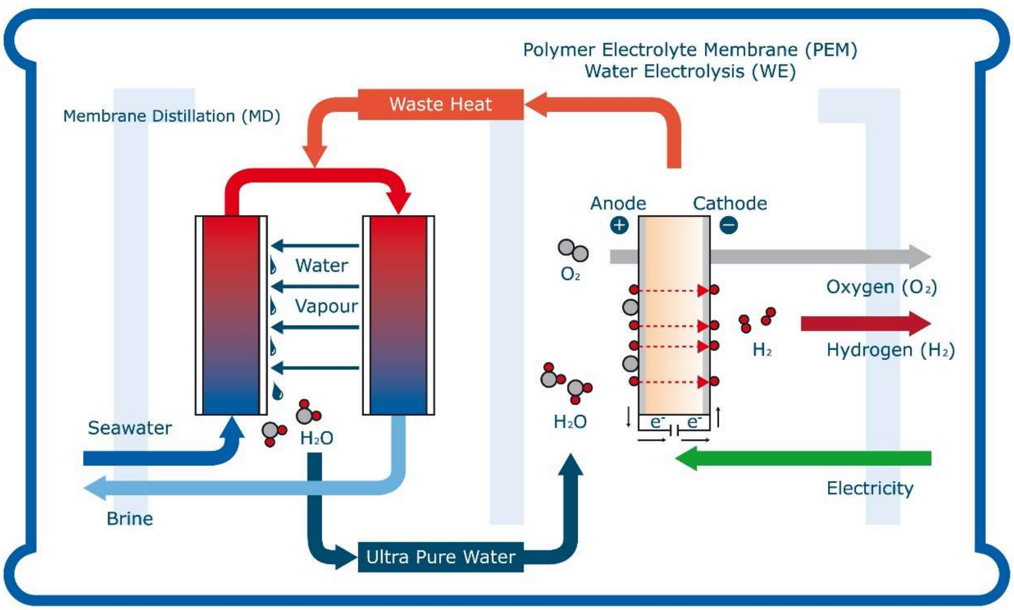
SEA2H2

Hydrogen from seawater via Membrane Distillation and Polymer Electrolyte Membrane Water Electrolysis



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Programme line: Production of Sustainable Hydrogen

Summary

Introduction

The production of hydrogen by electrolysis and renewable energy sources offers many opportunities for the energy system of the near future. The 'green' hydrogen can be used as a fuel for the transport sector, chemical raw material for various industrial processes and as an energy carrier for the transport and storage of renewable energy.

Polymer Electrolyte Membrane Water Electrolysis (PEMWE) is one of the most promising available technologies that can be widely used to produce green hydrogen. However, the cost of hydrogen produced by PEMWE is currently not competitive with "grey" hydrogen produced from fossil fuels. Lower operational costs and to a lesser extent lower investment costs are necessary for a positive business case.

Recently, there has been a lot of interest in the offshore production of green hydrogen by means of electricity generated by large-scale wind farms. The advantages of offshore hydrogen production from offshore wind energy are that the hydrogen produced can buffer the fluctuating wind energy on a large scale, and thanks to the reuse of already existing offshore oil and gas infrastructure, no expensive electrical infrastructure is needed to transport the generated wind energy to the coast.

However, the electrolysis process also requires Ultra-Pure Water (UPW) to function properly and ensure a long service life. The required UPW will have to be produced on site from seawater and will add costs to the production of hydrogen. Membrane distillation can produce pure water from seawater using residual heat from the electrolyzer as a driving force. The costs of UPW will be lower than, for example, the application of reverse osmosis that reduces the overall electrical efficiency of the entire hydrogen system because RO is an electrically driven process.

Objectives of the project

The SEA2H2 project contributes to the development and reduction of the costs of offshore green hydrogen production. The main goal is to provide a proof of concept for a seawater to hydrogen pre-pilot plant by integrating membrane distillation (MD) with polymer electrolyte membrane water electrolysis. The hybrid pre-pilot MD-PEMWE system has a nominal stack power of 50 kWe, which corresponds to approximately 1 kg of hydrogen production per hour. Valuable data is obtained and analysed under different operational conditions so that more insight is gained into the technical aspects of the SEA2H2 concept.

The main project results are:

- The development of an MD and a PEMWE demo installation (subsystems)
- The realization of a thermal and water integrated PEMWE and MD system that can be easily deployed and operated at most locations
- An MD-PEMWE demonstration with a duration of approximately 1000 hours at a relevant location where seawater is available
- A techno-economic evaluation for the MD-PEMWE integrated process on a scale of 1, 10 and 100 kg hydrogen production per hour

Results

The main results within the project are:

- A remote-controlled MD subsystem that can be easily integrated with the PEMWE subsystem and can also operate in standalone mode at a thermal output of 3-18 kWth
- A PEMWE remote-controlled subsystem with a stack power of 12-50 kWe that can be easily integrated with the MD subsystem and also operate in standalone mode
- An integrated MD-PEMWE system that can be controlled remotely
- A seawater intake equipped with multimedia filter to pump seawater into the integrated MD-PEMWE system for further processing
- ~1000 hours MD-PEMWE integrated demonstration on the dock of Seaport Texel
- A techno-economic analysis of the MD-PEMWE concept on a production scale of 1, 10 and 100 kg of hydrogen per hour.

Conclusions and recommendations

An integrated MD-PEMWE system has been developed and realized for the proof of concept of "Seawater to Hydrogen" (Sea2H2) and has been successfully demonstrated through thermal synergy.

At a rated stack power of 50 kW, the integrated system produced about 1 kg of hydrogen per hour, while producing nearly three times as much UPW as required for the PEMWE system. The system has been tested "in the field" at a site with full exposure to a harsh maritime climate over a period of approximately 1,000 hours in the months of October and November of 2021.

The techno-economic analysis has shown that large scale is essential for a positive business case. Furthermore, the cost of electricity, the price of hydrogen and to a lesser extent the cost and price of water play a decisive role in the overall business case. An improved Return on Investment (ROI) can be created if the excess water that can be produced with the MD process from the residual heat of the PEMWE can be sold.

