1 PUBLISHABLE SUMMARY

1.1 Project overview

The main objective of MEGASTACK is to develop a cost efficient stack design for MW sized PEM electrolysers and to construct and demonstrate a prototype of this stack. The prototype will demonstrate a capability to produce hydrogen with an efficiency of at least 75% (HHV) at a current density of 1.2 Acm^{-2} with a stack cost below €2,500/Nm^3h^{-1} and a target lifetime in excess of 40,000 hours (< 15 μV^{h-1} voltage increase at constant load). In the project we aim to take advantage of the existing PEM electrolyser stack designs of ITM power as well as novel solutions in the low-cost stack design concepts developed and further refined in the FCH-JU projects NEXPEL and NOVEL. In order to successfully up-scale the design concept from a 10-50 kW to a MW-sized stack, we will in the MEGASTACK project perform integrated two-phase flow and multi-physic modelling together with optimization of stack components such as MEAs, current collectors and sealings which are important for stack scale up.

To reach these ambitious objectives, MEGASTACK will develop and demonstrate an enhanced stack design essential for cost-competitive, efficient and dynamic PEM electrolysis systems through the following key concepts:

- The stack design process will have an integrated approach, involving stack manufacturers, component and MEA suppliers as well as PEM electrolyser experts from research institutes.
- Evaluation and adaptation of existing solutions and commercially available components for use in large format stacks and increased ease of stack assembly by the reduction of stack part count.
- Advanced multiphase flow modelling coupled with multi-physics models for electrochemical kinetics, heat and momentum transport will be used as detailed design tools for cell and stack components.
- Implementation of quality control measures and supply chain evaluation of all components will be performed in order to reduce costs and minimise technology and manufacturing risks.

1.2 Description of the work performed and main results of the MEGASTACK projects

During the final period of the MEGASTACK project, the consortium has performed a study on the cost and performance targets for large scale PEM electrolysers, including the organisation of a cost reduction strategy workshop. The technical work has involved development of multi-scale and multiphysics models for PEM electrolysers, performance and lifetime evaluation of CCMs and stack design and prototyping.

Cost and performance analyses

This activity has been focused on establishing cost targets for large-scale PEM electrolysers and establishing a robust cost reduction strategy. As part of this activity, the consortium organised a cost reduction strategy workshop in conjunction with the 2nd IEA ANNEX 30 Electrolysis Meeting at the Hydrogen Centre of Excellence in Herten, Germany. Within this workshop, the 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.

A comparative life cycle assessment on MW-sized PEM electrolysers based on i) the existing ITM stack design and ii) the cost-efficient stack design developed in the MEGASTACK project has been performed. The LCA compares in a life cycle (cradle-to-gate- plus use phase-) perspective the environmental aspects of the two design options by following practice guidance and required provisions developed by the FCH – a method that complies with the ISO 14040 and 14044 series.

Mathematical modelling and verification

The main objective of this activity is to develop and use multiscale and multiphase models as engineering tools for stack design and up-scaling. The models will be verified and validated using advanced experimental set ups such as distributed current mapping and flow visualization.

The modelling work has been performed by the partners as follows:

- SINTEF has modelled the two-phase flows occurring in the liquid/gas distributor region using ANSYS FLUENT®. It has performed several calculations in single phase and two-phase flows. These simulations have been compared to flow visualizations that demonstrated the good agreement between them. These simulations have been spatially averaged at large scale to derive the permeabilities requested by the Darcy-Forchheimer model used in the coarse nodalization code.
- Fraunhofer has developed a submodel in Comsol of anode half-cell to describe the electrical and electrochemical behavior. Polarization curves can be calculated depending on material properties and operation conditions. Further a deep experimental analysis of the through plane and in plane flow of single flow and two phase flow in the sinter (PTL) was performed. New experimental methods were developed to measure the capillary pressure versus liquid saturation and the inner mean contact angle in PTLs, using capillary flow porometry. From these measurements, the parameters requested in the macroscopic models (in plane and through plane permeability, capillary pressure, and contact angle) have been determined. The dependence of these parameters on the liquid saturation has also been explored. Based on these results a new parameter was introduced to describe the 'gas transportability' in through plane direction of partially saturated PTLs. This parameter helps to identify a risk of mass transport limitation due to the properties of the PTL by using only ex-situ characterization techniques.
- CEA has developed an electrochemical law from various measurements. All the parameters and laws deduced from small scale simulations and experiments have been implemented in the MePHYSTO_WE code (based on Matlab/Simulink). Then a validation step using the experimental data has been driven successfully. Finally, CEA has performed several simulations of a one hundred cells stack, varying the geometry parameters and operating conditions in order to help the design.

