Report on implications of electrolytic water demands on Europe's water network

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Abbreviation	Definition
ATR	Autothermal Reformer
BAT	Best Available Technology
BFD	Block Flow Diagram
BL	Battery Limit
CapEx	Capital Expenditure
CW	Cooling Water
DMW	Demineralized Water
EDI	Electrodeionization
ELY	Electrolyser
H2	Gaseous hydrogen
ISBL	Inside of plant battery limit
O2	Gaseous oxygen
OpEx	Operational Expenditure
OSBL	Outside of battery limit
PEM	Proton Exchange Membrane
SMR	Steam Methane Reformer

Executive Summary

This report provides a detailed assessment of the water demand for a 100 MW Proton Exchange Membrane (PEM) electrolyser plant in Wesseling (near Cologne), Germany, as a reference case. The analysis encompasses all relevant water streams, demineralized water (DMW), cooling water (CW), and plant water, and evaluates how operational, environmental, and technological factors influence overall water consumption.

PEM electrolysers require ultrapure demineralized water for the electrolysis process, which is produced through a combination of purification and polishing systems. Two polishing technologies are considered: mixed bed ion exchange, which is cost-effective but requires chemical regeneration, and electrodeionization (EDI), which offers continuous, chemical-free operation with higher water utilization efficiency.

The cooling water system is a major contributor to total water demand. A cooling tower is selected as the preferred solution due to the availability of water at the battery limit and the absence of discharge restrictions. A comparative climate analysis between Wesseling and Granada, Spain, highlights the sensitivity of cooling tower performance to ambient temperature and humidity. Air-cooled heat exchangers are considered as an alternative for water-scarce regions.

Plant water systems, including firefighting and potable water are also addressed. These systems are essential for safety and compliance but do not contribute to continuous water demand.

Furthermore, the report compares water consumption across hydrogen production technologies—SMR, ATR, and electrolysis. Most water is used for cooling, while SMR and ATR require additional water for steam generation, and electrolysis consumes water directly in the hydrogen production reaction.

To contextualize this, the water requirement of a large-scale electrolyser plant is modest when compared to the total water usage of major industrial operations. With Best Available Technique (BAT) water management strategies, such as recycling and efficient cooling, the impact of electrolyser plants on industrial water networks can be effectively minimized.

1. Introduction

PEM water electrolysis is a process that splits water into hydrogen (H_2) and oxygen (O_2). This method produces high-purity hydrogen and operates with high efficiency. The system is compact, responds quickly, and works at lower temperatures (20-80°C, preferably 50 to 65°C). It utilizes renewable energy sources like solar and wind, emitting only oxygen as a byproduct, thus avoiding carbon emissions.

For longevity of PEM electrolyser stacks I the REFHYNE 2 project (likewise also applicable to Alkaline technology), require a clean de-ionised water supply.

For large electrolysers, the quantity of water needed can create challenges for water distribution companies, who will often not have access to the level of water required without major disruption to the local water distribution system. The scale of electrolyser at which water supply becomes a limiting factor in countries around Europe will be assessed, and strategies developed to mitigate this issue.

Locations of electrolysers and the viability of various methods of sourcing water (desalination, recycle streams from chemical plants, electrolyser internal recirculation etc.), will be evaluated from a technical and financial standpoint. Options to improve integration with existing water systems will be assessed (e.g. strategies for altering operating conditions to deal with drought and therefore reduce the cost to the network of providing capacity).

A public report will be prepared with a view to highlighting this issue to water resource planners and policy makers across Europe.

2. PEM Electrolyser Water System Design

Electrolyser plants require three types of water for operation:

— Demineralized water (DMW)
— Cooling water (CW)
— Plant water

First, PEM electrolyser needs highly purified demineralized water for the electrolysis reaction, splitting water into H2 and O2. Both product gas streams are saturated with water vapor; the moisture content in the hydrogen stream is recovered via an integrated drying unit, while the water vapor in the oxygen stream is discharged to the atmosphere through venting.

