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Field demonstration of large scale stationary power and CHP fuel cell system

GA No. 621256



Demonstration of a combined heat and power 2MWe PEM fuel cell generator and integration into an existing chlorine production plant



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1 Publishable Summary

1.1 Summary description of project context and objectives

1.1.1 Project concept

The concept of DEMCOPEM-2MW is to explicitly demonstrate the feasibility, reliability, and availability of PEM fuel cells in a large scale stationary application of at least 2 MWe in China. The demonstration will take place in the industrial environment of a chemical factory.

In the chlorine industry hydrogen of high quality is often available at low or zero cost, and the heat and electrical power from hydrogen can be directly fed into the plant's production process. PEM fuel cell power and heat will be delivered at the industrial level of 2 MW electrical power (MWe) and 1.5 MW of heat. It is clean, silent, and non-polluting. The exhaust product, pure water, is also utilized in the process. The commercial viability of PEM fuel cells in competition with thermal machines is best demonstrated in the chlor-alkali industry in China because in this industry the value of the PEM fuel cell electrochemical power is highest. This is due to the relatively high electricity prices in most areas in China. These are up to 2 times higher than in Europe and rising; *i.e.* 550- 600 Chinese RMB/MWh (~ Eur 68-75/MWh) and the abundant availability of hydrogen that is vented by many of the ca. 180 chlor-alkali plants (~50% chlorine world production) in China. Also, the common shortage of electricity supply in China in certain periods of the year contributes positively to the business case via the contribution margin of additional chlorine production in these periods. However, to create real interest for the PPP in China a successful demonstration of PPP in China is needed. After a successful demonstration 20-50 PEM Power Plants of at least 2 MWe for H₂ conversion from chlor-alkali plants in the coming 5-8 years is a realistic scenario for the market introduction phase in China.

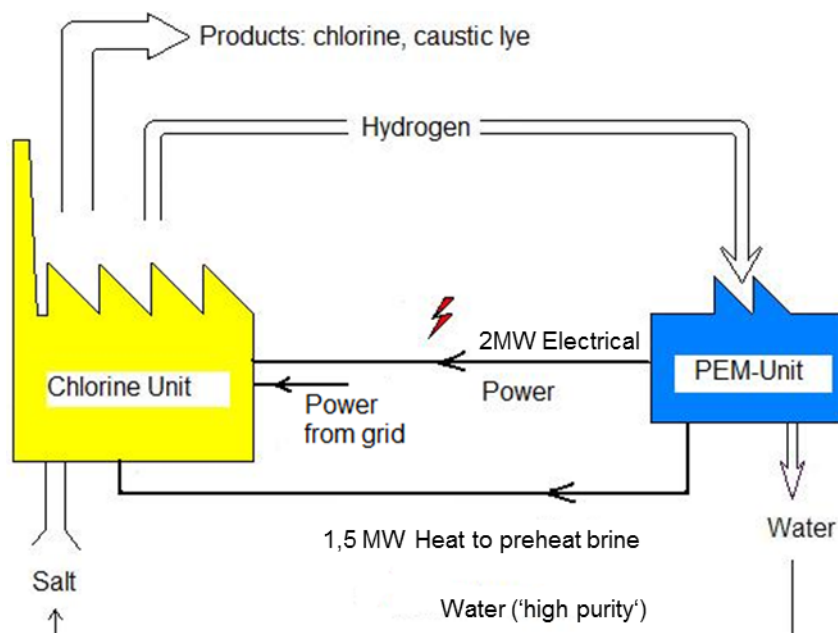


Figure.1-1 DEMCOPEM-2MW Concept. On the left, chlorine production plant; and on the right, the PEM fuel cell plant.