For future development, it is recommended that the concept be demonstrated on a larger scale, at an offshore site with the PEMWE-MD subsystems fully integrated into a single container to reduce thermal losses. Furthermore, it is recommended to start with the selection of a suitable test site and relevant certification and safety measures before the start of the actual system design.

CONTENTS

1.PROJECT DETAILS

Project number	TWAS119017
Title of the project	Hydrogen from seawater via membrane distillation and polymer electrolyte membrane water electrolysis (SEA2H2)
Project leader	Hydron Energy B.V.
Project partners	Wageningen University & Research (WUR) Hydron Energy B.V.
Duration of the project	1 October 2019 – 1 May 2022
Date	15-05-2022
Confidentiality	Public

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2. BACKGROUND AND OBJECTIVE OF THE PROJECT

BACKGROUND

Hydrogen production by **Polymer Electrolyte Membrane Water Electrolysis (PEMWE)** technology offers promising market opportunities. It is intended that hydrogen produced via electrolysis (i.e. green hydrogen) will be widely used in the transport, industrial and energy storage sectors (IRENA 2018).

The continuous rapid expansion of offshore wind energy capacity in the North Sea area, in combination with the intended decommissioning of waste oil and gas platforms, offers opportunities for offshore hydrogen production by means of water electrolysis installations. **Large-scale hydrogen production at offshore sites** powered by renewable electricity from offshore wind/solar farms can benefit from existing gas infrastructure to reduce transport costs and avoid large investments related to the electricity grid, as the transport of gases is significantly cheaper than the transport of electricity (TNO 2016).

Although promising, offshore hydrogen production through water electrolysis poses technical and economic challenges. First of all, the technology is currently perceived as too expensive for cost-competitive hydrogen production (ECN 2017). Secondly, the electrolysis process requires **Ultra-pure water (UPW)** as a raw material. Conventional offshore desalination processes such as reverse osmosis add costs to the hydrogen production technology, which has a negative impact on the levelled cost of hydrogen ($LCoH_2$). By applying **membrane distillation** to the heat released from the electrolyzer, costs can be reduced.

PROJECT OBJECTIVES

The core objective of the seawater-to-hydrogen project (SEA2H2) is to reduce the cost of H_2 by significantly reducing the investment and operational costs of the integrated offshore H 2-out-of-seawater production process.

To guarantee the service life and reliability for PEM electrolysers, UPW is required. On-site salinization of seawater based on membrane distillation (MD) offers a lot of added value compared to the current standard process (purer product water, less electricity and chemical consumption). In addition, MD makes efficient use of the residual heat from the PEMWE process. At the same time, savings are made on the cooling costs of the electrolyzer. This increases the efficiency and effectiveness of the total H_2 production process and thus reduces production costs.

Through the development and testing of a fully integrated pre-pilot installation, in which membrane distillation for the production of UPW from seawater and PEM electrolysis are effectively coupled, a Proof of Concept will be delivered. The SEA2H2 demonstration project also lays a techno-economic foundation for large-scale offshore H_2 production.

An overview of the work packages is shown in Table 1.

Table 1: Overview of work packages in Sea2H2 project

WP	Short description	Participants (Lead)	Results
1	Analysis (IO)	WUR, Hydron	Programme of criteria for integrated pilot plant, functional requirements MD and PEM subsystems, mass and energy balances
2	Development of a pre-pilot installation (IDE)	Hydron, WUR	Realization of an integrated pre-pilot H_2 production plant consisting of PEM electrolyser and MD subsystem
3	Testing and characterization (IDE)	Hydron, WUR	Proof of concept, test report
4	Techno-economic assessment (IDE)	Hydron, WUR	Cost models for electrical equipment and MD installation, report on techno-economic characteristics of technology
5	Project management and dissemination	Hydron, WUR	Timely delivery of project results, identification of risks and risk management, management of project deviations with consortium, dissemination, reporting

3. PROJECT RESULTS

WP1 ANALYSIS

Objective: In work package 1, the consortium partners develop a program of criteria for a pre-pilot installation consisting of an installation membrane distillation process, including seawater pre-treatment , product water polishing and a PEMWE process.

Results: The following deliverables are defined for work package 1:

- Process flowchart and functional description
- Mass- in energy balances
- Program of functional requirements and wishes

Result description:

PROCESS FLOWCHART AND FUNCTIONAL DESCRIPTION

The PEMWE system determines the amount of UPW to be generated by the MD system from residual heat and seawater. The desalinated water is purified to grade 1 UPW and fed into the PEMWE system. The PEMWE system uses electric current to electrochemically split the UPW into hydrogen and oxygen. The heat generated by the PEMWE system, due to ohmic losses in the stack, is used by the MD system to control the desalination process.

There are two interactions between PEWME and MD, namely:

- A water interface where the PEMWE subsystem uses UPW created by the seawater MD subsystem
- A thermal-energy interface where the MD subsystem uses the residual heat generated by the PEMWE subsystem

Figure 1 shows the main process diagram of the SEA2H2 integrated system. The system consists of an MD and PEMWE subsystem with a buffer in between for the ultra-pure water produced.

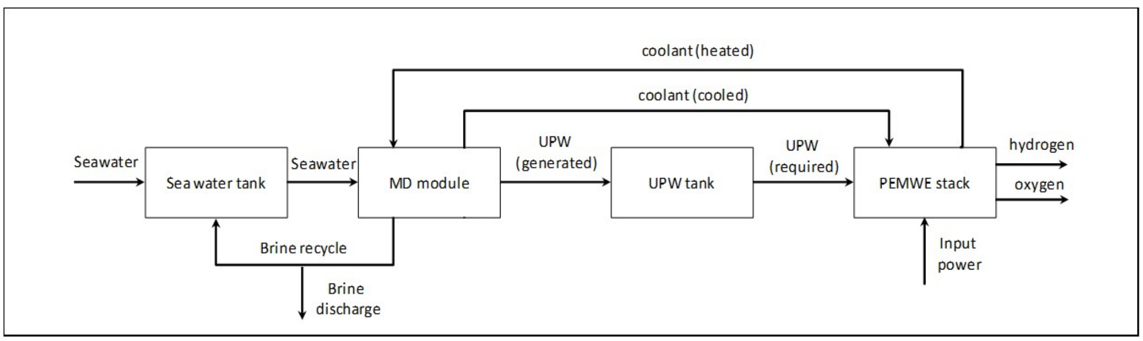

Figure 1: Process diagram of the integrated SEA2H2 system. The heat absorbed in the coolant of the PEMWE stack is circulated over the MD system which uses this heat to produce ultra-pure water (UPW). The UPW is fed to the PEMWE stack to be used for the production of hydrogen and oxygen.

