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Water Recycling Toolbox

Recycling treated wastewater for hydrogen production

Bornholm’s Energy & Utility Co. A/S

Feasibility study: pilot replication blueprint

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Introduction to the pilot measure

Recycling treated wastewater for hydrogen production

Bornholm’s Energy & Utility Co. A/S

15 March 2023

Program

Local water management situation

Feasibility study: Reuse of water for hydrogen electrolysis (PtX)

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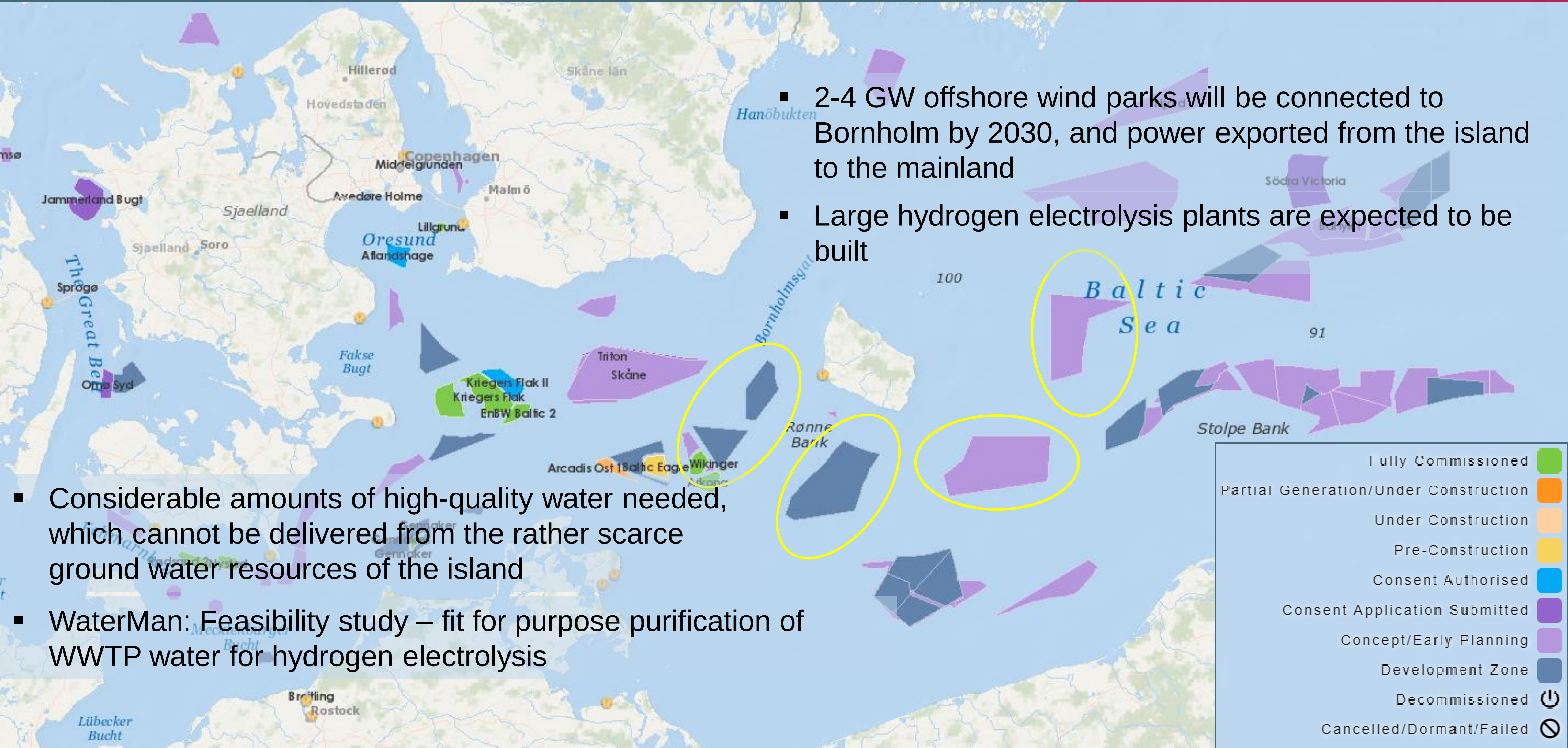
- Heavy rainfall – overflow of sewage system and nutrient outflow to the Baltic sea
- Draughts – impacting the agriculture and groundwater formation
- Tourist season puts a pressure on the wastewater treatment plants and drinking water supply
- Challenges with drinking water quality – organic micropollutants

