Project

MEGASTACK: Stack Design for a Megawatt Scale PEM Electrolyser

JU FCH project in the Seventh Framework Programme
Theme: SP1-JTI-FCH.2013.2.3
Grant Agreement No.: 621233

D.1.1 Cost benefit analysis and cost and performance target for large scale PEM electrolyser stack – Public Summary

Nature of the deliverable	: Report
Associated Work Package(s)	: WP1: Safety, RCS harmonisation, cost and LCA analysis
Lead beneficiary	: 2 / Fraunhofer ISE
Authors	: Tom Smolinka - Fraunhofer ISE / Germany Magnus Thomassen - SINTEF / Norway Alejandro Oyarce - SINTEF / Norway Frederic Marchal - ITM / United Kingdom
Due Date	: 31.03.2015
Date published	: 12.01.2016
Dissemination level	**: Public**

Content

Abbrerivations

CAPEX	Capital expenditure
GHG	Green-house gas
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
HRS	Hydrogen refueling station
KPI	Key performance indicator
MRP	Material requirement planning
MAWP	Multi-annual working programme
OPEX	Operational expenditure
PtG	Power to gas
PtP	Power to power
PEM	Proton exchange membrane
PV	Photovoltaic
RES	Renewable energy sources
T&D	Transmission and distribution
VRE	Variable renewable energy
WE	Water electrolysis

1. Introduction

The amount of renewable energy sources (RES) is expected to constitute a significant portion of the total electric power generation of Europe within the next decades, resulting in a power generating scenario subjected to both seasonal as well as hourly weather variability. It is also expected that significant amount of excess renewable energy (on the order of TWh) will start to emerge in countries across the EU, with surpluses characterised by periods of high power output (GW) far in excess of demand. These periods will alternate with times when RES are only generating at a fraction of their capacity. Therefore, new approaches and tools are required to ensure that this renewable energy is integrated into the power system effectively and have not a negative impact on security and grid stability.

There are four main options for providing the required flexibility to the power system: dispatchable generation, transmission and distribution (T&D) expansion, demand side management, and energy storage. These options have limitations and costs, and none of them are foreseen to solve the RES integration challenge alone. With respect to storage, there are three main categories of technologies:

- Power to power (PtP) storage (lead-acid, Li-ion, flow and NaS batteries, pumped hydro energy storage, compressed air energy storage, liquid air energy storage, and electrolytic hydrogen production and re-electrification);
- Conversion of electricity to heat and storage for later use (power to heat);
- Conversion of electricity to hydrogen for use outside the electric power sector (power to gas or power to liquid).

Although not the most efficient option in the PtP sector, the conversion of electricity into hydrogen by water electrolysis is expected to emerge as a viable alternative for energy storage beyond PtP. Produced hydrogen may be injected in the natural gas grid (often referred to as power-to-gas), used as an energy carrier in mobility applications or used as a feedstock in industry, further contributing to the decarbonisation of these sectors. Within the water electrolysis technologies, proton exchange membrane (PEM), alkaline and solid oxide electrolysers are currently the most promising technologies for this application.

During the last years, several studies on electric energy storage in general [Kin15] [IEA14] and the use of hydrogen from water electrolysers as an energy storage medium [E4T14] [DNV13] [IEA15] have been published. In these reports, several analyses on the need for energy storage, the degree of curtailment of renewable energy production and costs of different storage options are presented.

This report provides an updated overview of the market sizes as predicted by these recently published studies and summarises the current status of PEM water electrolysis technology and what is needed for today's PEM electrolyser technology to achieve its full potential as megawatt (MW) or multi-MW energy storage devices. The report is divided in three sections (Chapter 2 - 4):

- **Chapter 2:** Water electrolysis market size, state-of-the-art and targeted cost and performance based on recently published techno-economic analysis.
- **Chapter 3**: Cost reduction strategies and guidelines based on recently held stakeholder participation in MEGASTACK workshop
- **Chapter 4**: Cost reduction strategies within the JU project MEGASTACK

2. Market size and state-of-the-art vs. targeted cost based on published techno-economic analysis

2.1 Market size and energy storage demand

The European Commission is currently setting challenging targets for the reduction of green-house gas (GHG) emissions in order to keep the EU on track to meet its ultimate objective of reducing GHG emissions by at least 80 % in 2050 compared to the reference year 1990 [Eur11]. This is motivated by the objective to keep climate change below the 2 Kelvin target [Kin15]. Reducing GHG emissions from the electric power sector is a key part of the EU efforts. In fact, studies have shown that in order for the EU to achieve the ultimate objectives, a nearly complete (90 to 100 %) decarbonisation of electric power production may be required [Kin10]. This in turn calls for considerable changes in how electric power is produced in the EU. The European Commission has also put forward a set of scenarios for the power sector in which the share of renewable energy in electricity generation ranges from 59 to 85 %. A majority of these RES production targets will be covered by photovoltaics (PV) as well as on- and offshore wind, whose production is subject to both seasonal as well as hourly weather variability (variable renewable energy (VRE)). This is projected to lead to increased requirement of system flexibility, driven by supply variability. Also, significant amounts of excess renewable energy (on the order of TWh per year) will start to emerge, causing surpluses that are characterised by periods of high power output (GW) far in excess of demand, resulting in power production from renewables may be curtailed dramatically [IEA14].

