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 structural mechanics modelling together with optimization of stack components such as MEAs, current collectors and sealings that 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 multiphysics 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 1st period of MEGASTACK

During the first 18 months 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.

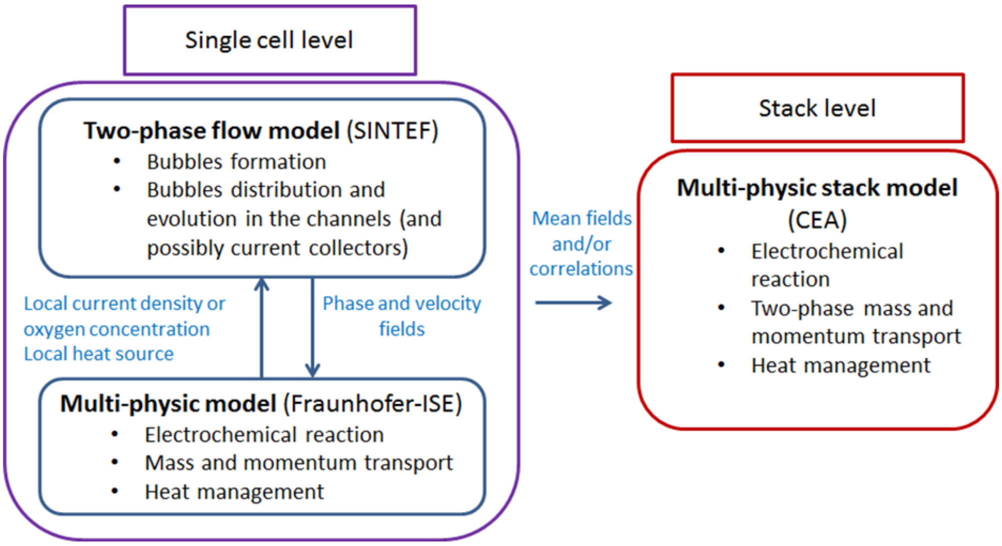
Cost and performance analyses

This activity has during the first year mainly been focused on establishing cost targets for large-scale PEM electrolysers and 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. In general, the 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 at higher current density operation through improved catalyst systems
- (i) Increasing the 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 labour costs through higher automation and improved quality control methods

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 distributed among the partners and the interactions between the models have been defined as well as the role of the partners as shown in the figure below.



During the first period, Fraunhofer has commissioned a single test cell for I-V-characterisation in order to study different combinations of MEAs, current collectors and flow fields. An electrical and electrochemical model has been developed to study local current density in catalyst layer/current collector interface and to calculate I-V-curves.

At SINTEF, a two-phase flow model has been developed in order to study the gas-liquid flows during water electrolysis process. Relevant experiments have been designed to validate the two-phase flow model. A high speed camera is used to capture images of gas bubbles which then are analyzed by means of advanced image processing. The results from numerical simulations is processed using the same algorithms and the results are compared.

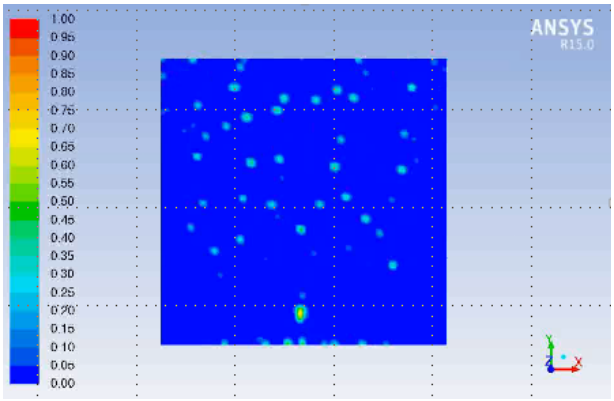


Figure 1: Multiphase flow model framework (right) and simulated bubble flow in PEM electrolyser (left).

CEA has adapted their PEMFC code PS++ to PEM electrolyser conditions. The software structure is now operational after the necessary code changes and debugging work. The simulated results have been validated against experimental polarization curves and water crossover measurements. Proof of concept on the use of acoustic emission (AE) measurement to characterize diphasic flow within the cell was set up and the absolute energy was found to follow the various current regimes.