Bornholm: The world's first Energy Island

REUSE OF WATER FOR HYDROGEN ELECTROLYSIS

- 2-4 GW offshore wind parks will be connected to Bornholm by 2030, and power exported from the island to the mainland
- Large hydrogen electrolysis plants are expected to be built

- Considerable amounts of high-quality water needed, which cannot be delivered from the rather scarce ground water resources of the island
- WaterMan: Feasibility study – fit for purpose purification of WWTP water for hydrogen electrolysis



Thanks!

Sara and Daniel kan be contacted at sb@beof.dk and dsl@beof.dk

We are looking forward to the collaboration!

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1st Peer-review session

Recycling treated wastewater for hydrogen production

Bornholm’s Energy & Utility Co. A/S

7 November 2023

Deliverable D2.2

Feasibility study: Reuse of WWTP effluent for hydrogen electrolysis on Bornholm

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All partner meeting Bornholm – 7.11.2023

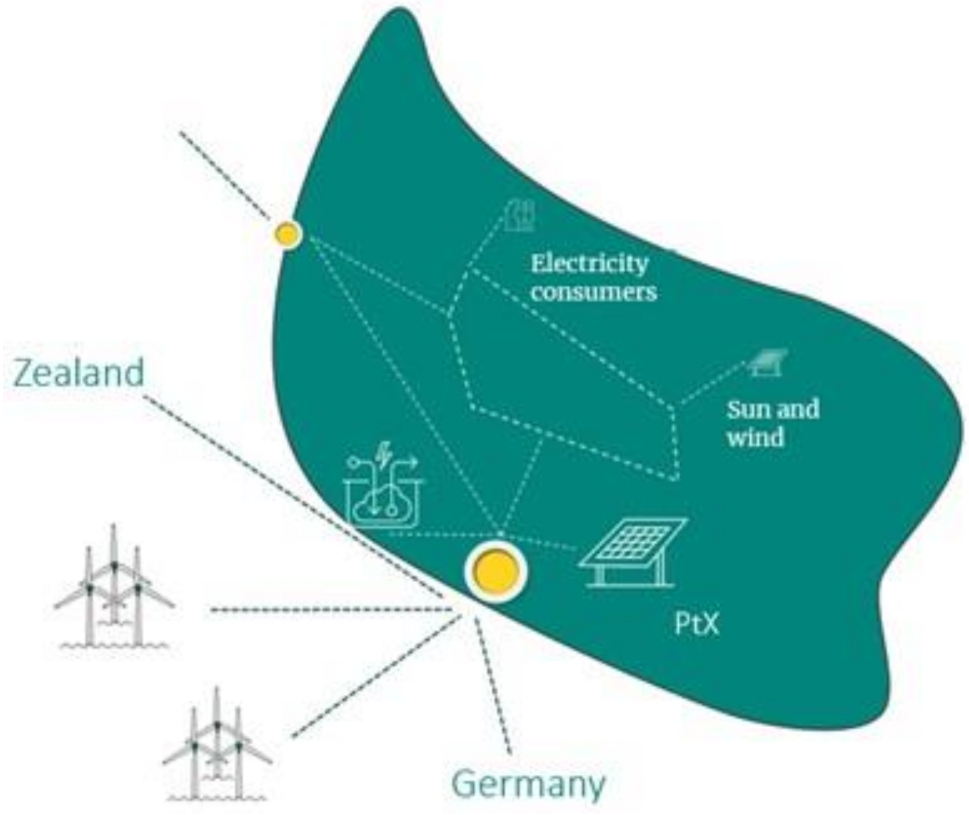
Agenda

- Background for the feasibility study
- What is Power-to-X (PtX)?
- How much water is needed for PtX?
- Why is Ultrapure water (UPW) needed?
- Water sources on Bornholm
- Tentative approach
- Workplan