The demand for energy storage in the future energy system is dependent on several factors, such as the share of variable renewable energy production, the capacity in electricity transmission grids and competitiveness against alternative solutions such as demand side response technologies and reserve energy generation capacity. The international energy agency (IEA) recently published a technology roadmap for energy storage [IEA14] where the potential for electricity (PtP) storage capacity in the EU was estimated to be in the range of 70 to 90 GW in 2050. In this scenario (2DS), the share of variable renewable energy installed in the EU is assumed to be about 45 %.

In comparison, a recently published energy storage commercialisation study [Kin15] have estimated that in a high-renewables scenario (60 % and more VRE penetration by 2050), there will be economic potential for about 400 GW in the EU of PtP storage for the integration of intermittent renewables or about four times higher than reported by the IEA.
Storage demand however, will depend on country-specific characteristics, in particular on the level of interconnectivity. One example for a country-specific consideration is the so-called “ReMoD-D” model developed at Fraunhofer ISE [Hen15]. Optimisation of the German future energy system is done with a holistic model based on an hourly energy balance and a generic optimiser with the goal function of total minimum annual cost. The results for an 80% reduction scenario are in rough accordance with [Kin15] predicting only for Germany a total electrical electrolysis capacity of 33 GW_{el} which is needed mostly for mobility.

Assuming a tenfold increase in installed PtP storage capacities by 2050, a significant amount of backup non-renewable generation and large installed non-RES power plant capacity will still be required for prolonged periods (several days or even weeks) with low wind and sunshine. At the same time, in the high-RES scenario, there will still be periods with large amounts of excess renewable energy that cannot be used in the electric power system directly or through PtP storage.

Therefore, the economic potential of hydrogen to the contribution to RES integration is also being considered in [Kin15].

The same study [Kin15], estimates the demand for electrolyser capacity and the amount of hydrogen produced in 2030 and 2050. They assume that the electrolyser is only operating at times when electricity would otherwise be curtailed. As a proxy for societal value of electrolyser output, they assume that hydrogen produced is worth EUR 2/kg, corresponding to the predicted 2050 plant gate value of hydrogen for industrial use. The cost of including an electrolyser in the system is set at EUR 60/kW per year, corresponding to the 2030 costs of large (10 MW) alkaline electrolyser CAPEX and OPEX. Additionally, it is assumed that operation of the electrolyser is assumed to use only excess energy. Finally, it is assumed that no PtP time shift or heating storage utilises the excess energy and that the hydrogen can be used at the location of the electrolyser or that it can be economically transported to a demand centre. With these assumptions, the study shows that there is little economic electrolyser capacity in 2030 (unless T&D constraints are put in place), as there is very little curtailed energy for the electrolysers to utilise. In the case of low connectivity, an economically viable electrolyser capacity becomes substantial as early as in 2030. In 2050 however, it is expected that the large amount of excess energy would further increase the economically viable capacity of electrolysers to the extent that it would exceed the average load of the electricity grid. Hydrogen demand at the assumed price of 2 €/kg would be the limiting factor for electrolyser deployment at this point. The electrolysers would produce 3.5 million tonnes of hydrogen in the high-connectivity case and 5 million tonnes of hydrogen in the low-connectivity case. Conversion of electricity to hydrogen through water electrolysis and use of this hydrogen in the gas grid (PtG), mobility or industry can productively utilise nearly all excess renewable energy in the high-renewables scenario, contributing to the decarbonisation of these sectors. It is concluded that European potential for installed electrolyser capacity in 2050 high-RES scenarios would be in the hundreds of GWs. On the other hand, this requires that there either is local demand for hydrogen at the production site or that the hydrogen can be economically transported to a demand centre. Additionally, in order for this storage technology to develop, regulators need to create a level playing field on which storage can compete with the other options.