After the process and the link between the MD and PEMWE process has been established, mass and energy balances have been established. The PEMWE system has a nominal stack power of 50 kW with which roughly 1 kg of hydrogen can be produced per hour. The required ultra-pure water production is calculated at a minimum of 9.6 l/h.

A prediction has been made of the amount of water that can be produced with MD under different conditions. This has been elaborated with a mathematical MD model from WUR and shown in Figure 2. This graph also shows the amount of water required by the electrolyzer depending on the stack power. This WUR model was used to select a good working area in the run-up to the design of the pilots .

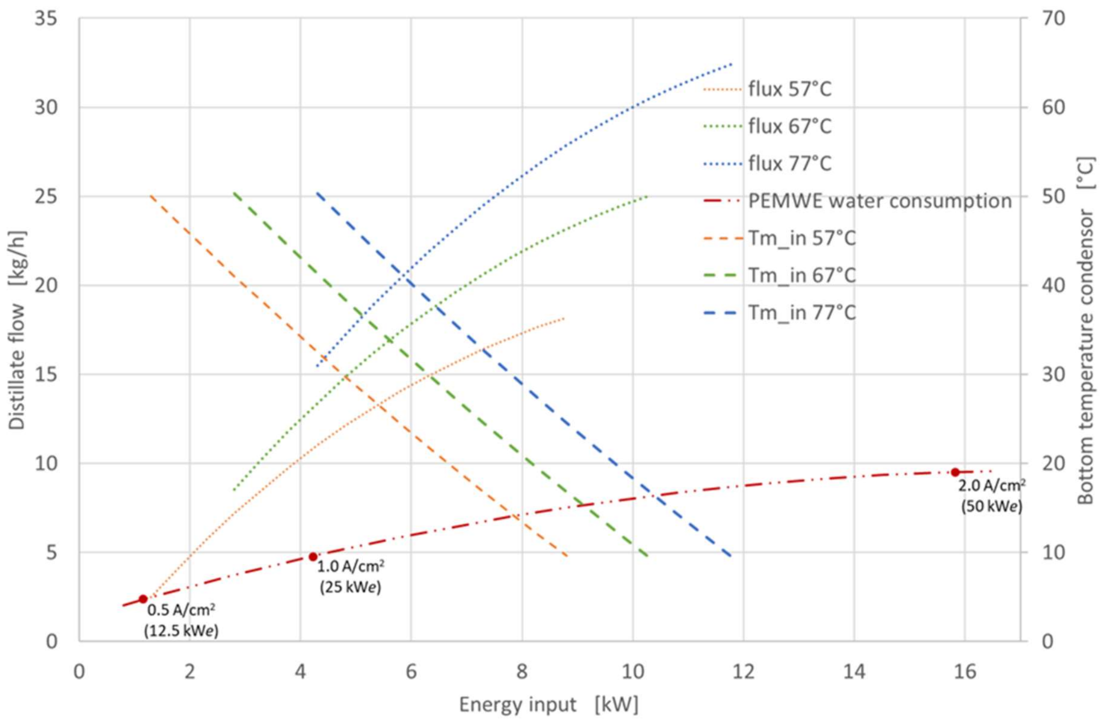

Figure 2: predicted MD distillate flow (dotted lines) and input (bottom) temperature (striped lines) for a commercially available MD module with a constant circulation flow of 600 l/h at 3 residual heat temperatures (60, 70 and 80 °C). Created with WUR's membrane distillation (Mathematic) Model version 3.13. The PEMWE water consumption is shown also at different stack capacities and the amount of residual heat released (theoretically).

Finally, within this work package, a program of requirements for the installation has been drawn up that the total system and subsystems must meet. The system requirements have been drawn up in the areas of safety, construction, maintenance, operation and maintenance.

WP 2 DEVELOPMENT OF PRE-PILOT INSTALLATION

Purpose: Based on the deliverables of WP1, a design will be made for the pre-pilot installation that includes planned processes (pre-treatment seawater, membrane distillation, polishing and electrolysis). An MD and PEMWE demo installation is designed, built and integrated in such a way that maximum synergy is achieved on both heat and water transfer.

The nominal hydrogen production capacity of the pre-pilot plant will be 1 kg/hour (Hydron's 50 kW PEMWE stack platform will be used). In addition, the UPW production capacity will be ~10 kg per hour.

Results: The following deliverables are defined for work package 2:

- Realization of the membrane distillation demo installation
- Realization of the electrolyzer demo installation

- Realization of the integrated MD-PEMWE system

Result description:

An MD and PEMWE demo installations have been developed, built, tested and commissioned. Both installations can operate independently of each other, but also in an integrated system configuration.

Due to budget constraints and underestimated system costs, it soon became clear that building an entirely new MD installation was not feasible. In addition, it was the desire to work with full scale commercial modules instead of small-scale, self-build modules. That is why it was decided to update and adapt an existing MD demo installation for use in combination with the electrolyzer and for use with commercially available modules.

The system has been carefully tested at Wageningen Research with tap water and synthetic seawater obtained by adding salts to tap water. Figure 3 shows both the inside and outside of the transportable lab (sea container) in which the MD Demo installation is installed. On the left hand side picture on the front, the MD installation is visible with the main switch box with touchscreen to operate the installation . 3 modules (blue) are located on top of the installation. On the back of the left picture the circulation pump (black) for the heat integration loop is shown (including the expansion vessels (red) under the pump). On the right hand side picture, the outside of the container is shown with a Full Width Visual of the container designed especially for this project and applied to the container.