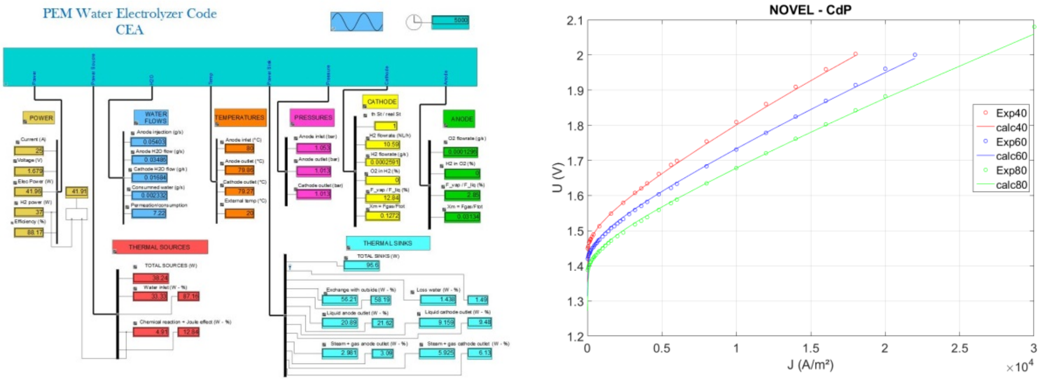


Figure 2: Multi-physic stack model framework (right) and simulated polarization curve (left).

Membranes and MEAs

In the period, a screening and selection of MEAs for the project has been performed. A number of MEA suppliers across Europe were provided with a design plan, and in return a large number of MEA's were provided for testing. Over the range of MEA's received were the suppliers' standard MEA designs; however there were also several containing trial materials such as new membranes, low-cost catalysts and very low catalyst loaded designs. Several of these MEA's thus had the potential to offer significant cost-reductions of the electrolyser, reducing the overall Capex of the electrolyser system by reducing the cost of one of the more expensive components.

The MEA's underwent a standardized regime of tests covering a range of operating conditions. This allowed the down selection of the most efficient MEA designs based on their performance and resistance to adverse conditions such as frequent power cycling and high current density operation. Through this project new MEA tests were developed which promise to accelerate long-term MEA lifetime tests (which take several thousands of hours or even years) into tests which take only several days.

The evaluation of MEAs was based on multiple criteria, such as cell voltage at high current density, resistance to ITMs proprietary accelerated stress tests (AST) and the hydrogen crossover rate at differential pressures. More than four suppliers of MEAs have been tested and it was found that MEAs with low loadings of PGMs gives the best balance between cost, performance and durability.

Stack design and manufacturing strategies

Main objective of WP4 is the development of a large scale stack design for PEM electrolysis. This is based on taking existing stack concepts developed and used by ITM and upscaling them. Based on the cost benefit analysis for electrolysis stacks and systems in WP1 a global approach to stack design was applied using a multi-criterion (e.g. technical/economical risk, supply chain strength, cost reduction potential) design verification plan (DVP). **Engineering development** for stack design comprised modelling analysis using engineering principles such as FEA, CFD and mathematical calculations. Comprehensive testing of individual cell and stack components as **design verification** was part of this approach and is ongoing for further analysis as **product verification**.

Apart from upscaling the cell area from 415 cm² to larger than 1000 cm² (more than a factor of 2.5), the main difference in the MEGASTACK design compared to previous ITMs designs is the move to a rectangular active area from the circular active area. The reason for this is a result of WP1 where the cost benefits due to material waste compared to circular systems is covered.

Large scale stack prototype construction and testing

The goal of this activity will be to construct and test short stacks based on the stack design developed in the project. Technical validations of the stack design, the efficiency and stack performance will be performed under real life data cycles and the capability of the stack to operate in different applications such as HRS or direct coupling to renewable energy sources will be evaluated. This activity has during the first year been limited to establishing the necessary test bays for the upcoming stack evaluation. The design was made with focus on the overall reactant flow rates, removal of gas and cooling of the stack which lead to dimensioning of the manifolds in the stack and the main geometric parameters.

A general view of the cell design and assembly is given in the following figure.

Figure 2: Large area cell design and assembly as developed from ITM within the project

Dissemination activities

Dissemination activities have a high focus in the project and the consortium acknowledges the importance of promotion of the development of technologies for sustainable hydrogen production. Our public webpage (www.megastack.eu) is continually updated with news from the project, the latest dissemination activities and scientific presentations and papers.

1.3 Expected final results and potential impacts and use

The results obtained in the first period of MEGASTACK are promising and demonstrate a high probability for achieving improved performance and reduced cost of PEM water electrolysers. The main expected outcomes from the technological developments are:

- A stack design for MW sized PEM electrolyser with significant lower cost that state of the art.
- Additional cost reductions of existing electrolyser products through improvements in supply chains and assembly.
- Modelling tools for stack, cell and component optimisation and control of PEM electrolysers.

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)