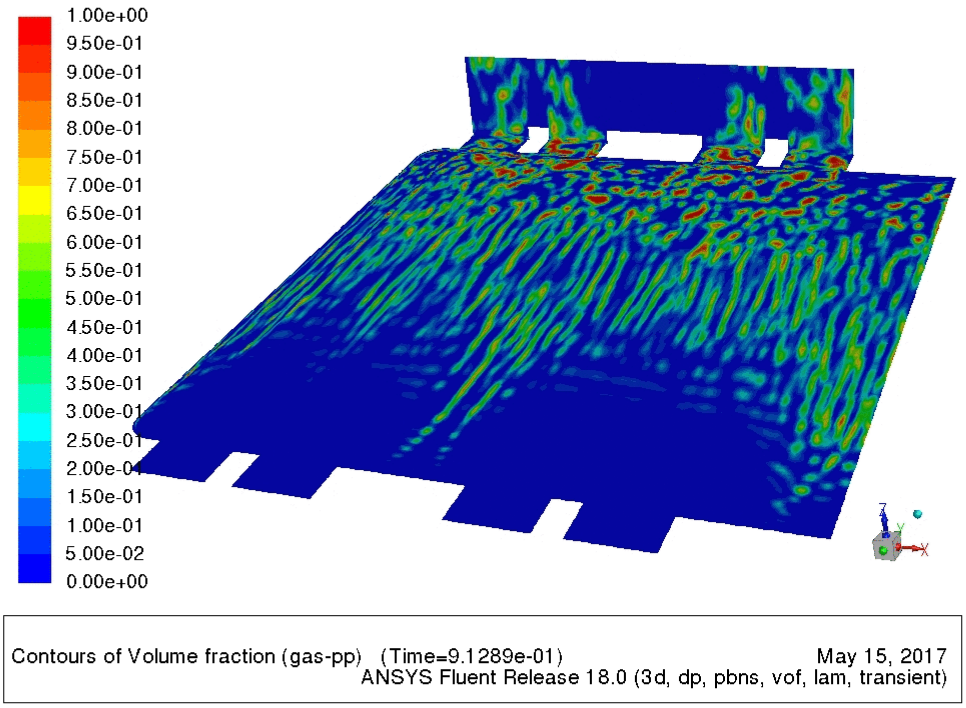

Figure 1: Simulated bubble flow in PEM electrolyser (left).

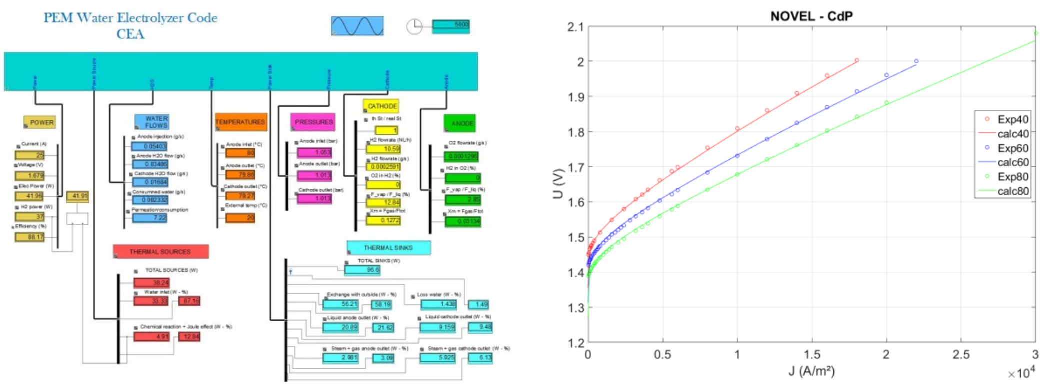

Figure 2: Multi-physic stack model framework (right) and simulated polarization curve (left).

Membranes and MEAs

In the period, full scale MEAs were developed to reduce the overlap of sealing area. Through experimental work we were also able to reduce the dry catalyst coated areas resulting in a reduction of ink required. The supplied CCMs were successfully integrated into the cell and proved to withstand the required temperature and pressures set out in the project.

The low cost manufacturing of the MEA is based on three methods:

- Increasing the coated area versus uncoated surface area of the membrane. The improvement seen in the MEGASTACK project is quantified versus ITM current technology.
- Reduction of catalyst coated area in line with expected membrane expansion (distortion printing)

- Less catalyst wastage (during manufacturing) by moving from circular design to a rectangular design

Stack design and manufacturing strategies

The main objective of this activity was the development of a large-scale stack design for PEM water electrolysis based on an upscaling of existing stack concepts from 415 cm² to approx. 1000 cm². The stack design approach and methodology was set up in the first period of the project and followed a process used by ITM in previous system designs including: (1) Cell component layout, (2) Material choices, (3) Structural analysis of sealing faces and pressure bearing components, (4) Contact pressure across active area, (5) Cooling and flow distribution, and (6) Manufacturing strategy.
In terms of cell components testing a set of 4 porous transport layers (PTL) has been investigated with respect to their stability against anodic oxidation. For comparison, also a titanium sheet and a commercial Ti sinter were tested in the same way.

Large scale stack prototype construction and testing

A prototype electrolyser system for testing of MEGASTACK short stacks has been designed and constructed. The system consists of a stack skid, balance of plant equipment and programmable power supplies. The cell plates is housed in structural frame (called the stack skid) which is a patented ITM design. This allows the variation of cell sealing pressure without the need to use spanners and Bellville washers. ED goals devised using petro chemical gasket maintenance factor values and empirical data from previous systems to set a sealing force requirement. Based on these values the skid has been designed and analysed against EN13445 and EN13121-3 using long hand calculations and 3D nonlinear FEA contact analysis.

Figure 2: MEGASTACK stack skid

The BoP design has been based around existing ITM product knowledge. Certain control aspects were developed from understanding gained from the previous FCHJU PEM project "Phaedrus" Vessel and pumps were selected based on theoretical flow rates required for an up scaled system of this size. A bespoke Siemens S7 1200PLC control system was developed to allow accurate control, safe operation and data logging capabilities.

Figure 3: Completed prototype electrolyzer system.

1.3 Expected final results and potential impacts and use

The results obtained in the MEGASTACK project are very promising, with a functioning large-scale PEM electrolyser stack and balance of plant designed, constructed and tested. The MEGASTACK system is now part of ITMs commercial offerings. The main expected outcomes from the technological developments are:

In addition, performed market analyses of the utilization of PEM electrolysers in different application areas (micro wind & PV for telecom, green H_2 stations and large scale H_2 production from renewable energy sources), will give a better understanding of the role of PEM electrolysers in a future hydrogen economy.
More information can be obtained by contacting the project coordinator (magnus.s.thomassen@sintef.no)