Figure 3: Membrane distillation system (left) in transportable lab with Visual of the project on the outside wall (right).

Because there was no seawater intake at the demo location, it was also necessary to design it and purchase it yourself. Figure 4 shows a picture of the seawater take-in (at the demo location) with the sand filter (blue), 3000 litre buffer tank (black) and automatic valves (orange). This sand filter works fully automatically, but can also be operated manually via the touch screen on the control box.

Figure 4: Seawater intake as installed on the dock of Seaport Texel, with the sand filter (blue), 3000 litre buffer tank (black) and automatic valves (orange). Equipped with touch screen for operation

The system for operating the PEMWE electrolyzer was designed, built and tested at Hydron Energy. The system, PEMWE stack, power supply and monitoring equipment are installed in a custom-made 15ft. high cube container. The container is segmented by a gas-tight wall into a process compartment and an electric compartment. Various vent panels have been installed on both compartments, so that explosive gas concentrations cannot form in the container. The oxygen and hydrogen gas produced is cooled to a dew point in the range of 10 to 30 ^{o}C before being diluted with air and discharged into the atmosphere.

After a delayed delivery of the container, the electrolyzer stack and the electrical subsystems were built and installed in accordance with the technical documents. To check the integrity of the system, several leak tests were carried out with nitrogen and water. A special control strategy has also been developed and coded internally to monitor and control the PEMWE subsystem. The subsystem has been tested for a maximum of 31 kW on the Hydron Energy site.

Figure 5 shows the PEMWE system and stack as built and eventually transported to the final test site.

Figure 5: PEMWE subsystem with stack in the foreground.

WP3 TESTING AND CHARACTERIZATION

Objective: To determine KPIs in terms of process performance and efficiency for the pre-pilot PEMWE and MD integrated system. More specifically, for the MD system, seawater and distillate will be monitored, as well as temperatures and product flux. Temperature, pressure, product gas flows and water resistance are closely monitored and recorded by the PEMWE system.

Results:

I. Characterization of seawater intake, brine and distillate
II. Testing of integrated pre-pilot installation
III. Installation Performance Report
IV. Report on the water treatment subsystem
V. Report on the electrolyzer subsystem
VI. Report on integrated pre-pilot installation

Description of the result:

Finding a suitable location for the MD-PEMWE pilot was a time-consuming process. The requirements for a suitable test site were twofold:

- A grid connection of at least 400 V/250 A was required to power the PEMWE and MD subsystems. Most of this power was needed for the PEMWE stack
- For the MD installation, a seawater intake with multimedia filter (sand filter) was required

Finally, after a long search through WUR's contacts, a location was found that was very willing to make it available for the demonstration. Figure 6 shows the demo location on the basis of aerial photographs (google maps), a photo of the Seaport Texel website and a photo taken with the help of a drone.

Figure 6: Demo location, research port Seaport Texel

On 4 October 2021, both subsystems, the flow distribution box and the seawater intake were transported to the selected demo location on the dock of Seaport Texel.

The systems were then installed and integrated on site to arrive at the intended "seawater to hydrogen" pre-pilot installation. Figure 7, Figure 8 and Figure 9 show the Sea2H2 installation on the dock of Seaport Texel seen from the dock and from the air (drone).

Figure 7: Visual on the MD container, the power distribution box (grey RECO container) and in the background the blue container with the PEMWE installation

Figure 8: PEMWE (blue container) and MD (grey container) installation with the installed seawater intake at the right head of the dock.

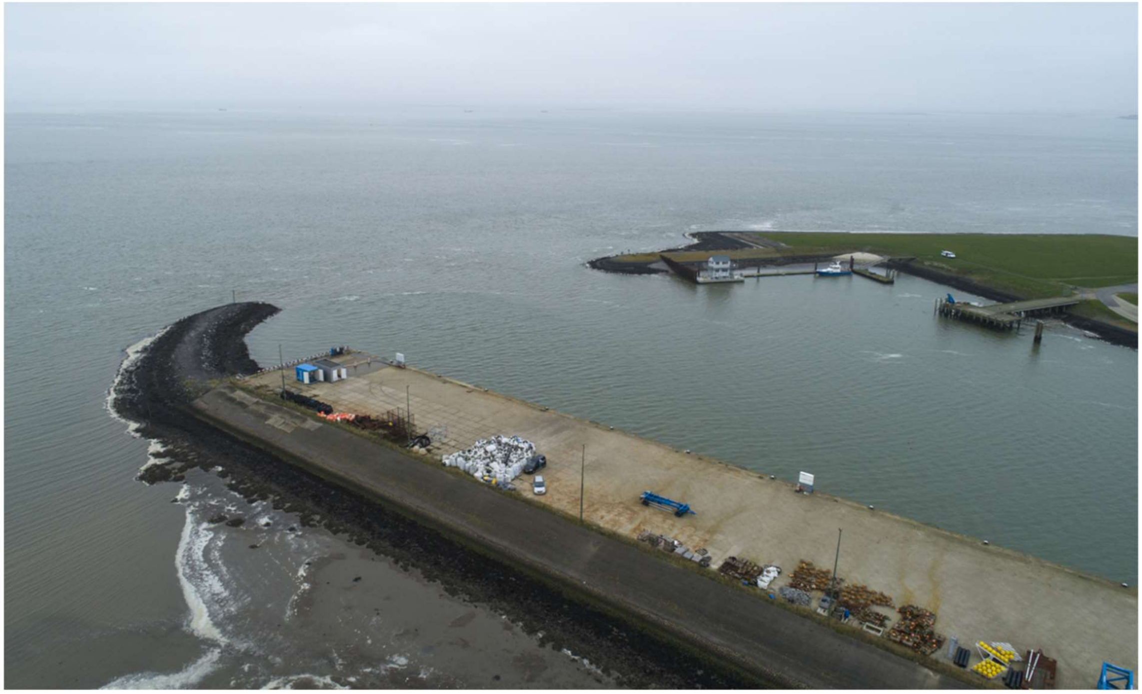

Figure 9: Sea2H2 installation and the Seaport Texel seen from the air (Drone images) with a view of the Waddenzee southeast of the harbour

The installation and integration went well and the integrated system was extensively tested over a period of almost 7 weeks. The excess amount of water produced has been returned to the sea. The PEMWE system has been tested for stack power up to 60 kW and temperatures up to 80 °C. The gases produced were first cooled, and then the flow rate was accurately measured before the produced hydrogen and oxygen gas was blown off to the atmosphere via 2 chimneys. Different temperatures as well as seawater supply volumes and qualities have been tested whereby in all situations the MD system could continue to cool the PEMWE system sufficiently and produce water suitable for the PEMWE process.