Recently, the FCH JU commissioned a study to better understand the conditions under which water electrolysers may play a role in the energy system [E4T14]. The study also gathers the view of stakeholders on the future market size for water electrolysis, summarised in Figure 1. The consensus among stakeholders is that that electrolysis will play an important role in the future energy system. New uses of electrolytic hydrogen in transport and energy storage are expected to outgrow traditional industrial use, although there are different views as to when this point will be reached. It is expected that electrolytic hydrogen use will gradually evolve from limited industrial exploitation today, through early energy and transport uses around 2015, to wide deployment in hydrogen refueling infrastructure around 2020. Views on energy storage related deployments (e.g., power to gas) and industrial uses vary among stakeholders, but in general energy storage related applications are expected to grow significantly only after 2020. It is widely accepted that this growth will depend on the evolution of the energy system and of regulatory frameworks.

Hydrogen as an industrial chemical	Existing markets for electrolytic hydrogen expected to grow moderately		Potentially emerging	Energy system and use cases expected to have evolved significantly by this time
Energy storage, grid services & Renew.-heat	Pilot stations in several countries (MW scale)	Deployment of multi MW systems	Cumulative deployments reach GW scale	
Hydrogen refuelling stations	Hundreds of stations (100 kW – 2 MW)		Thousands of stations (1 MW to 5 MW)	
	Now to 2015	2015 - 2020	2020 - 2030	Beyond 2030

Figure 1: Stakeholders view on future market size for water electrolysis [E4T14].

2.2 Capital expenditure for WE systems

One of the main key performance indicators (KPI) for water electrolysis at system level is the capital expenditure (CAPEX). The FCH JU has revised cost and technical targets for electrolyser technology and deployment to be established by 2023 [FCH14]. Table 1 shows state-of-the-art and expected trends for the most relevant KPI's, including CAPEX (KPI 2) reduction data for water electrolysers.

Table 1: Most relevant KPI's for PEMWE according to the MAWP of FCH-JU [FCH14]

		State-of-the-art	**2017**	**2020**	**2023**
KPI 1	H2 production electrolysis, energy consumption (kWh/kg) @ rated power	57-60 @100kg/d	55 @500kg/d	52 @1000+kg/d	50 @1000+kg/d
KPI 2	H2 production electrolysis, CAPEX @ rated power including ancillary equipements and comissioning	8.0 M€/(t/d)	3,7 M€/(t/d)	2.0 M€/(t/d)	1.5 M€/(t/d)
KPI 3	H2 production electrolysis, efficiency degradation @ rated power and considering 8000 H operations / year	2% - 4% / year	2% / year	1,5% / year	<1% / year
KPI 4	H2 production electrolysis, flexibility with a degradation < 2% year (refer to KPI 3)	5% - 100% of nominal power	5% - 150% of nominal power	0% - 200% of nominal power	0% - 300% of nominal power
KPI 5	H2 production electrolysis, hot start from min to max power (refer to KPI 4)	1 minute	10 sec	2 sec	< 1 sec
	H2 production electrolysis, cold start	5 minutes	2 minutes	30 sec	10 sec

The costs may also be described as KPI in € per kW, which can be translated into cost per hydrogen output (€/Nm^3/hr) if multiplied by the energy input (kWh/Nm^3) of a specific system but this KPI is not preferred as different WE system efficiencies preclude a direct comparison.

Target cost for KPI 2 in the MAWP does not distinguish between different WE technologies but in [E4T14] a comparison for low temperature WE systems (PEM WE and alkaline WE) according to stakeholders expectations is given, see Table 2. It is estimated that current alkaline electrolyser systems cost 1,000 to 1,500 €/kW, excluding installation and grid connection. These costs are expected to be reduced to about 600 €/kW by 2020 (central case). More optimistic estimates see alkaline electrolyser costs approaching 370 €/kW (best case). Very aggressive targets of below 200 €/kW have also been reported in [E4T14], although these figures are clearly below the typical range of expectations.
Costs at around 1,000 €/kW (central case) are expected by 2020, although several manufacturers anticipate costs near 700 €/kW (best case). Limited data on cost reductions beyond 2020 are available, though in the best case PEM cost could drop to 250 €/kW. This expectations could be confirmed by own calculations as predicted in [Smo15] for 2030. As the uncertainty is significantly high, the mean central case cost comes to 760 €/kW, as summarised in Table 2.

Table 2: Present-day and future capital expenditures of electrolysis systems according to [E4T14]

System cost (1)			Today	2015	2020	2025	2030
EUR/kW	Alkaline	Central	**1,100**	**930**	**630**	**610**	**580**
		Range	1,000 - 1,200	760 - 1,100	370 - 900	370 - 850	370 - 800
	PEM	Central	**2,090**	**1,570**	**1,000**	**870**	**760**
		Range	1,860 - 2,320	1,200 - 1,940	700 - 1,300	480 - 1,270	250 - 1,270

(1) incl. power supply, system control, gas drying (purity above 99.4%). Excl. grid connection, external compression, external purification and hydrogen storage

2.3 Hydrogen production cost

Hydrogen production cost specifies all cost to bring out one unit of hydrogen (volume or mass) at the installation site. Probably this is the most important KPI for an end user as it allows an economical evaluation against other hydrogen production technologies, e.g. steam reforming or partial oxidation from fossil fuels. Main shares of the hydrogen production cost are:

- investment cost or capital expenditure through depreciation (CAPEX), see above;
- electricity cost to run the electrolysis process as main part of the variable costs;
- remaining operational expenditure (OPEX) for water, operating resources (e.g. nitrogen for purging) and service, planned and unplanned maintenance, overhaul, rental charges etc.

