies • Work towards investigating and integrating the role that FCH2 could play in the Swiss Energy Strategy 2050 • Regularly present the results of key analysis on the potential role and prospects of FCH2 for Switzerland, or updates on progress, at federal parliamentarians' sessions on energy

[12] The project Pharos, supported by the SVGW (Schweizer Verband des Gas- und Wasserfachs), is targeting fuel cell microCHP
[13] Verband Schweizerischer Elektrizitätsunternehmen

Barrier category	Barriers	Possible measures
Economic	Most emerging FCH2 technologies are not yet competitive and require some form of support to enter markets. Switzerland supports some emerging energy technologies but not others.	Support mechanisms vary widely and will have different impacts on different FCH2 technologies and applications. However, the benefits of enabling early markets can be significant. Support mechanisms are largely appropriate for nearly commercial technologies, such as mCHP or certain vehicles, though this will depend on Swiss objectives. SFOE might be able to work with others to: • Assess the specific support mechanisms that might be appropriate and their budget or other implications • Put them into the context of a long-term Swiss vision for FCH2 technologies
Economic	Difficult in ensuring a local supply chain is considered where possible, due to a lack of visibility on suppliers	No obvious meaningful measure can be proposed. Developing supply chains not only takes considerable investment, but would be hardly economic before the market for FCH2 technologies has kicked-off, while their long term viability is likely to be threatened as large international players develop mass production capacities.

5.3 Impact of proposed mitigation measures

The implementation of the package of measures proposed in Table 3 above could contribute to lowering structural barriers to technology development and product deployment. The impact that these actions would have on the actual opportunities depends on the specific opportunity.

The level of effort required from the Confederation for each impact is presented in a qualitative way in Figure 9, which only shows those opportunity areas where we think there may be some possibility to move the players significantly upwards. The opportunity areas shown in Figure 7 that would not be affected by the package of proposed measures have been deleted for clarity in Figure 9. Those support measures that help enable the development of a local market for certain FCH2 applications appear the most useful actions.