1.1.2 Objectives

The main objective of the four years DEMCOPEM-2MW project is to design, build and operate a 2 MW power generator, with the following attributes:

- Full integration of heat and power with an existing chlorine production plant
- High net conversion efficiency, i.e. > 50% electric energy on system level and > 85% for combined heat and power
- Long lifetime of system and fuel cells, i.e. over 2 years (16,000 hrs) for fuel cell stacks without any need for repair or maintenance of the membranes. The long-term target is 5 years (40,000 hrs) for fuels cell stacks
- Fully automated way of operation and remote control
- Economical design to reach a competitive price, i.e. < €2,500 / kWe with potential for reaching < €1,500/kWe in 2020. With membrane lifetime of 5 years and high volume series (> 25 MWe/y) production the cost price of the electricity produced with a PEM power plant is estimated to drop from 0,075 to below 0,04 Euro/kWh.
- Demonstration of power and heat generation for over 2 years i.e. on-stream availability of > 95% for over 16,000 hours, in line with the Annual Implementation Plan 2013 objectives
- Contribute to the general goals of the JTI FCH, as stated in the revised Multi Annual Implementation Plan, to have > 5 MW @ € 3,000/kW installed fuel cell capacity in 2015 and > 50 MW @ € 1,500/kW installed fuel cell capacity in 2020.



Figure.1-2 – One of the DEMCOPEM-2MW container at Ynnovate

1.2 Description of the work performed since the beginning of the project and the main results achieved so far

1.2.1 Main technical Achievements/results

The most relevant result for this second period of the DEMCOPeM project is the installation and commissioning on-site and operation of the PEM power plant.

This includes also the understanding of possible problems and failures.

In particular the following technical results have been achieved by the specific categories (RTD and DEMO) / work packages:

RTD

WP3:

- At plant commissioning and in the first months of operation the behaviour of the plant corresponded to expectations, with performances fully in line with the project targets. In the next operating period, the occurrence of an unexpected, mostly reversible decay generates some differences with expectations.
- The analysis on possible uneven distribution of flows among the stacks, performed through direct measurements at MTSA, evidenced some differences in the distribution of air and cooling water. Possible impact on performances was preliminarily discussed as a basis for further assessments.
- The general behaviour of the plant in the observed operating period allowed to identify some issues, such as oscillations in the hydrogen pressure and flow rate that evidenced issues in the valve control logics, which has been later improved and solved.
- Calculations have been performed in order to look for possible causes of decay, at any rate indicating no correlation between observed trends in voltage differences among the stacks in the module and corresponding overall plant operating conditions.
- With respect to the model calibration and validation, the comparison shows that the voltage at nominal current is well modelled. In addition to the comparison of stacks performances, the overall plant behaviour is simulated and compared with the data. Globally, the model performs satisfactorily (errors < 2%) and most variables are well predicted by the simulations. Adjustment are required in terms of decay rate.
- The model is applied to investigate the effects of possible unexpected phenomena on the plant operation (e.g. occurring of an incomplete humidification, uneven flow distribution), discussing also the operating conditions and strategies once the conventional minimum voltage threshold for voltage is reached.

WP6:

Results from the power plant suggest the fuel cell MEAs are affected by short-term, reversible decay, which appears to be caused by impurities in the reactant gases at the 2MW power plant at Ynnovate. This means developing an improved MEA to mitigate early failures due to MEA design has been difficult. Nevertheless, JM have produced four MEA prototypes to offer potentially some combination of longer lifetime, higher performance and lower cost, and resistance to a common hydrogen contaminant. These MEAs have been delivered to NFCT for testing in a mixed (“rainbow”) stack.

WP7:

- The 2MW unit has been put in successful operation since Sept 2016 and showed varying uptimes, mostly due to hydrogen feed and grid capacity restrictions of the Ynnovate site until mid 2017. Since then the uptimes have improved considerably, reaching at least 90% for all 6 groups in Dec 2017.
- Only in the first operational months some stacks have been returned to Nedstack for analyses and repair, mostly due to a temporary, external particle contamination.
- The dedicated cell voltage monitoring software is fully operational since Jan 2017 and shows a (reversible) performance decrease in Yingkou, which is higher than expected. When return stacks from China are operated in the Delfzijl plant, they show a normal performance again, indicating an external

cause for the behavior in China. A joint investigation plan to determine the root cause of this behavior has been made and is being discussed with Ynnovate.