> Note: The associated water loss via oxygen venting is considered negligible, typically less than 1 % of total water consumption, and is therefore omitted from the overall water balance. Technically, this stream can be recovered by condensation / adsorption drying. Due to contamination with ions the condensate stream would be further treated before tie-in to the main water loop. Anyhow, from an economic point of view, recovery will take place in connection with oxygen by-product valorisation, where drying is an integral step of product conditioning.

The DMW is obtained through water purification and polishing systems. Additionally, cooling water is necessary to main the system at the designed temperature. Lastly, some plant water is required to operate the plant efficiently for different purposes.

The report will analyse the entire water demand for a 100 MW PEM Electrolyser at Shell Energy and Chemicals Park Rheinland in Cologne, Germany), as a reference scenario. This refinery is gradually converted from a conventional refinery to a specialty sustainable products site and hence has a high awareness on feedstock and utility inputs.

The analysis accounts for variations in water consumption driven by the quality of feedwater at the battery limit and prevailing environmental conditions. Consequently, water demand may fluctuate under different operational and ambient scenarios.

2.1 Design Philosophy of 100 MW Electrolyser Plant

Table 1: Design data for electrolysis unit at BL.

Parameter	Description
Technology	PEM Electrolysis
Operating Pressure	29.5 bar(g)
Operating mode	continuous
Total hydrogen production	Approx. 20,000 Nm³/h (=1,800 kg/h)
Hydrogen Purity	≥99.999 vol. % dry basis, after purification
Residual content of oxygen	≤ 5 ppm

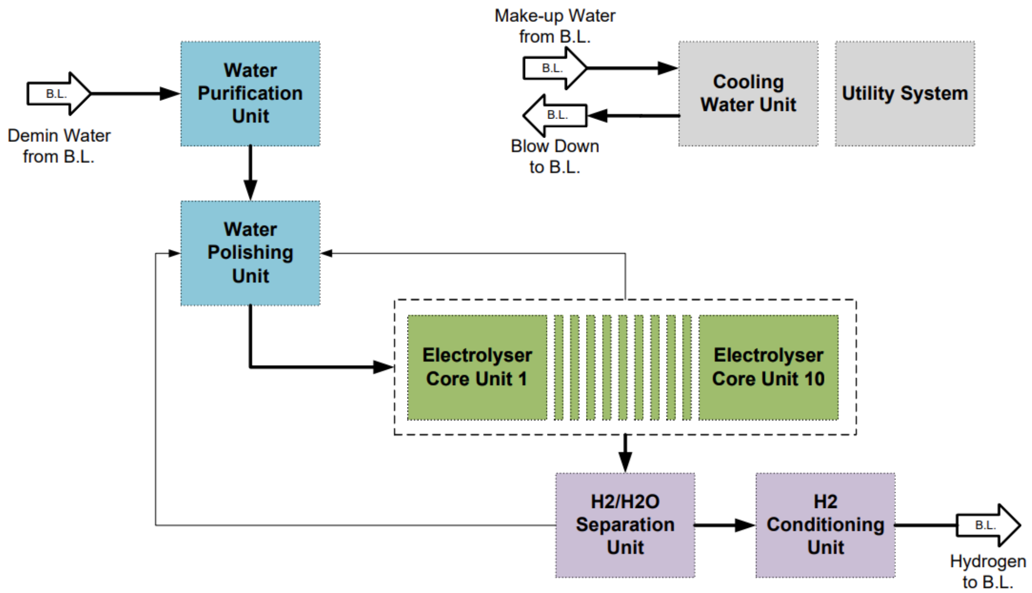

Figure 1: BFD of 100 MW PEM Electrolyser Plant.

2.2 Demineralized Water

The following demin water is provided from the BL.

Table 2: Demin water from BL specified by key parameters.