Figure 10 gives an overview of the top temperature of the MD module and the conductivity of both the power supply of the MD module and the distillate of the MD system over the entire runtime.

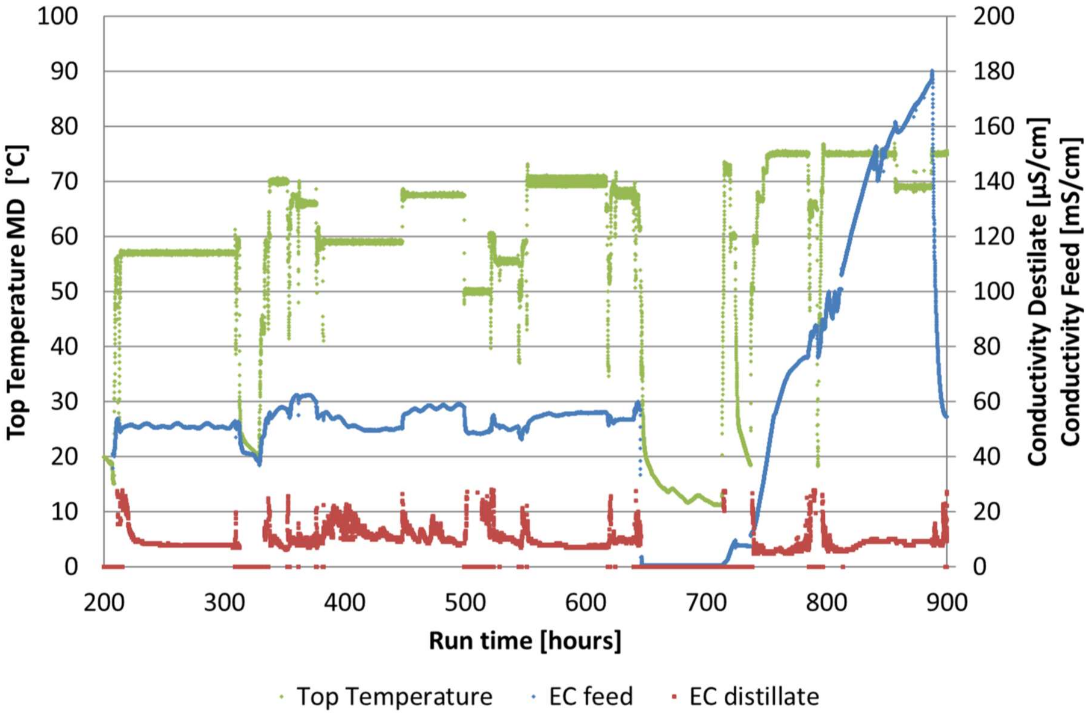

Figure 10: Top temperature and conductivity of power supply and distillate of the MD system over the entire duration (after the first week of installation and adjustment). From 200 hours after start to 650 hours, the MD system is run on seawater. From 650-700 hours, the system is rinsed with tap water. From 700 hours to 900 hours, the discharged distillate volume is supplemented with seawater, but no concentrate has been removed. As a result, the conductivity has continuously increased to 180 mS/cm, which corresponds approximately to a concentration factor of 7 compared to average seawater. The conductivity of the distillate also remains around 7 µS/cm under these conditions.

Over the entire duration, the water production from the MD system was between 13 and 27 l/h depending on the soil and top temperature, circulation flow and concentration. In all cases (even at low top temperature) this was more than enough to provide the electrolyzer with the required amount of water of 2.4 - 9.5 l/h at a stack power of 12.5 – 50 kWe respectively.

Over the entire duration and also under the various weather conditions such as wind direction and wind force (storm and thunderstorm), the seawater intake has been very stable and no pollution has occurred in the MD system.

WP4 TECHNO-ECONOMIC ASSESSMENT

Objective: To develop a techno-economic model to gain insight into the economic aspects of offshore hydrogen production by water electrolysis with seawater as a raw material.

Results:

I. Analyse state-of-the-art KPI's for electrolysers
II. Engineering cost model for offshore water treatment
III. Engineering cost model for $LCoH_2$, TCO and ROI for offshore hydrogen production
IV. Cost forecast offshore Hydrogen production

Description of the results:

The main conclusions of the techno-economic assessment are:

- The MD-PEMWE system needs a large scale to be cost-effective
- The cost of electricity is the most dominant factor for the $LCoH_2$
- The use of all the heat generated by the PEMWE for the MD process is more favourable than partial heat use when produced water can be valorised.
- By valuing the excess water produced by the MD system, a positive ROI is possible where this is not possible without water.

The cost model is based on input data from Hydron Energy for the systems related to the PEMWE. For the systems that relate to the MD, a publication[1] of the producer of the MD modules is used as input.

Figure 11 shows the impact on ROI of an integrated MD-PEMWE system for different production capacities. A comparison was made between the situation in which the amount of water required by the PEMWE is produced with RO and/or MD. The "capacity factor of MD" is the ratio of the thermal cooling capacity of the MD installation over the total required cooling capacity. At a factor of 1, the MD installation completely cools the PEMWE installation. In this situation there will be a surplus of UPW production which is sold at market value. This cost model is based on a market value of 1, 5 and 10 €/m3. It should be noted that the selling price of water is highly dependent on the location where the MD-PEMWE system is installed. When the excess water is on an offshore platform, it can be used on site for personal use or use in other processes on the offshore platform. Alternatives such as water production on or transport to the platform can cost up to 42 €/m^3 of water[2]. When this can be omitted by using the excess water from the MD, the ROI further increases significantly. With a "capacity factor" of 0, the PEMWE system is fully cooled by a dry-cooler and the UPW will be obtained from a local offshore RO installation at a price assumption of 5 €/m^3.