- Together with JMFC alternative MEA options have been selected with improved durability, economics, or contaminant tolerance. The first proto-stack has been analysed in detail, prior to installation in the Delfzijl Pilot plant for durability testing.

DEM

WP2: Most of the work for this WP has been already finalised; the complete process and lay-out design of the PEM plant, including the planning and set-up of the operating system have been prepared and submitted.

WP4: Most of the work for this WP has been already finalised; the 2 MW PEM Power Plant was installed and connected on the local utilities and functioning since then integrated with the local site. During the test period and in the first operational period however, a number of non-conformities in the utilities and hydrogen feed were observed. A main number of the non-conformities are solved by means of corrective actions.

WP5: Successful SAT, and full 2 MWe power since Jan 2017. Some support has been provided and partners are collaborating with Ynnovate in order to solve the non-conformities observed onsite.

The complete overview of the work undertaken and the results for the different WPs are reported in the Core Part of this report.



1.2.2 Other Achievements

Technical Aspects:

- Full integration of power with an existing chlorine production plant has been achieved; thermal heat is currently not yet used by the customer
- High net conversion efficiency, i.e. 50% electric energy on system level has been demonstrated, as well as the availability of heat, to reach up to 80% for combined heat and power
- Long operational lifetime of system and fuel cells, i.e. over 7000 operating hrs have been achieved already.
- Fully automated way of operation and remote control has been demonstrated
- Demonstration of power generation achieving an average on-stream availability of > 95% towards the end of 2017.
- Already over 11 kton CO₂ emission reduction has been realized by operation of the plant during the project

Other Aspects:

- Up and running project website: www.demcopem-2mw.eu
- Launching Ceremony & First project workshop (more information reported in the public project [deliverable D8.5](#)). Below few pictures of the event (project presentation at workshop, and Ribbon Cutting Ceremony)



1.3 Expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far)

1.3.1 Expected Final results

The application area of the project DEMCOPEM-2MW is “Field demonstration of large scale stationary CHP fuel cell systems”, Topic SP1-JTI-FCH.2013.3.5. The proposed PEM fuel cell power plant is to be demonstrated at a chlor-alkali plant in China, and will serve as showcase for the prospected roll out of the PEMFC technology in China/Asia. Several chlor-alkali plants have shown serious interest and signed LOI's for a PEM power plant and at least 25 show an attractive business case for the next series PEM power plant. The final selection of the chlor-alkali plant for the demonstration will be based on the attractiveness of the business case and the suitability to act as showcase.

Based on the attractiveness of the business case and the suitability to act as showcase, the selected candidate has been Ynnovate Sanzheng (Yinkou) Fine Chemical Co. Ltd. In total 24,000 Nm³/hrs of H₂ purged (of which 4,400 Nm³ very pure from Chlor Alkali).

DEMCOPEM-2MW provides and demonstrates:

- An industrial fuel cell system, rated at 2 MW_e fully integrated into the chlorine plant.
- Conversion to power of the by-product/waste hydrogen.
- Restitution of the energy content of the by-product/waste hydrogen to the production process
- The employment of fuel cell technology perfectly matched to a chlorine production process that is also based on membranes and operates on similar pressures and temperatures. Demonstration of the lifetime of PEM fuel cells well beyond 16,000 hours is one of the main objectives. The MEAs for this stationary application will be applied with reinforced membranes and stabilized cathodes.
- Automatic operation with remote monitoring, backed-up by an advanced data-acquisition system that will enable improvement of parameters during the period of demonstration.
- Contribute to the general goals of the JTI FCH, as stated in the revised Multi Annual Implementation Plan, to have > 5 MW @ € 3,000/kW installed fuel cell capacity in 2015 and > 50 MW @ € 1,500/kW installed fuel cell capacity in 2020.
- A lifetime of the system that exceeds the 40,000 hours, as required in the 2013 Annual Implementation Plan.