Parameter	Unit	Min.	Average	Max.
Temperature	°C	-15	9.6	35
Pressure	bar		27	
Quality:				
pH at 25 °C		9.4	9.7	9.9
Specific Conductivity at 25°C	µS/cm	9	15	18
Acid Conductivity at 25°C	µS/cm			0.2
Total Silica	mg/l	0.01	0.01	0.02
Total Iron	mg/l			< 0.02
Total Copper	mg/l			< 0.003

Given the specified quality of demineralized water from BL., it is essential to install both a water purification unit and a polishing unit to supply demineralized water to the electrolyser. The water purification unit removes the bulk of contaminants from raw water. Then, the water polishing unit provides final treatment to already purified water to achieve ultrapure demin water for PEM electrolysers.

Table 3: Demin water quality requirements for Electrolysis unit inlet.

Parameter	Unit	Specification	Remark
pH value (25 °C)	-	n.s.[1)]	not alkalized or acidified
Specific Conductivity at 25°C	µS/cm	< 0.1 /1.5	Depends on OEM specification
Acid Conductivity at 25°C	µS/cm	< 0.2 [2)]	
Sodium	mg/l	< 0.005	
Total Iron	mg/l	< 0.02	
Total Silica	mg/l	< 0.003	
Chloride	mg/l	< 0.005	
Fluoride	mg/l	< 0.05	
Total Organic Carbon (TOC)	mg/l	< 0.05	

Notes:

[1)] Based on difficulties of measuring pH in high purity water and the significance uncertainty of the value obtained, limits have not been specified for pH values.

[2)] Acid conductivity required to ensure low quantity of dissolved gases such as CO2 and dissolved solids

2.2.1 Technical Solutions for Demin Water Supply

2.2.1.1 Demin Water Buffer Tank

To ensure a stable and continuous supply of demin water to the electrolysis process, a buffer tank is integrated into the process water loop. This tank serves to compensate for short-term fluctuations in water demand and acts as a stabilizing element within the system. Multiple process water recirculation lines are connected to the buffer tank, facilitating system integration and operational flexibility.

From a water demand perspective, the initial fill volume of the buffer tank represents the primary demineralized water requirement. This volume is a function of both the plant capacity and the operational profile. Larger plants require proportionally larger buffer tanks. Additionally, facilities operating under dynamic or variable load conditions, characterized by frequent changes in hydrogen production rates, necessitate increased buffer capacity. Also, start-up conditions are considered during conceptual design, e.g., with increased need for flushing.

This ensures resilience against temporary water shortages and supports stable operation during periods of fluctuating demand.

2.2.1.2 Mixed bed ion exchange

The mixed bed ion exchange system utilizes vessels filled with a homogeneous mixture of cation and anion exchange resins, which continuously remove residual ionic species to ensure compliance with stringent process water quality specifications.

This technology is characterized by a low initial CapEx and high-water utilization efficiency. However, due to the need for periodic chemical regeneration, its operation is inherently intermittent, limiting its suitability for continuous processes. Additionally, the use of regeneration chemicals contributes to higher operational costs and raises environmental, and safety considerations related to chemical handling and waste management.

Despite these trade-offs, the mixed bed ion exchange system has been selected for the scenario study due to its proven reliability, simplicity of integration, and suitability for the expected operational profile.

2.2.1.3 Electro-deionization System

The polishing stage can alternatively be performed using an EDI system, which delivers ultrapure water suitable for PEM electrolysis. The EDI system operates continuously and does not require chemical regeneration, thereby eliminating downtime associated with maintenance cycles.

EDI systems typically achieve a feed water utilization efficiency of approximately 95%, meaning that only 5% of the feed water is discharged as waste, with the remainder purified for process use (Khan, 2023)

Key advantages of EDI technology include:

— Chemical-free operation, reducing environmental and safety risks.
— Stable and consistent water quality due to continuous operation
— Low OpEx, owing to minimal chemical use and reduced maintenance requirements.
— Compact system footprint and simplified maintenance procedures

However, these benefits are offset by a higher CapEx compared to conventional ion exchange systems.