Background for the feasibility study

Energi Island Bornholm

- Project decided by the Danish parliament 2020
- Large scale green electricity project
- Two fields with total 3,2-3,8 GW offshore wind turbines
- HVDC Converter station on Bornholm
- Cables to Zealand and Germany
- 2030 commissioning
- Possible overplanting 0,6-0,8 GW that can be used for PtX
- Private actor for PtX – Who?
- PtX requires Ultrapure Water to produce green Hydrogen
- Wastewater as a potential source
- Alternatively brackish water.



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What is PtX?

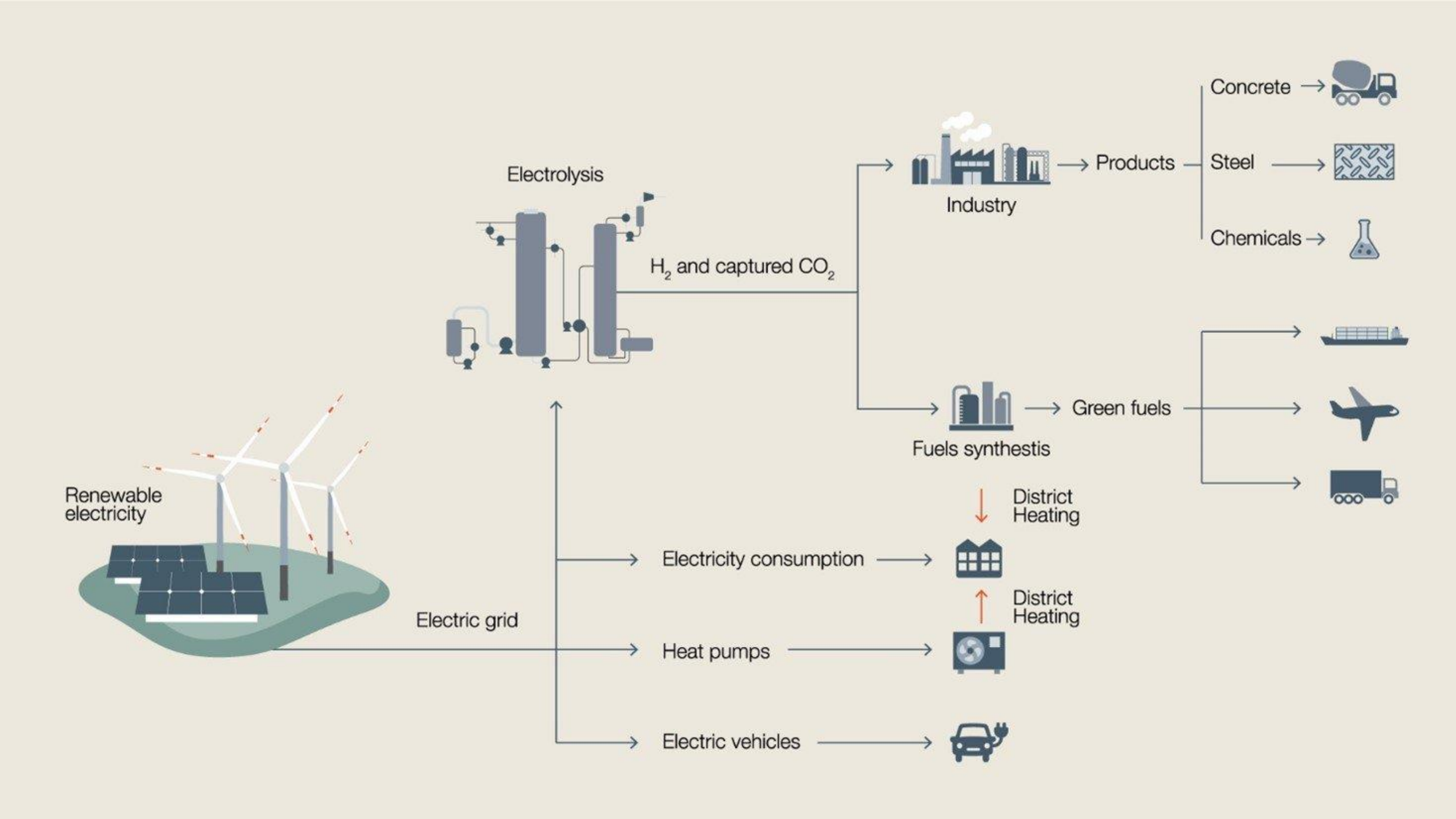
Splitting of water molecules to H_2 and O_2 by electrolysis.