To create real interest for the PPP in China a successful demonstration of PPP in China is needed. After a successful demonstration building 20 - 50 additional PEM power plants of at least 2 MWe each for H₂ conversion from chlor-alkali plants in the coming 5-8 year in China is realistic. With the expected development of the lifetime of the membrane to 5 years, the further reduction of the investment to below 1,500 Euro/kWh, the cost price will become well below 0,04 Euro/kWh making the technology economically feasible for all chlor alkali plants in the world and also the chlorate production process.

Worldwide the amount of hydrogen produced by chlor-alkali plants would be sufficient to produce about 3,000 MW with a PEM power plant. The ultimate target would be to have at least 1,000 MWe/h produced via a PEM power plant worldwide.

1.3.2 Expected Impact

DEMCOPEM-2MW designed, built and integrated a 2 MW PEM fuel cell power generator in an existing chlorine production plant in China, and started demonstrating power generation (planned period is for over 2 years) with one set of fuel cell stacks and over 95% on-stream availability. Further, it developed MEAs and fuel cell stacks with improved performance and lifetime that will be validated in ANIC's PEM pilot plant in Delfzijl (and in the PEM demo plant in China) and a roll out plan (exploitation plan) for the Market Entry.

In the figure below a scheme of the project exploitation plan as well as DEMCOPEM-2MW's position in respect to the road map towards full implementation of PEM power plant in 2020 onwards.