The effect of an enlarged MD system is clear; a higher capacity factor and system scale combined with a high selling price of the additional water produced has a positive effect on the return on investment as can be deduced from Figure 11.

1 Techno-economic assessment of seawater reverse osmosis (SWRO) brine treatment with air gap membrane distillation (AGMD). M. Bindels, J. Carvalho,C.Bayona Gonzalez, N. Brand, B. Nelemans. s.l. : Elsevier, Desalination, 2020, Desalination 489 (2020) 114532

2 Moddeling of water supply cost for offshore platforms, N. Ismail, M.Z. Ahmad, M.N. Hussoin, A.N. Ariffin, Zainol I., Internationla journal of schientific & technoloy research volume 8, issue 12, December 2019, ISSN 2277-8616

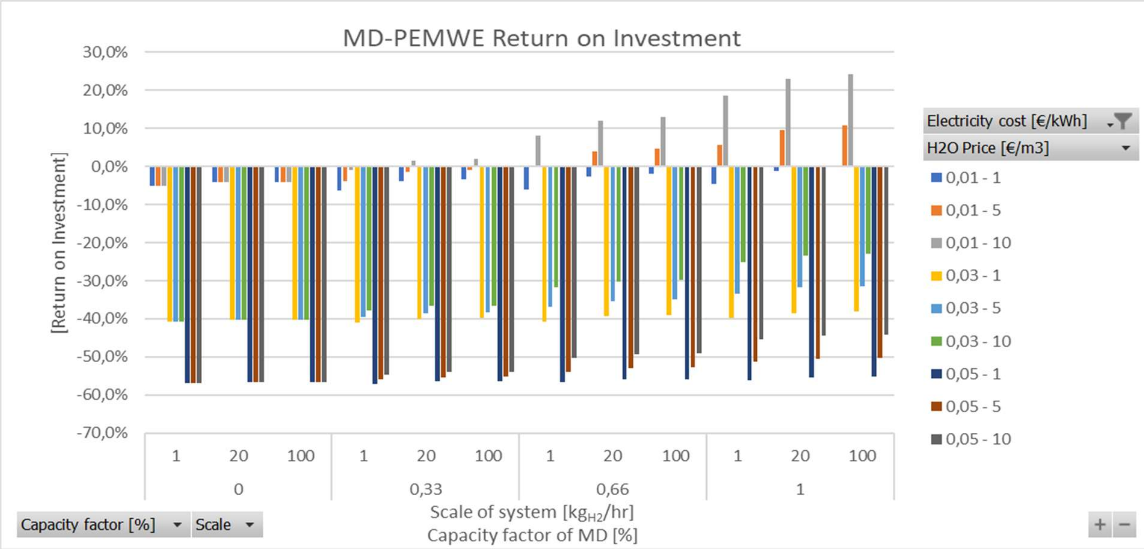

Figure 11: Return on Investment for hydrogen production (PEMWE) at a price of 2 €/kg H_2 for integrated system with MD. With a variable capacity factor between 0 (100% RO + dry cooler) and 1 (100% MD) and a system scale between 1 kg_{H2}/hr (~50 kW) and 100 kg_{H2}/hr (~5 MW).

The impact on yield (price) of hydrogen has a significant impact on ROI. If the price is increased from 2 €/kg to 5 €/kg, a significantly more positive business case is found, see Figure 12.

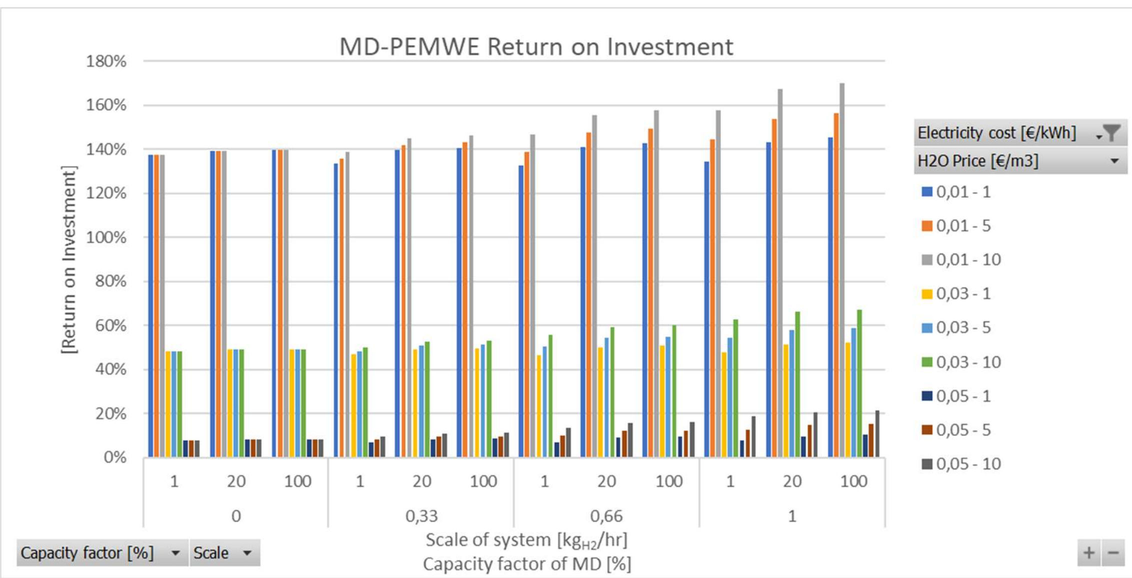

Figure 12: Return on Investment for hydrogen production (PEMWE) at a price of 5 €/kg H_2 for integrated system with MD. With a variable capacity factor between 0 (RO) and 0.33 -1 (MD) and a system scale between 1 kg_{H2}/h (~50 kW) and 100 kg_{H2}/h (~5 MW).