H_2 = Hydrogen

Hydrogen + CO_2 = eFuels

Hydrogen + N_2 = eFuels

O_2 can be used in the WWTP process



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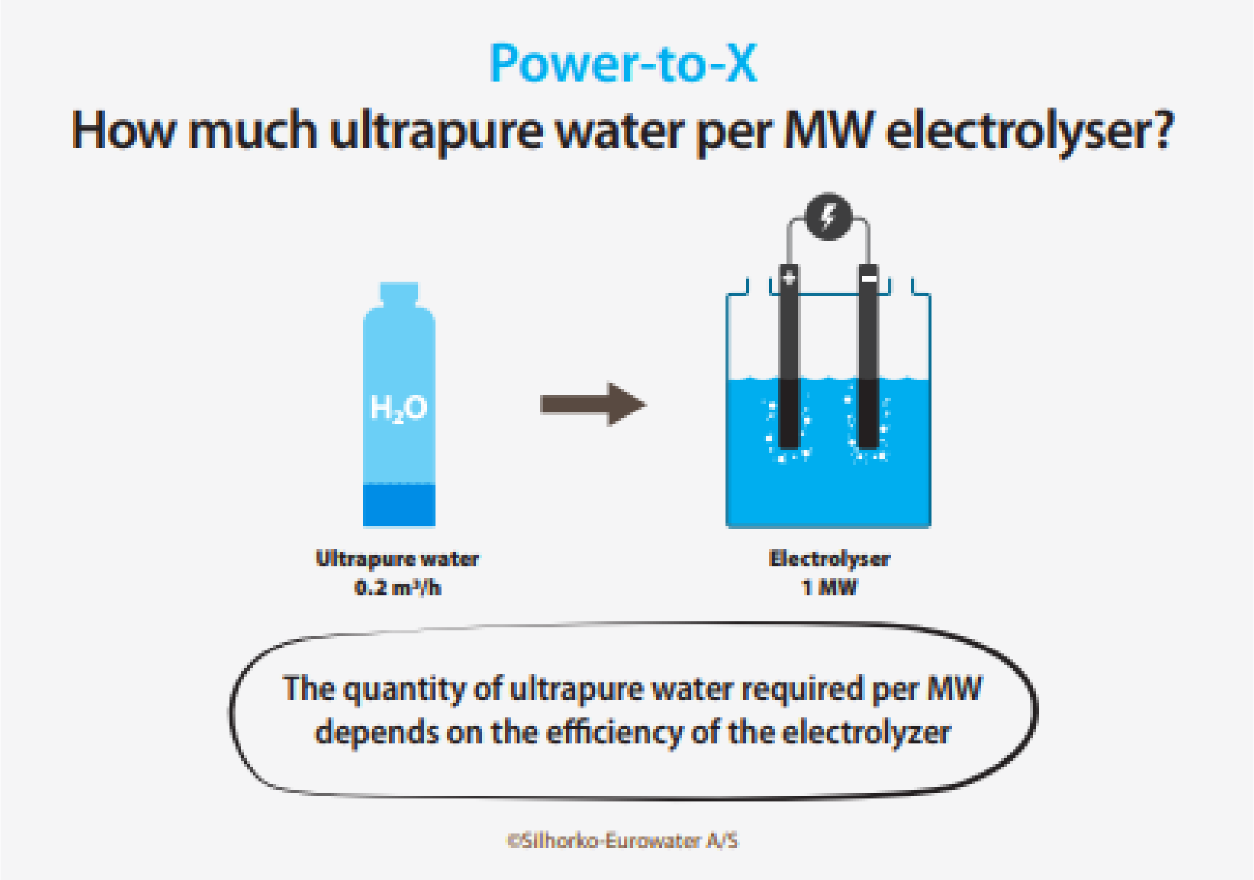
How much water is needed for PtX?