Storage, transportation and distribution are not included in the hydrogen production cost. From this list it becomes clear that CAPEX is only one part of the hydrogen production costs. In industrial applications with a constant hydrogen demand, the electrolysis process runs continuously resulting in a high number of annual full load hours. In such applications hydrogen production cost are dominated by the cost for electricity and capital expenditure are only of minor importance. Thus, high efficiency of the electrolysis process is essential as it determines the electricity demand.

Technology improvements and cost reductions concerning conversion from electricity to hydrogen will come from the development in electrolyser technology. At the same time, hydrogen storage relies on mature technologies with limited improvement potential. In this sense, the technological and cost development of electrolysers will act to reduce the cost of electrolytic hydrogen production. Simultaneously, increasing average grid electricity costs will act in the opposite direction. As it can be seen from Figure 2 electricity prices vary considerably from a geographical perspective, as well as with the type of regulatory frameworks of each country.

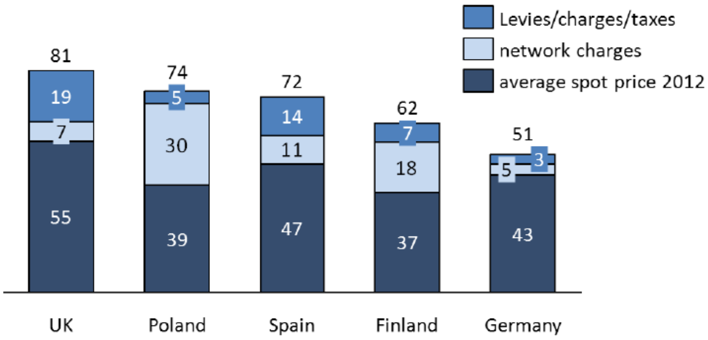

Figure 2: Average electricity cost in €/MWh to industrial electroysers [E4T14]

Based on these electricity costs for different countries marginal hydrogen production costs can be derived. Taking into account the KPI 1 targets of the MAWP from Table 1 marginal production costs are presented in Figure 3 excluding any CAPEX or further OPEX. Production cost varies between 2.5 €/kg and 4.8 €/kg hydrogen for average electricity costs from 50 to 80 €/MWh.

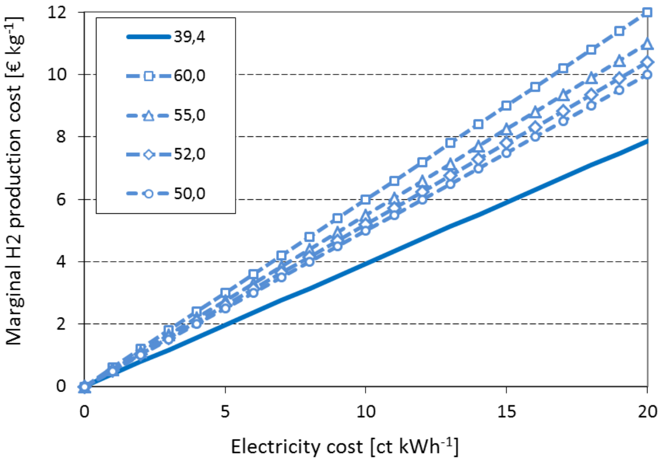

Figure 3: Marginal hydrogen production cost for different efficiencies (in €/kg hydrogen) of the electrolyser according to the KPI 1 targets of the MAWP

Applying the electrolysis process in the energy sector, e.g. to enable a flexible load management, requires different features and operation strategies of an electrolysis system. In such applications the annual full load hours - which can be expressed as utilisation rate - are considerable lower and CAPEX drives the hydrogen production costs. Although a high efficiency is still important, reduction strategies for CAPEX become more dominant. The influence of the utilisation rate is given Figure 4 based on a simple annuality model to calculate the hydrogen production costs (recovery period = 20 years, interest rate = 5 %, electricity cost = 5 ct/kWh). Values for efficiency, production rate and CAPEX are taken from Table 1 for the years 2015 – 2023. Additionally, 10 % of CAPEX are assumed for planning of the installation and 4 % of CAPEX are calculated for maintenance incl. overhauling of the stacks.