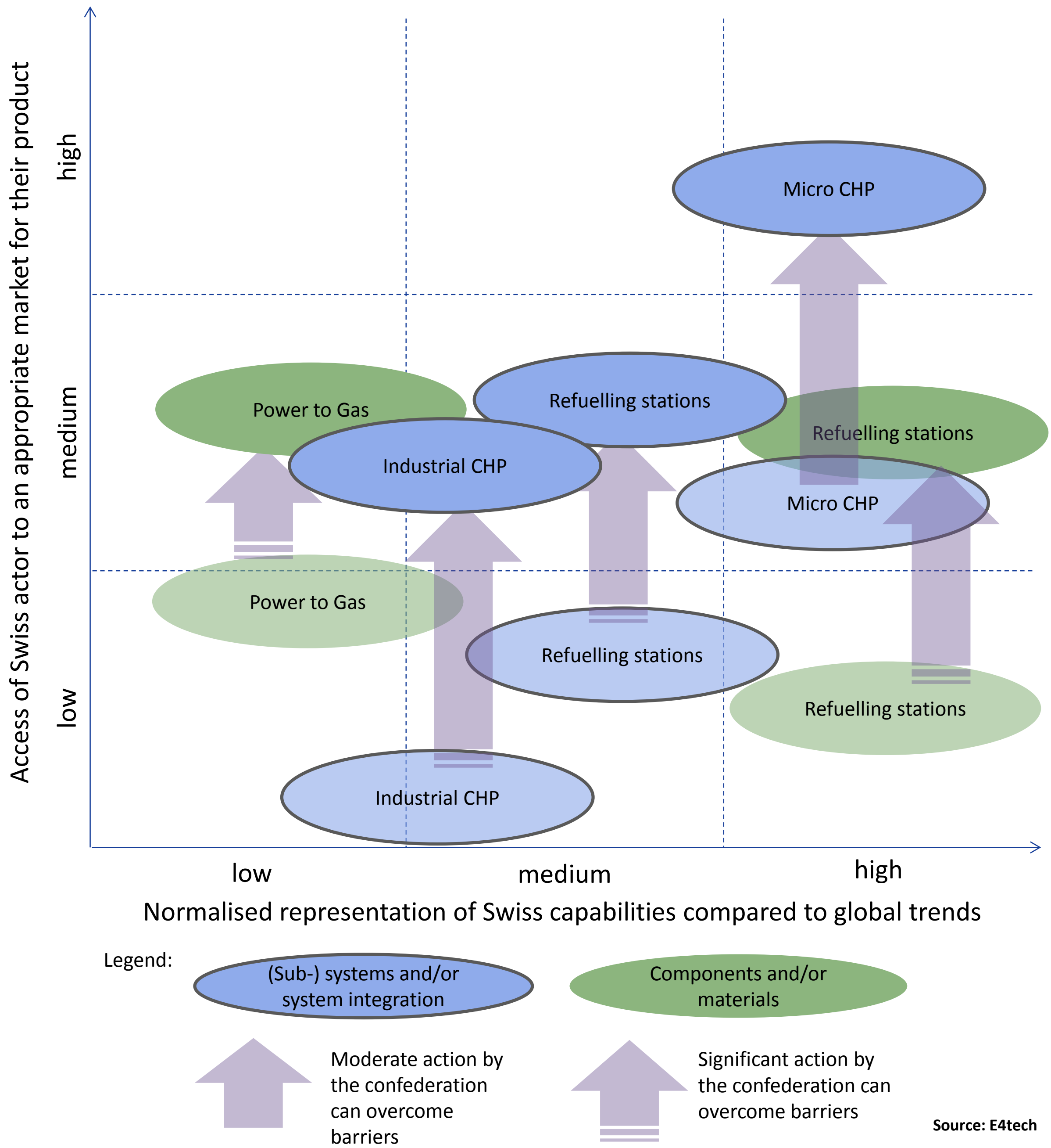


Figure 9 – Possible impact of proposed measures on barriers for different relevant market sectors

5.4 Final considerations

Two threads run through this study and strongly affect the direction and potential of any measures taken:

- The heterogeneity and small size of the Swiss FCH2 sector
- The absence of recognition of the potential role of FCH2 technologies in the Swiss context, and any vision for the future

In this context, developing a common vision for the role of fuel cell and hydrogen technologies in the near-term and future Swiss energy system could play the role of a meta-measure, with the potential to address many of the more detailed issues raised earlier. Specific building blocks of this action might include:

1. Initiating and managing one or more debates in the broader energy and policy community around hydrogen and fuel cells, their status and what roles they may play generally;
2. Using this debate and some structured analysis to define a common vision about the roles that hydrogen and fuel cells could play in Switzerland;
3. Integrating this vision into the Energy Strategy 2050 and defining clear objectives for fuel cell and hydrogen technologies and applications;
4. Using the vision and objectives to define clear short-term objectives and measures to support them.
5. Performing ongoing analysis and support as required to maintain the momentum.

Initiating and managing an honest and disinterested debate may prove challenging, given a divergence of views and some already strongly set opinions that can be observed amongst Swiss energy leaders around hydrogen and fuel cell questions. For it to be done properly would require good preparation, objective facilitation and probably some significant bilateral as well as multilateral interactions.

Two pragmatic options could be pursued to start with:

- Organisation and hosting of a fully inclusive event for all Swiss FCH2 actors to meet, discuss and interact, with an especial focus on forging contacts between those who interact little;
- Gathering and wide dissemination of facts and statistics about the current status of fuel cell and hydrogen technologies and markets, in the EU and globally, together with other countries' views on their potential.

The Swiss FCH2 sector has significant skills and competencies, only some of which are strongly exploited. By taking focused measures it may be possible to increase the dynamism and enthusiasm of the Swiss FCH2 sector and support the development of a broader, common vision for fuel cells and hydrogen in Switzerland, both in terms of development of the industry and the role FCH2 technologies and options may play in the Energy Strategy 2050.

6 References

6.1 Interviews

Type of organisation	Name of group / organisation
Industry	Belenos
	CEKAtec
	Diamond Lite
	Fiaxell
	GreenGT
	Hexis
	Htceramix
	IHT
	Schmidlin
	Weka
Academic	BFH-TI - Instit. for Energy a. Mobility Research - FC Group
	EMPA – Internal Combustion Engine Lab
	EPFL - Groupe de Catalyse pour l'Energie et l'Environnement GCEE
	EPFL - Laboratory of renewable energy science and engineering (LRESE)
	EPFL - Institute of Chemical Sciences and Engineering
	EPFL – Industrial Energy System Laboratory (LENI)
	ETH – Lab of energy science & Engineering
	PSI - Electrochemistry Lab

We attempted to contact a number of other relevant groups, but unfortunately they were not always able to accommodate our request for interviews.

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