Case 0,8 GW PtX

- 160m3/h = 1,4 millon m3/year
- Feed: ~225m3/h = 2 million m3/year
- Recovery rate: 70%
- Quality: Ultrapure water

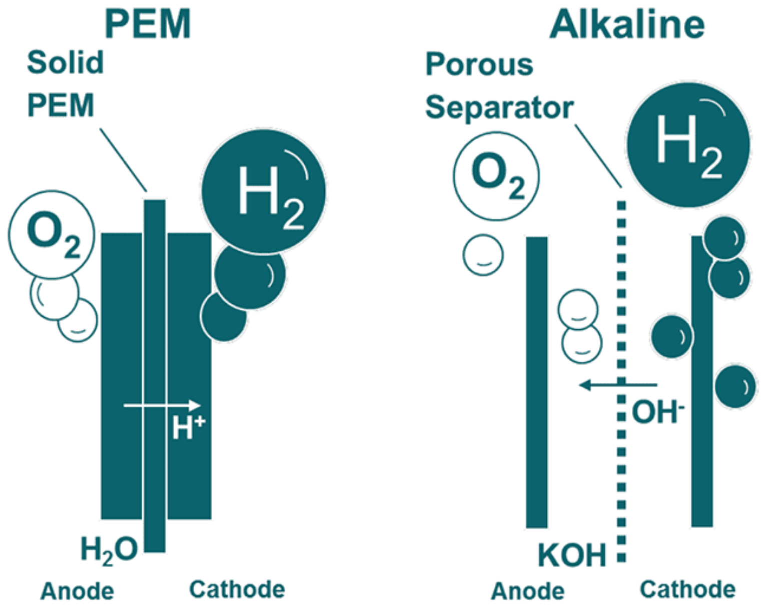


Why is Ultrapure water needed?

- Electrolysis equipment is sensitive to water quality, with a range of common impurities impacting performance, hydrogen quality and device lifetime.
- Quality also highly depends on type of electrolysis cell used technology that is used:

❑ PEM:**< 0.1 µS/cm**
❑ Alkaline: **<1 µS/cm**

Drinking water: ~600 µS/cm
Wastewater effluent: ~850-1200 µS/cm



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WASTEWATER ON BORNHOLM

BEOF handles all wastewater on Bornholm

7 WWTP with a yearly treatment of 7 million m^3 wastewater.

898 km pipes
213 pumpstations

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OTHER WATER SOURCES ON BORNHOLM

Source	Quantity (BEOFs estimate)	Salinity ppt
Drinking water (ground water)	< 100.000 m3/year	0,3-0,4
Low-quality drinking water	< 1 mio. m3/year	0,3-0,4
Stormwater/rainwater	> 1 mio. m3/year	0 – 0.02
Wastewater	7 mio. m3/year	2
Surface water Baltic Sea	Infinite	7-8
Surface water North Sea	*Infinite*	*28-35*

The feasibility study will focus on wastewater effluent.

Brackish water as a source will also be analysed but on a general level.