2.2.1.4 Thermal evaporative desalination

Process waste heat can be used for evaporative technologies. These operate under reduced pressures of 50 to 100 mbar where also process waste heat can be utilized. Anyhow, for high-efficient PEMEL systems and here above all under partial load conditions, the waste heat duties need for evaporation cannot be supplied. If no other waste heat sources exist, this technology category becomes unattractive from OPEX point of view.

2.3 Cooling Water

2.3.1 Ambient Conditions

Table 4: Ambient Conditions Summary in Wesseling, Germany.

Parameter	Unit	Min.	Average	Max.
Ambient Pressure	mbar	978	1015	1046
Ambient Temperature	°C	-15	9.6	35
Relative Humidity	%	13	85	100
Design Temperature for Air Cooler (Dry-bulb Temperature)	°C		27	
Design Temperature for Cooling Tower (Wet-bulb Temperature) 1)	°C		19.4	

Notes:

1) Based on exceeding at 2 % frequency the daily average wet bulb temperature

The performance of the cooling water system is significantly influenced by both the availability of water supply and the prevailing ambient conditions. To evaluate the sensitivity of the system to environmental factors, an additional climatic scenario based in Granada, Spain has been considered. This allows for a comparative assessment of how elevated ambient temperatures and differing humidity levels can impact cooling system efficiency and overall water demand.

Table 5: Ambient Conditions Summary in Granada, Spain.

Parameter	Unit	Min.	Average	Max.
Ambient Pressure	mbar	1002	1006	1012
Ambient Temperature	°C	-7	16.5	37.4
Relative Humidity	%	22	60	94
Design Temperature for Air Cooler (Dry-bulb Temperature)	°C		35.2	
Design Temperature for Cooling Tower (Wet-bulb Temperature) 1)	°C		20.8	

Notes:

1) Based on exceeding at 2 % frequency the daily average wet bulb temperature

2.3.2 Technical Solutions for Cooling Water Supply

The selection of a cooling water system is primarily influenced by water availability, environmental constraints, and site-specific climatic conditions. Two common technical solutions are employed for process cooling: Cooling towers and air-cooled heat exchangers (air coolers).

2.3.2.1 Cooling Tower

Cooling towers are the preferred solution in regions where water resources are readily available, water consumption is not restricted, and wastewater management is straightforward. These systems offer lower CapEx and are widely adopted in industrial applications due to their high thermal efficiency and scalability.

In the scenario study, cooling water is supplied at the battery limit, with no constraints on water availability or wastewater discharge. As such, a cooling tower has been selected as the preferred cooling technology due to its cost-effectiveness, proven performance, and suitability for locations with unrestricted water use and manageable effluent handling.

To assess the impact of ambient conditions on cooling tower performance and water consumption, two climate scenarios were evaluated. Although Granada exhibits higher ambient temperatures, its lower relative humidity increases the evaporative cooling potential. However, this also results in greater evaporative losses, leading to a higher make-up water requirement for the same cooling tower capacity (40 MW) compared to Wesseling for compensating such water losses.

This analysis highlights the sensitivity of cooling tower water demand to climatic conditions, particularly in arid or semi-arid regions.

Table 6: System Parameters of Cooling Water System.

Parameter	Unit	Wesseling	Granada
System Volume	m^3	687	
Recirculation Rate	m^3/h	3435	
Delta T	°C	10	
Evaporation Factor (per 10 °C)	%	***1.35***	***1.5***
Evaporation Loss	m^3/h	46.4	51.5
Spray Loss Factor	%	**0.003**	**0.003**
Spray Loss	m^3/h	0.10305	0.10305
Blow Down & Spray Loss	m^3/h	20	22
Blow Down	m^3/h	20	22
Cycle of Concentration		3.3	
Make Up Water	m^3/h	***66.5***	***73.9***
Holding Time HTI	h	23.6	21.3

2.3.2.2 Air Cooler

Air coolers are typically selected in scenarios where water availability is limited, water consumption must be minimized, or wastewater discharge is not permissible. In arid or dry climates, air coolers can operate with high efficiency due to favourable ambient conditions. These systems require only an initial water fill for closed-loop operation, significantly reducing ongoing water usage and eliminating the need for continuous water replenishment.