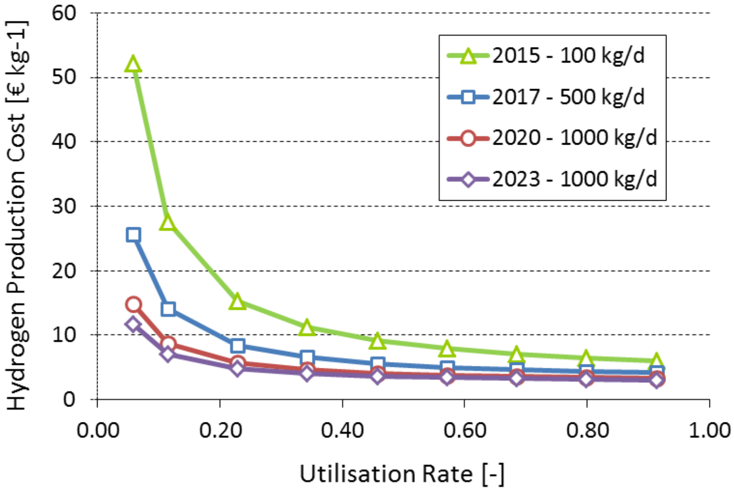

Figure 4: Hydrogen production cost (in €/kg hydrogen) for different scenarios according to the EU targets for water electrolysis of the MAWP, see Table 1 [Smo15a].

With higher utilisation rates the hydrogen production cost approaches the marginal hydrogen production cost as given in Figure 3. The lower the utilisation rate the more dominantly is the influence of the CAPEX. Please note that electrolysers which different production rates are compared in Figure 4. Smaller systems may be deployed in the future for installations with high utilisation rates (e.g. hydrogen refueling stations with a daily constant hydrogen demand). Thus electricity cost and efficiency would be more important than investment cost. For larger electrolysis installation in the x-fold MW scale (energy storage applications with low utilisation rates) CAPEX and thus cost reductions strategies will decide about their competitiveness.

Furthermore, operating strategies are projected to provide additional revenue for the water electrolyser operators, including providing load balancing services for the electricity grid or siting the system in a location that allows grid operators to avoid reinforcing the network. In such context, countries such as Germany may exhibit lower hydrogen production costs thanks to lower wholesale electricity prices and reductions in the transmission/distribution costs payable by industrial electrolyser users, where electrolysers modify their electrical demand according to a signal from the network operator - a service for which they receive a reimbursement.

The production cost of hydrogen from water electrolysers only tells part of the story. To fully assess the economic potential of electrolytic hydrogen, it is important to define use cases which determine the technical steps and economic effort required to take the hydrogen from the electrolyser system and deliver it to the end user. According to [E4T14] this may result in three broad categories, varying both the size of the electrolyser systems, and the end use for the hydrogen:

i) Small systems for transport applications and use of electrolytic hydrogen in hydrogen refueling stations (HRS) for fuel cell vehicles and buses;
ii) Medium systems for industrial applications, e. g. use of electrolytic hydrogen in ammonia production; and
iii) Large systems for energy storage applications, e. g. hydrogen production from excess renewables as storage medium.

[E4T14] reports the case of Germany, indicating that for distributed transport applications (where the electrolyser is sited at the station), is able to achieve the central KPIs allowing water electrolysers to compete with SMRs, provided the electrolysers can attract grid balancing payments (see Fig 4).

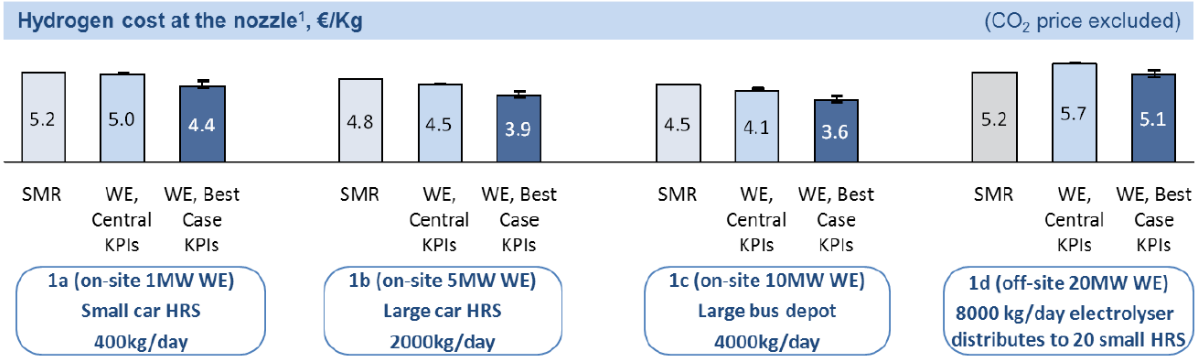

Figure 5: Hydrogen cost at the nozzle for transportation applications in Germany in 2030 [E4T14]