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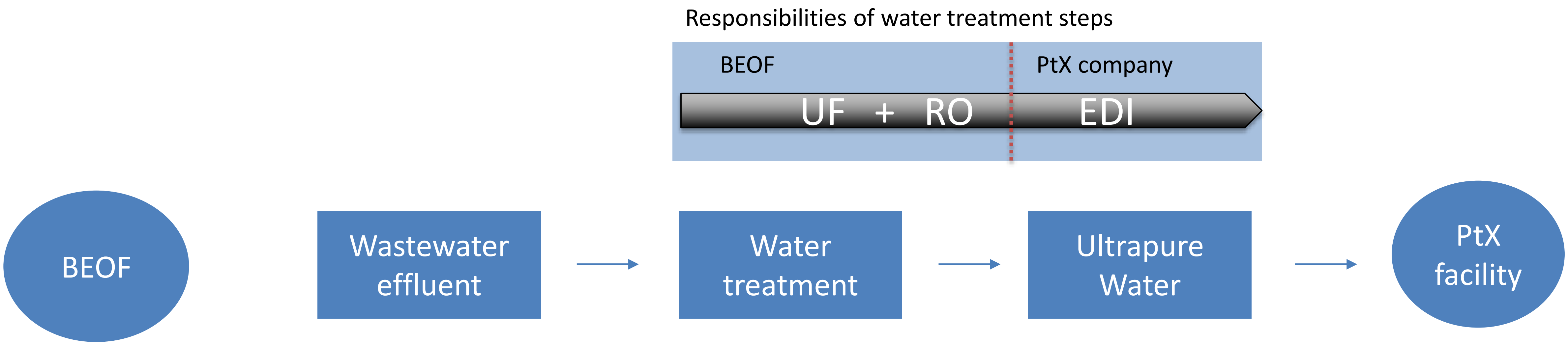
Tentative approach - Wastewater



- Water sector regulation
- Company structure
- Price ceilings & performance benchmarking (monopoly)
- Business case
- Risk analysis: one single customer etc.

- Quantities
- Quality of effluent
- Seasonal variations
- Future quality (New WWTP?)

- Treatment technologies: Focus on membrane based as it is the standard.
- CAPEX, OPEX, KwH/m3
- Brine handling, impact on WWTP process and sludge
- Synergies
- RO quality or Ultrapure water

- Quantities required
- Quality requirements: Alkaline vs. PEM electrolysis
- Other water needs: cooling water
- Distribution: Location & transport
- Excess heat (evaporation)

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Tentative approach – Brackish seawater

- Quality of BW
- Seasonal variations
- Future quality
- Temperature
- Depth of intake

- Treatment technologies: Focus on membrane based as it is the standard.
- CAPEX, OPEX, KwH/m3
- Brine handling, discharge back into Baltic sea?

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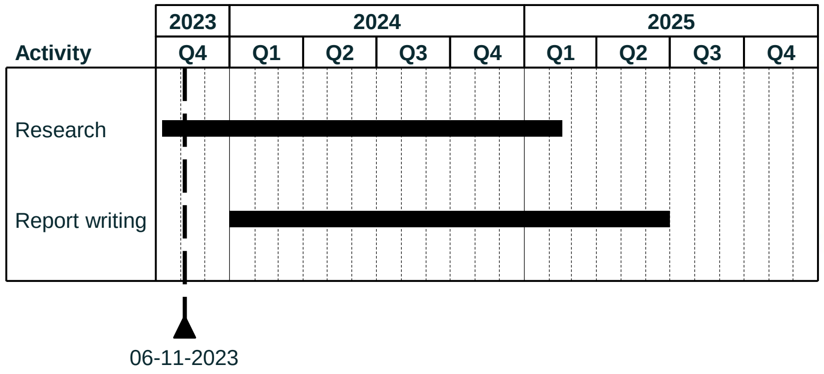
Workplan

Workplan

- Align scope with WATERMAN project requirements
- Incorporate value generation for BEOF
- Desktop research
- Collect BEOF internal data (wastewater)
- Identify knowledge gaps and sources for expert interviews