While air-cooled heat exchangers can be considered as an alternative for the cooling water system, they are not favorable in this scenario due to the availability of cooling water at the battery limit and the high dry-bulb temperatures, particularly in locations such as Granada. Under such conditions, achieving the required cooling water temperatures using air coolers alone becomes technically challenging. If the use of air coolers is unavoidable, enhanced configurations such as air coolers with evaporative spray systems or glycol-water mixtures may be explored to improve thermal performance.

2.4 Plant Water

The plant water systems include provisions for firefighting and potable water, both of which are characterized by intermittent or non-continuous usage patterns. These systems are not part of the process water loop but are essential for safety and regulatory compliance.

2.4.1 Firefighting Water

A dedicated firefighting water system is required to comply with site-specific safety standards and regulatory requirements. According to the fire protection assessment for the Wesseling site, the system must be capable of delivering a minimum flow rate of 192 m^3/h for a duration of 2 hours. This specification determines the design capacity of the fire water storage and distribution infrastructure. The system operates as a standby reserve, activated only during emergency events such as fire incidents.

2.4.2 Potable Water

Potable water is required for emergency safety fixtures, including safety showers and eye wash stations, in accordance with occupational health and safety regulations. The actual consumption depends on the type, number, and usage frequency of these fixtures, which are to be defined by the operator based on site-specific safety requirements. As potable water is not used in the process, its demand is intermittent and on-demand, and the final system design will be based on environmental conditions, regulatory guidelines, and operational safety standards.

3. Calculated Continuous Water Demand of 100 MW Electrolyser Plant

Table 7: Water Demand of Electrolyser Plant.

Description	Unit	Value
Demin Water	m^3/h	17
Cooling Water Make-up	m^3/h	67
Fire Fighting Water	m^3/h	-
Potable Water	m^3/h	-

Only demineralized water and cooling water make-up represent continuous or regular operational demands. Firefighting and potable water are excluded from continuous demand as they are used only in emergency or safety-related scenarios.

3.1.1 Scaling Water Demand with Electrolyser Capacity

The water consumption requirements for electrolyser plants with capacities of 100 MW, 400 MW, and 1 GW are summarized in the table below.

Table 8: Water Demand of Electrolyser Plant at different Capacities.

Description	Unit	100 MW	400 MW	1 GW
Demin Water	m^3/h	17	68	170
Cooling Water Make-up	m^3/h	67	266	665
Total Water Consumption	m^3/h	**84**	**344**	**835**

As the electrolyser plant design is modular and relatively simple, scaling up the capacity primarily involves adding more electrolyser units. Consequently, the water demand increases proportionally with plant capacity. For instance, a 100 MW plant requires 84 m^3/h of water, while a 1 GW plant demands 835 m^3/h. This includes both DMW and CW make-up. However, for large-scale installations exceeding 1 GW, implementing a closed-cycle cooling water system becomes a viable strategy to significantly reduce the need for continuous cooling water make-up. In such configurations, only DMW would be required on a continuous basis, optimizing water usage and enhancing sustainability.

4. Comparison of Water Demand across Hydrogen Production Technologies

Table 9: Water Demand of H_2 Generation Plane with different Technologies.

Description	H2 Product Rate	Water Consumption	Remark	H2:H2O
Steam Methane Reformer	18,500 Nm³/h	352 m³/h	322 m³/h CW Recirculation Rate	53:1
Auto Thermal Reformer	335,000 Nm³/h	954 m³/h	596 m²/h CW Make-up (30,277 m³/h CW Recirculation Rate)	351:1
ELY	20,000 Nm³/h	84 m³/h	67 m³/h CW Make-up (3435 m³/h CW Recirculation Rate)	238:1

The table above presents water consumption across three hydrogen production technologies: Steam Methane Reformer (SMR), Autothermal Reformer (ATR), and Electrolyser (ELY). Both SMR and ATR processes require water primarily as boiler feed water for steam generation and for cooling purposes. However, due to the integration of extensive heat recovery systems, the cooling water demand in SMR and ATR plants is significantly reduced. In particular, the large-scale ATR plant is equipped with air coolers, further minimizing the need for cooling water. In contrast, the ELY plant consumes water in the form of 17 m³/h of demineralized water and 67 m³/h of cooling water make-up.