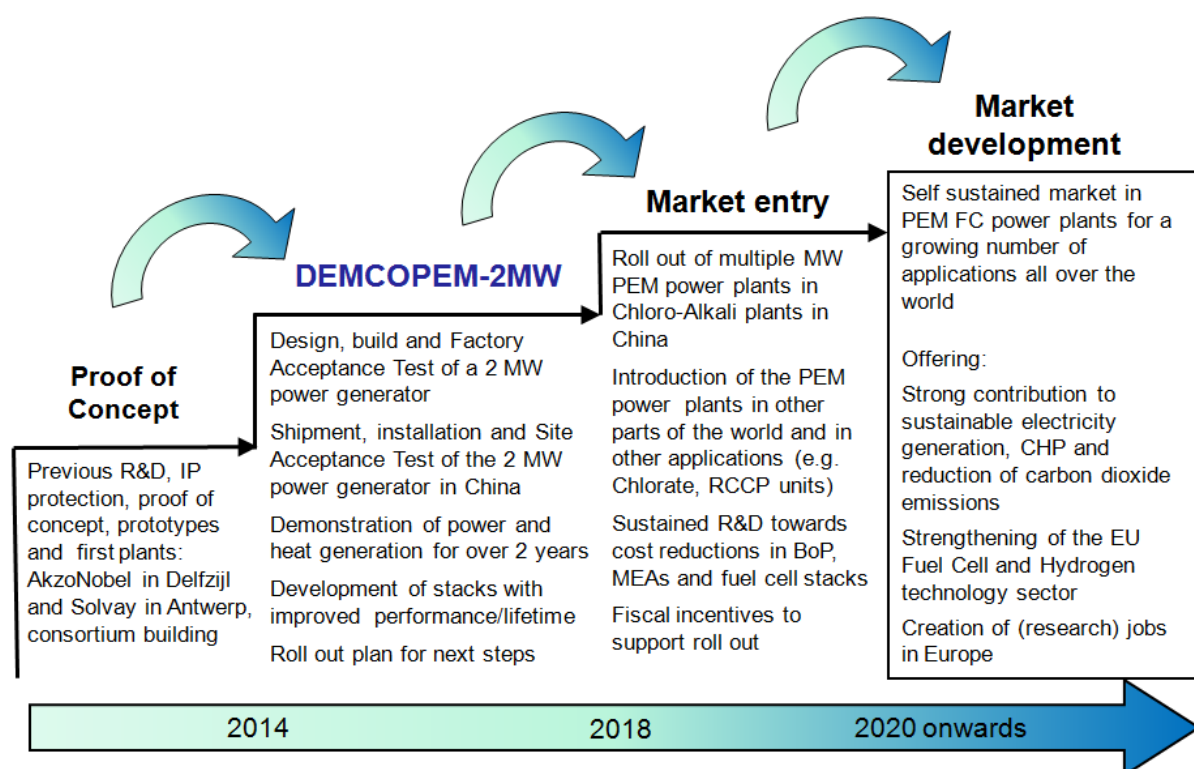


Figure 1-3 DEMCOPEM-2MW's position and roadmap towards full implementation in 2020 onwards.

For the **Market Entry** phase the plan is to roll out multiple PEM power plants in Chlor-Alkali plants in China together with Chinese partners. ANIC has already made an inventory of potential customers and locations that have been informed of the demonstration and its results during the demonstration period through newsletters, workshops and site visits.

To understand the potential of the list of potential customers and locations presented in the table one should realize that a 2 MW PEM Power Plant requires a hydrogen capacity of 1,300 Nm³/h. In other words, **the list cumulates at least 25 plants and in total over 100 Megawatts.**

The manufacturing possibilities in Europe are as follows:

- JMFC will produce and sell improved MEAs to NFCT;
- NFCT will purchase MEAs from JMFC and produce and sell improved fuel cell stacks
- MTSA will develop and build series of the PEM Power Plants, integrate the fuel cell stacks, and ship the plants to China.

The second project period focused on the possibilities to extend contacts with the Chinese (and worldwide) Chloro-alkali industries and possible synergies with other sectors/projects. We received enquiries from different continents to explore the possibilities of the DEMCOPEM technology for the local Chlor-alkali industry. We are also exploring the possible fit of the DEMCOPEM technology may have in large scale energy and hydrogen projects in the context of the energy transition in Europe. Moreover the DEMCOPEM technology may play a role in the hydrogen economy in balancing supply and demand.

Socio-economic Impact

At the moment commercialization is most interesting for cases where hydrogen is a waste product, vented to the atmosphere. Large reduction of CO₂-emission is possible when the energy content of the otherwise vented hydrogen is used. To enter the market the production of electricity with by-product hydrogen should be competitive with the price from the local grid, taking into account the avoided CO₂-emission. The chlor-alkali industry, and to a lesser extend the chlorate industry, generally has favourable contracts with electricity companies as cost of electricity is crucial. In Europe, these tariffs can be as low as € 40/MWh and sometimes even less. Therefore, China has been selected as, in this strongly growing economy, the electricity prices can be as high as €70 to €80/MWh. Moreover, rationing of energy is common practise in various regions of China as the

build-up of power plants does not keep pace with the economic growth and growing energy demand. In these situations, *i.e.* a high electricity prices and rationing of electricity, the business case for a PEM power plant is economically viable as showed in the beginning of this section.

Chlorate plants in the world produce a quantity of hydrogen that would enable PEM fuel cells to generate 300 MW of power continuously. Three molecules of by-product hydrogen are released for every molecule of sodium chlorate. These plants are connected to wood pulp factories, associated with the paper industry. They are often positioned in remote areas with limited possibilities for the utilization of hydrogen. Technically a multiple MW PEM-unit can readily be fitted, but commercial criteria for cost and lifetime, similar to those of the chlor-alkali industry, must also be met.

Some years ago AkzoNobel developed Remote Controlled Chlorine Production units (RCCP units) as an environmentally friendly alternative for chlorine transportation and as an economic and environmental alternative for smaller plants based on the mercury electrolysis process. The coupling of a PEM FC power unit to an RCCP unit is promising as the hydrogen is freely available in most cases. The size of 1-3 MW is a perfect match for the RCCP-unit as it takes all by-product hydrogen, reducing the intake from the grid by 20 %. The utilization of the heat from the PEM-unit means extra savings in fossil fuels.