This is because the cost of hydrogen distribution for the centrally produced SMR is higher than any additional cost of electrolytic production. For a mode where hydrogen is distributed from centralised electrolysers to filling stations, competition only appears feasible if the best case KPIs are met. In these figures the electrolysers are operated in grid-connected mode and provide balancing services. In industrial and energy storage applications, however, even water electrolysers achieving best case KPIs will find it challenging to compete in the majority of use cases, without additional carbon payment (or very high balancing revenues).

3. Cost reduction strategies for PEM electrolysers

Chapter 1 reveals the large cost reduction potential for electrolysers stakeholders expect, see Table 2, which can meet the target of the European commission for the near future (according to the KPI 2 values, see Table 1). Further analysis of marginal cost for PEM electrolysers considers even lower capital expenditure which can be achieved if certain boundary conditions are given in the future [Smo15]. However, realistic cost targets and possible reduction potentials for water electrolysers are uncertain as the data base is comparably small and detailed information are not available. Today’s worldwide low annual production volume of water electrolysers does not allow a comprehensive evaluation of cost structures. Electrolysis systems are produced mostly in single order manufacturing and custom-made and only few companies offer standardised electrolyser products. Certainly, most of the manufacturers have a cost reduction strategy according to their business plan. But derived cost targets - if known at all - probably are not comparable as the expected market forecast can differ by an order of magnitude. Last but least, it is not defined on a binding basis what exactly belongs to an electrolysis system for a certain application and therefore is included in the investment cost.

3.1 General classification of cost reduction strategies

Despite these difficulties to evaluate and compare cost targets, a classification of different cost reduction strategies will be given in the following section. In general, cost reductions for the manufacturing of water electrolysers can come from many areas, grouped here into the categories of (i) technology related cost reductions, (ii) design and process choices, and (iii) manufacturing related cost reductions:

i. **Technological cost reductions include**
  - Operating window optimisation (temperature, current density)
  - Larger scale technology (reduces part count, better material usage)
  - Lower cost materials (reduced material costs, conserve PEM benefits)
  - Longer life (decreases the cost of ownership and maintenance costs)
  - System simplifications (high pressure operation to lower or eliminate cost of compression)
  - Attracting additional payments (rapid response, intermittency and gas quality)

Example i-1: Increased current density and larger stack are the core strategy of the Megastack project. Increasing current density reduces the quantity of active materials required for a given hydrogen production capacity. Larger stacks package the active materials more efficiently, reducing part count further.

ii. **Design and processing savings include**
  - Choices of material (process-ability, lower weight material)
  - Choice of processing technology (avoiding certain processes, opting for simplicity)
  - Part count & grouping of parts (affects future manufacturing cost reductions)

Example ii- 1: A stack of electrochemical cells should have no tie rods, end plates or Belleville spring washers. There is little design justification for this. Downstream, efficient manufacturing links can be foreseen or forgone because of this.

Example ii-2: Sintering under vacuum is very often uneconomical in Europe. The reason for this is the transformation processing of certain metals (such as joining under vacuum) is inefficient and very carbon intensive whilst necessitating considerable fixed assets.
A consideration of extraction, primary processing carbon footprint and cost of certain metals is critical; preferably before they enter the supply chain. It can be favourable for European electrolysis manufacturer to prefer processes that are economically viable in Europe.

Example ii-3: Design for lowest cost of service-ability implies light weight and replacement of the smallest possible entity during intervention. It is essential to form relevant groups of parts. Value can also be recovered more easily from replaceable cells.

iii. Manufacturing savings

Manufacturing savings deal with the strategy required for the manufacture of upwards of 100s of Megawatt electrolysis plants per annum and what must be implemented for economies of scale to materialise.

- Manufacturing system model (discrete event simulation before expenditure is commited to assess key manufacturing indicators in a simulation environment)
- Organising manufacturing in a different way (from static to line manufacture)
- Significantly accelerate build cycle time (Lower part counts, spanner-less assembly, lower weights are established pre-requisites which support this)
- Low waste between each sequences of build (reduced time is reduced cost)
- Supply and manufacturing system strategy (flexibility of product mix and scale)
- Strategic alliances (supply chain and expertise of confirmed manufacturers to reduce cost)

Example iii-1: Significant savings are expected from electrolysis containers built on a line, with the same staff level. This is to be opposed to building containers statically with a push MRP (Material requirement planning) system and insufficient low visibility of cycle time performance (operator or task efficiency).