- Electrolysis Reaction:

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2$$

- Steam Methane Reforming Reaction:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

Despite stoichiometric predictions suggesting that electrolysis requires nearly twice the water per unit of hydrogen compared to SMR (or adjacent Fossil Fuel based technologies), actual operational water demand is comparable. This is due to the high efficiency of water utilization in electrolysis system and the absence of additional water consuming processes such as steam generation. As a result, transitioning from traditional hydrogen production technologies to green hydrogen via electrolysis can be achieved without imposing significant additional load on existing water infrastructure.

It is important to note that simplistic, one-to-one comparison of water usage between electrolysis and conventional hydrogen production technologies such as SMR or ATR can be misleading. A meaningful assessment requires a detailed and specific analysis. This includes evaluating factors such as hydrogen delivery temperature, ambient environmental conditions, utility integration, internal heat recovery strategies, and the configuration of cooling system. These variables significantly influence the actual water footprint and must be thoroughly assessed to accurately understand the impact of different hydrogen production methods on water infrastructure.

5. System Level Impact on Water Networks

According to BASF's 2023 water consumption report (BASF, 2023), the company's total water use amounted to approximately 6,722 million m³, with a water withdrawal of 1,518 million m³. Most of this water was used for cooling and returned to the environment without product contact, while only 67 million m³ were classified as actual water consumption due to evaporation or incorporation into products.

Another reference is the tap water consumption of cities. For Europe, the following rough numbers for very large and small ones could be compiled. Private consumption is typically 60 to 80%. So up to 50% of demand may be added to the listed numbers.

Table 10: Comparing industrial water consumption with cities, Berlin consumes more than twice BASF globally (160 versus 67 million m³ /annum) at about a dozen of large chemical parks.

City	Population	Total Use Private (m³/day)	Per Person use (L/day)
London	9 000 000	~2 600 000	290
Berlin	3 600 000	~4 50 000	120
Madrid	3 300 000	~1 200 000	360
Rome	2 800 000	~1 100 000	390
Paris (city)	2 140 000	~ 545 000	250
…	…	…	
Ljubljana	295 000	~15 000	50
Monaco (city)	39 000	~6 000	150
Valletta	42 000	~3 000	70
Vaduz	5 500	~1 500	270

In comparison, a 1 GW electrolyser (ELY) plant operating continuously would require approximately **7.1 million m³ of water per year**, including cooling water make-up.

- This represents just over **0.1%** of BASF's total water use and about **10.6%** of its actual water.
- This represents about 4% of Berlin's private household or 3% of its total tap water consumption.

If applying dry cooling the ratio reduces to about **2%** and **0.5%.**

While this is not negligible, it remains relatively modest in the context of large-scale industrial operations. Moreover, with the implementation of closed-loop cooling systems and water recycling strategies, the net impact of electrolyser plants on regional water networks can be further minimized, supporting sustainable hydrogen production.

Appendix – Fun fact

The average demand for an 18-hole golf course in Germany is about 44,000m³/year. There are plants in precipitation locations that get by with 7,500m³. In dry regions, up to 70,000m³/year water for irrigation are sometimes needed. This equals about 4,000 tons of Hydrogen, which again equals 25,000 people driving their annual milage with a FCEV.

To put it into slightly different context: 700 courses in Germany consume > 30 million m³ tap water per year which could alternatively feed more than 4 GW @ reasonable part-load. This is halfway to Germany's 10 GW target.

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