The specific benefits of the DEMCOPPEM-2MW fuel cell stack are in particular interesting in the following applications (in China, Europe and worldwide):

- Range extension in EV's; this market has gained substantial traction in Europe and in Asia. TCO and lifetime are essential and will be outcomes of the DEMCOPPEM-2MW project
- Grid-balancing and reduction of CO₂ emission in electricity production. Fuel cell technology can play an important future role here and relevant companies as State Grid should be made aware of the advancements and reliability of fuel cell technology for large scale power supply
- Base-load power or extended back-up in telecom and utility market. These units typically provide < 10 kW power and with ongoing developments in reformer-technology these markets become within reach. Especially in the larger Southeast Asian region exists a huge demand for reliable (implying very long lifetimes) and clean power supply.

Wider Societal Implication

In December 2015, at the Paris climate conference (COP21), 195 countries adopted the first-ever universal, legally binding global climate deal in order to avoid dangerous climate change by limiting global warming to well below 2°C. This agreement is due to enter into force in 2020.

Before that date countries need to work on their 'National Climate Action Plans' (already prepared before the Paris conference).

One of the most important possible solution for limiting global warming is to reduce or completely eliminate the use of fossil fuel. With this vision in mind the renewable energies became/ will become main actors.

The technology developed in the DEMCOPPEM project will provide main advantages in this direction.

The climate will benefit by the reduction in CO₂-emission.

The PEM power plant technology, developed within the DEMCOPPEM project, will be introduced in other parts of the world and in other applications (e.g. Chlorate, RCCP units). In this phase it is important that sustained R&D efforts are taken to realise continuous cost reductions in Balance of Plants, MEAs and fuel cell stacks. Incentives for supporting the roll out, *e.g.* subsidies or fiscal measures for customers will be useful in the Market Entry phase.

The next step is the **Market Development** phase. In this phase, the market in PEM FC power plants has become self-sustained and cost-efficient for a growing number of applications all over the world.

The chosen project structure and approach ensures that the technology value chain in Europe now gets the opportunity to launch and develop as the business case for a PEM power plant in China is economically favourable. A successful field demonstration will pave the way for commercial introduction of PEM power plants in China (over 20 sites and potential for over 50 similar sized PEM power plants), will open up opportunities for introduction of the PEM power plant technology in other parts of the world and in chlorate and RCCP processes and will enable sustained research and development efforts to achieve cost reductions in fuel cell stacks and BoP, improved performance and longer lifetimes.

Demonstrating in China means a continuation of the development of the PPP technology. As soon as the PPP technology becomes cost competitive in Europe, it is ready for introduction in the EU.

1.3.3 External factors that may determine whether the impacts will be achieved

Tax on CO₂-emission would raise the price of electricity from the grid appreciably and would make the PEM-unit more competitive. Electricity produced with the most efficient natural-gas-fired units (50 % efficiency) leads to an emission of 0.4 tons of CO₂ per MWh. A charge of € 50 per ton of CO₂ raises the electricity price by € 20/MWh. Power produced with coal-fired units would be more expensive by € 60/MWh.

Further, the possibilities will be assessed at the Chinese Government to acquire subsidy for the introduction of this type of sustainable and energy saving technology; especially after a successful demonstration.

For fuel cell stacks also outside the chemical industry important opportunities in China and the Southeast Asian region are imminent.

The DEMCOPEM-2MW fuel cell stack (commercialized as XXL stack) is designed for high efficiency and exceptionally long lifetime. The actual demonstration of these features in the power plant will help to convince potential Chinese stack customers of the benefits of this specific stack technology over other suppliers.

1.4 Address of the project public website, if applicable

www.demcopem-2mw.eu

2 Acknowledgment

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<http://www.fch-ju.eu/>

<http://ec.europa.eu>



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