Example iii-2: In fuel cells, economies of scale are attainable because fuel cells can be produced like modules on an assembly line. The same learning rate will be anticipated with electrolysers.

From an engineering perspective it is vital to engage with all possible avenues of cost reduction and in doing so consider the entire electrolysis product from technology, to design through to manufacture. In addition to the above, cost reduction avenues do exist with aggressive procurement negotiation and global sourcing strategy. This is also supported by corporate alliances.

3.2 Cost reduction strategies by PEM electrolysis manufactures

As it was the intention of the project team to build up the cost benefit analysis on a commonly accepted view on the market for large scale (PEM) electrolysers and in reflecting cost reduction strategies by different manufactures of these systems an international workshop was executed with representatives from public organisations, research institutes and industrial companies.

The workshop was titled “Cost Targets for Water Electrolysis and Cost Reduction Strategies for PEM Electrolyser” and executed in conjunction with the 2nd IEA ANNEX 30 Electrolysis Meeting on April 20-21, 2015 at the Hydrogen Centre of Excellence in Herten, Germany. The workshop was attended by roughly 30 participants from nine different countries (Denmark, France, Germany, Japan, South Korea, Norway, Switzerland, United Kingdom and USA) and various types of affiliation. In particular electrolyser companies were strongly represented at the workshop:

France:	ArevaH2Gen
Germany:	Hydrogenics, McPhy Energy, Siemens and ThyssenKrupp
United Kingdom:	ITM Power
United States:	Giner and Proton OnSite

Moreover, representatives from components suppliers as Evonik Industry (Germany), IRD Fuel Cells (Denmark), SolviCore (Germany) and system integrators as Schmack Carbotech (Germany) attended the workshop and the IEA meeting. In different presentations the companies ArevaH2Gen, Siemens, Proton OnSite and ITM presented their view on cost reduction strategies for PEM electrolysers. All provided presentations are available in [Meg15].

ArevaH2Gen

The targets for the near future are to expand the product line to 5-240 Nm³/h at 35 bar. In order to address future markets like grid balancing, Power to gas and hydrogen stations, it is necessary to reduce cost without compromising overall efficiency. ArevaH$_2$Gens strategy to achieve this is as follows:

- Increase cell surface area.
- Increase current density
- Increase operating temperature

Increasing the number of cells in the stack does not influence the overall stack costs, but has a significant impact on the BOP costs.

Proton OnSite

The company has developed several PEM product lines in the last 20 years. Currently, Proton expands as well their product portfolio to the MW range (development of the M series). So far, the stack accounts to less than 50 % within smaller systems (< 10 Nm³/h) and the power electronics to roughly 20 %. Flow field, membrane electrode assembly, and labor have a high cost share on the stack level, whereas catalyst represents only 6 % of the total stack cost. Cost reduction was and will be achieved by:

- Development of stack platforms with larger active area
- Continuous design improvements, e.g. reduction of stack parts, material reduction through improved stack design
- Aiming higher current density operation through “catalyst strategy” (increasing OER activity, improving electrical conductivity, decreasing noble metal content through engineered structures)
- Decreasing labor costs through higher automation and improved quality control methods
- Increasing operating temperature through different membrane modification approaches (however, increasing operating temperature is not only a technical challenge)

Additional considerable cost reduction can be achieved with economies of scale, in particular on the system level. A cost reduction through scale up in capacity (from 100 % to 28 % for the scale up of the S series to the C series) could be demonstrated. It is expected that an advanced 2 MW system will have less than 10 % of the specific $/kW cost of the S series.

Siemens

The company pointed out that cost of hydrogen mainly depends on electricity costs, number of operational hours and capital costs. A detailed cost reduction strategy was not presented but the known technological roadmap of Siemens favours a cost reduction through scale up of the cell area in the range of square meters and the installation of large PEM electrolysis systems up to 100 MW. Moreover economic benefit should be feasible through an overload capacity of the system to enable with a given size at rated power a large application window.

ITM Power

ITM Power is a company that is specialised in the manufacture of integrated hydrogen energy systems. ITM focuses its development on savings coming from running the water electrolyser at higher current density with only a small penalty on electrolyser efficiency. Already today CAPEX of

WE systems based on ITM’s LEP stack design are close to the MAWP targets of 2017. The new stack design followed in the Megastack project enables a further cost reduction potential clearly below the EU targets for 2017. Cost considerations are separated for the stack and for complete systems. On the stack level, cost reduction can be achieved by technology choices (e.g. higher current density) but also processing strategies (e.g. material and process selection), manufacturing strategies (e.g. reducing assembly times, supply chain engagement) and lifecycle strategies (e.g. minimising service times). On the system level further steps are possible for cost reduction, e.g. design reviews and cost cutting exercises.