Figure 13 shows that electricity costs play a very dominant role in the system's ROI investment. In addition, larger-scale systems (> 5 MW) benefit from a synergy with MD technology, although this advantage is highly dependent on the market price for the water produced.[3]

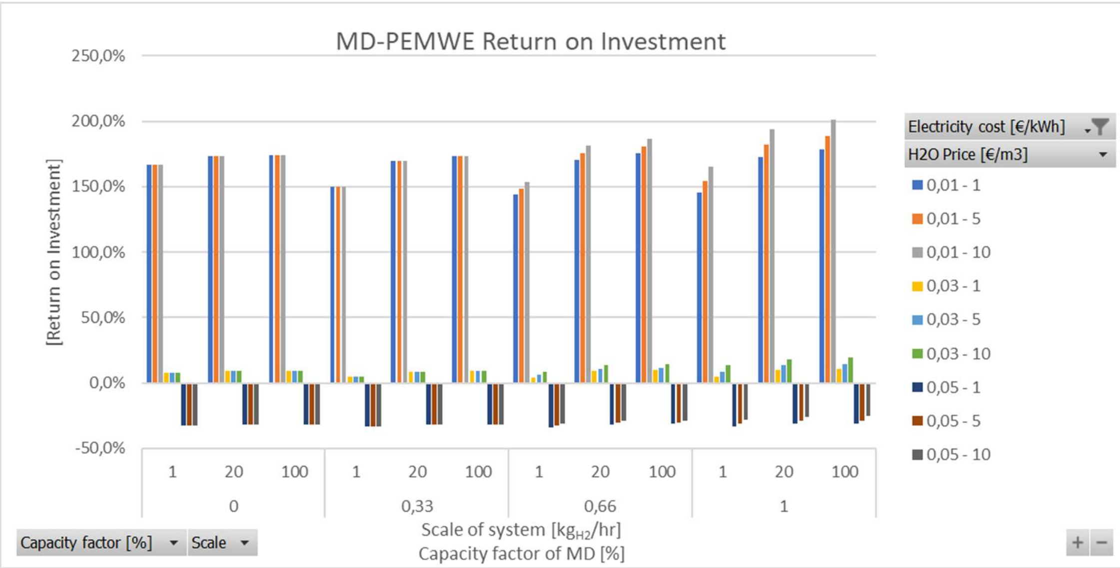

Figure 13: Future forecast (2050) for the return on investment in hydrogen production (PEMWE) at a price of 2 €/kg H_2 for integrated system with MD. With a variable capacity factor between 0 (RO) and 0.33 -1 (MD) and a system scale between 1 kg_{H2}/h (~50 kW) and 100 kg_{H2}/hr (~5 MW)

WP5 MANAGEMENT AND COORDINATION

Purpose:

I. Daily project progress management, reporting and control of project finances
II. Dissemination of project results

Results:

I. Two interim reports
II. Final report
III. A suitable test location for the integrated system
IV. Site visit by RVO

Description of the result:

The SEA2H2 project was coordinated by Hydron Energy in close collaboration with WUR. Several project meetings and teleconferences were organized to monitor progress and discuss system interfaces. Various meetings were held with 3rd parties to find and discuss a suitable test location for the integrated system. In addition, RVO was invited during testing at the dock of Seaport Texel.

3 Modelling of water supply cost for offshore platforms, N. Ismail, M.Z. Ahmad, M.N. Hussoin, A.N. Ariffin, Zainol I., Internationla journal of schientific & technoloy research volume 8, issue 12, December 2019, ISSN 2277-8616

4. CONCLUSIONS, RECOMMENDATIONS AND BOTTLENECKS

CONCLUSIONS

An integrated Membrane Distillation – Polymer electrolyte Membrane Water Electrolysis system has been developed and the proof of the seawater to hydrogen concept through thermal synergy has been successfully demonstrated. At a rated output of 50 kW, the integrated system produced approximately 1 kg/h of hydrogen and produced nearly three times as much ultrapure water as the PEMWE system required.

The system has been tested "in the field" at a site with full exposure of a marine climate in October/November 2021. The field tests carried out within the SEA2H2 project have been a real stepping stone to test the concept on the open sea.

The techno-economic analysis has shown that large-scale business operations are essential for a positive return on investment. Furthermore, the cost of electricity, the price of hydrogen and to a lesser extent the cost and price of water play a decisive role in the overall business case. An interesting added value is that the available residual heat from the PEMWE can result in a surplus of water, which can be valorised by offshore application.

RECOMMENDATIONS

The main recommendation specific to this demo concerns parasitic losses in pipes between the MD-PEMWE system and the alignment of the dimensions of the systems. In addition, the MD system was oversized in relation to the entire system. In order to make optimal use of the heat, the systems should preferably be packaged in one container in order to optimize heat transfer and reduce losses.

For a demonstration of the combined system, the chosen stack power of 50 kW was ideal and feasible, which is why this demo project was successfully completed. However, in order to be important for the offshore wind energy industry, the nominal PEMWE capacity must be significantly increased in a follow-up project.

This report discussed the valorisation of excess water produced. However, in remote locations with water scarcity, it is also very beneficial to produce excess water. In these situations, it is very useful to apply all the heat generated by PEMWE for the MD process. From a social and environmental point of view, it can also contribute to the development of areas that need water, such as the coastal area of the West African countries. An additional study into the societal impact of more drinking water availability in combination with abundant sun for hydrogen production could be an interesting research topic.

BOTTLENECKS DURING THE PROJECT

Below is a short list of bottlenecks that have occurred in the project. It must

stress that despite these bottlenecks, the main objectives in the project have been achieved and the demonstration has been successfully completed.

Bottleneck 1:	There were major delays in the delivery of components and thus the realization of the PEMWE system due to the Covid-19 pandemic.
Solution:	A project extension of 7 months was requested and awarded funding by RVO.
Bottleneck 2:	Hydron Energy underestimated the workload of designing, building and testing a PEMWE system in containers. More hours were spent than expected.
Solution:	Hydron Energy contributed more hours to the project.

Bottleneck 3: The budget for the MD system was insufficient to build a dedicated MD installation.

Solution: An existing MD pilot was overhauled and adapted to make it suitable for the SEA2H2 project.