4. Summary and conclusions

The conversion of electricity into hydrogen by water electrolysis is expected to emerge as a viable alternative for energy storage beyond conventional power to power systems. Produced hydrogen may be injected in the natural gas or hydrogen grids, used as an energy carrier in mobility applications or as a feedstock in chemical industry, further contributing to the decarbonisation of these sectors. Due to the constantly growing utilization of RES a large market growth for electrolytic hydrogen production is expected in the next 10 to 20 years. The market could be in the range of several tens of GW and will become even larger until 2050 if an 80% reduction in GHG emissions remains a worldwide goal. However, the actual market growing will depend on: i) the real penetration of RES in the energy sector, ii) market development for sustainable transport based on BEV and FCEV and iii) on political and legal frameworks, e.g. environmental protection and climate protection policies.

Despite of these uncertainties, the future worldwide annual production capacity of electrolysers will be a multiple of today’s market volume for electrolysers. It is expected that both low temperature - alkaline and PEM - electrolyser technologies will have its market share in the future, but it seems to be clear that PEM electrolysers will be favoured at least for distributed or decentralized hydrogen production with the need for higher pressures required from the application (e.g. on-site electrolysers for HRS) whereas both technologies are suited for larger hydrogen production installations. For the small PEM electrolysis manufacturing industry this means:

- Complete new supply chains with capability of large volume production will emerge;
- Scale up of cells and stacks will be crucial to reach required production volume - from kW into (multi-) MW scale on stack level;
- Today’s electrolyser manufacturing must turn into (semi-) automatic production processes and lines with new production technologies.

Within the workshop “Cost Targets for Water Electrolysis and Cost Reduction Strategies for PEM Electrolyser” a commonly accepted view on the market application for large scale (PEM) electrolysis systems and possible/preferred cost reduction strategies by manufactures were presented and discussed. In general, cost reduction strategies can be classified into the categories of (i) technology related cost reductions, (ii) design and process savings, and (iii) manufacturing related cost reductions. Mostly cost reduction strategies of different PEM electrolysis manufactures comprise:

- (i) Aiming higher current density operation through improved catalyst systems
- (i) Increasing operating temperature(through novel membranes)
- (ii) Development of stack platforms with larger active area
- (ii) Design improvements, e.g. reduction of stack parts, material reduction through improved stack design
- (iii) Decreasing labor costs through higher automation and improved quality control methods

Additional cost reduction can be achieved with economies of scale, in particular on the system level. The approach followed in the project Megastack is a combination of the above mentioned cost reduction strategies and will be in the window of the MAWP targets.

Bibliography

[DNV13] DNV KEMA Energy & Sustainability: “Systems Analyses Power to Gas”, Final Report, June 2013.

[E4T14] E4tech Sàrl with Element Energy Ltd for the Fuel Cells and Hydrogen Joint Undertaking: “Development of Water Electrolysis in the European Union”, Final Report, February 2014.

[Eur11] Homepage EUR-Lex: “A Roadmap for moving to a competitive low carbon economy in 2050”, http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:52011DC0112, last access 2015-10-13.

[FCH14] Fuel Cell and Hydrogen Joint Undertaking: “Multi Annual Work Plan (MAWP) 2014 - 2020”, June 2014.

[Hen15] Henning, H.M. et al. (2015): “What would be the ideal combination of technologies and fuels in the energy system of the future?”, Presentation, Conference “Technology Challenges and Regional Approaches for integrating Renewables and Energy Security“ Brussels, Belgium, May 27-28, 2015.

[IEA14] International Energy Agency (IEA): “Technology Roadmap Energy Storage”, Report, March2014.

[IEA15] International Energy Agency (IEA): Technology Roadmap Hydrogen and Fuel Cells, Report, June 2015.

[Kin10] McKinsey & Company: “A portfolio of power-trains for Europe: a fact-based analysis” (known as EU coalition study), Final Report, November 2010.

[Kin15] McKinsey & Company: ”Commercialisation of Energy Storage in Europe”, Final Report, March 2015.

[Meg15] Homepage FCH JU project Megastack: “ Presentations” http://www.sintef.no/projectweb/megastack/news-and-events/presentations/, last access 2015-10-13.

[Smo15] Smolinka, T., Voglstätter, C., Fallisch, A.: “Cost Break Down and Analysis of PEM Electrolysis Systems for Different Industrial and Power to Gas Applications”. Poster presentation, Int. Conf. Renewables Energies, Düsseldorf, Germany, March 09-11, 2015.

[Smo15a] Smolinka, T.: “Cost Break Down and Analysis of PEM Electrolysis Systems for Different Industrial and Power to Gas Applications”. Presentation, World of Energy Solutions, Stuttgart, Germany, October 12, 2015.