Bottleneck 4: The previously intended pilot location (with existing seawater intake) turned out to be unavailable. Purchasing seawater and transporting it to the test location is expensive, time-consuming and highly inefficient and therefore not an alternative.

Solution: An alternative demo location directly at the sea has been found, but for this it was necessary to purchase a seawater intake. WUR has had a mobile water intake custom-made and installed on the dock of Seaport Texel.

5. IMPLEMENTATION

FOLLOW-UP PROJECTS

The intention is to realize a pilot on a larger scale (at least 1 MW) at a representative location. The project plan for this is not yet available.

An inventory is made of whether and to what scale technological scale can be scaled up and to what scale MD-PEMWE can be applied to an offshore platform.

Important partners in a follow-up project are of course the supplier of the electrolyzer and MD installations and the manager/owner of an offshore platform, but also stakeholders such as the manager/owner of the wind farm and the network managers of the gas and Electra infrastructure.

As indicated in the recommendations, a remote location with water scarcity is an alternative case which can be investigated.

Both WUR and Hydron Energy are open to discussing a follow-up project with interested potential partners.

CONTRIBUTION TO THE OBJECTIVE OF THE SCHEME

This project is registered with RVO with the following Project Information:

Innovatiethema('s)	Waterstof	(Hydrogen)
Subsidieregeling	TSE-19-15-01-Waterstof	
Stroomschema-onderdelen	Waterstof productie.	(Hydrogen production)
Projectnummer	TWAS119017	

The aim of the Hydrogen Programme Line is to support research- and development projects that contribute to achieving cost reduction for the use of hydrogen as an energy carrier in various applications (industry, mobility, energy sector and built environment) in 2030 by reducing the investment costs and operational costs of existing and new technology and systems for production, transport, storage and application. Projects must enable a significant improvement in costs, efficiency and reliability with a high repetition and growth potential, provide insight into robust business cases and explicitly take into account social embedding and acceptance among the most important stakeholders for the implementation of the innovation.

The programme line to which this project applies:

Production of hydrogen using sustainable electricity, especially from wind and sun.

Projects focus on:

1. cost reduction of electrolysis from order of magnitude 1000-1200 €/kW now to order of magnitude 300-400 €/kW in 2030, by preparing and developing pilot installations of smart system concepts (minimizing Balance of Plant), and improved membranes and materials that enable production at elevated pressure for systems in the order of a few tens to hundreds of MW, with attention to possibilities to be able to produce the components cheaply and on a large scale. Innovations for automated mass production of electrolysers (manufacturability) are also part of this;
2. improving the service life and slowing down the degradation behaviour of electrolysers, including under dynamic loads, and testing components from material suppliers;

3. cheaper and/or better purification technology (such as gas cleaning and reprocessing) to turn low-grade hydrogen into high-grade hydrogen.

This project has contributed to this in both points 1 and 2:

1. By clever integration of membrane distillation and electrolysis, the residual heat from electrolysis is effectively used for the production of the required ultra-pure water. It has also been shown that the valorisation of extra produced water (on excess residual heat from the electrolyzer) has a very positive influence on the Return on Investment and thus reduces the overall cost of the hydrogen.
2. The on-site demo has shown that under harsh conditions such as storms and thunderstorms in a seaport, the systems of both the PEMWE and the MD show stable business operations, which is a good stepping stone to a larger-scale system offshore.

DISSEMINATION

In the course of the project, the following actions were taken with regard to knowledge dissemination, public relations and publications:

- WUR and Hydron gave a presentation about the project on 6 April 2021 at the online knowledge session on hydrogen organised by RVO; "knowledge sessions hydrogen part 1: water electrolysis", with 185 participants.
- WUR gave a presentation about the Sea2H2 project on 28 October 2021 during the offshore energy fair and conference tour through the Netherlands for a delegation of executives and harbour masters hosted by Pondera in Arnhem (NL).
- WUR designed a Visual that was applied as foil onto the container with the MD installation. This Visual and the project plan was also shared on the WUR website (www.wur.eu/sea2h2) and the link to the website was shared on LinkedIn. A QR code with a link to this site is located in the lower right corner of the Visual. Figure14 shows the full Visual and the front page of this report shows a cut-out of the Visual with the schematic drawing of the operating principle of both processes with integrated heat and water. Figure 3, Figure 7 and Figure 8 show the Visual on the container (respectively in Wageningen and at the demo location).
- On December 20, 2021, a press release from Hydron Energy appeared and shared a media message on LinkedIn regarding the PEMWE part of the Sea2H2 project. Several international articles and blogs have appeared that refer to the press release.
- At the AquaNL fair in Gorinchem (NL) from 15-17 March 2022, WUR presented the Sea2H2 project at their stand.
- Once the public report has been completed, WUR intends to share a press release about the results of the project and to update their Sea2H2 webpage.

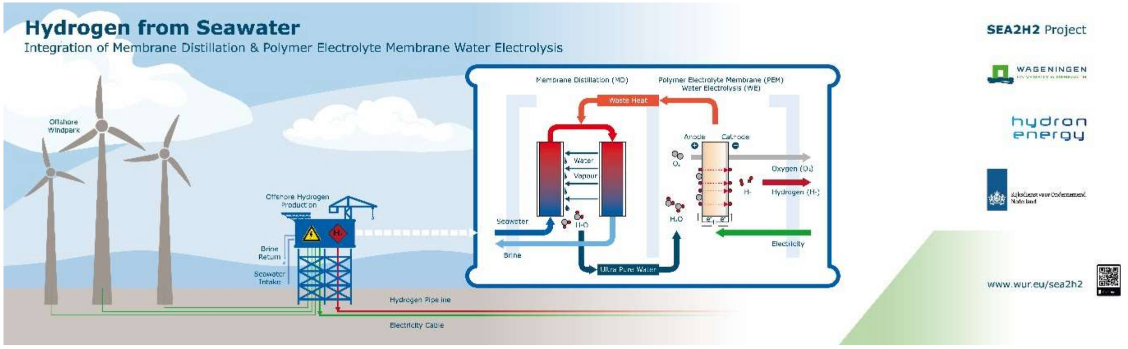

Figure14: Visual op MD-container with logos of partners