Challenges

- Legal and regulatory complexity
- On going dialog with authorities



1st Peer & expert review session: Recommendations & conclusions

- Further factors to take into account in the business model:
  - Energy price: Most likely in times of high prices, the power plant owner will be more inclined to sell the energy on the market, than to deliver it to the PtX.
  - Overplanting: It will fluctuate over the time of the year. It would be economically feasible to flexibly choose when to produce the hydrogen.
  - Storage: The above would mean that you may have to store the ultrapure water (if you decide for ultra-pure treatment) for longer periods of time (until when the energy is cheaper). From the management point of view it may be better to leave the ultra-pure stage of treatment to the PtX.
  - Contract: You have to have a clear agreement with the PtX plant, under which condition you can shut-off the delivery of water to them (i.e. private sector), to be prepared for cases when it will be necessary to prioritise the delivery of water to the general public, and for public uses.
  - Legislation: The new centralised WWTP is likely to fall under the new Urban Wastewater Treatment Directive. This means that you have to consider the removal of trace organic compounds.
  - Use of residues / products: Think about how you can reuse not only O2, but also the mineral residues after ultrafiltration and reverse osmosis. In Germany there are examples where the oxygen is used in industrial symbiosis.
  - Consider security risks for the plant & PtX infrastructure (security is a factor as recent events showed that e.g. underwater infrastructure cables are under attacks).
  - Consider involvement of the local public into the process at early stages.
- Technology:
  - Planning of the new WWTP: Consider to set up a Membrane BioReactor (MBR) instead of a conventional plant. By combining the microbial degradation with an ultrafiltration you will extend the potential scope of utilisations of the treated water, and also increase the microbial safety (e.g. for remaining water that eventually goes to the sea)
  - Consider adding advanced oxidation process to the regular treatment to remove persistent organic pollutants.
  - Reverse osmosis permeate quality (for considering ultra-pure solution): Single pass has a conductivity of 15 µS/cm, and double pass has a conductivity of about 3 µS.
  - In case of using brackish water, consider that also storm water from the cities is a source of organic compounds in it.
  - For lowering the concentration of Nitrogen, willows in a constructed wetland can be considered, because they have a high tolerance towards salinity (e.g. a related project conducted in Belgium can be a model for this).
  - The “Green Steel” project in Lulea / SE can be also worth investigating.

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<u>2nd Peer-review session</u>

Recycling treated wastewater for hydrogen production

Bornholm’s Energy & Utility Co. A/S

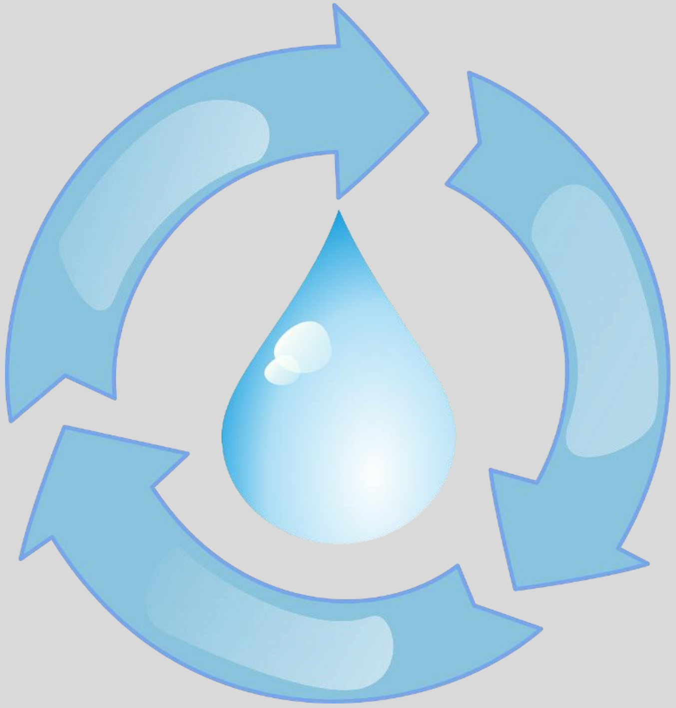
1 April 2025

Feasibility Study on Reuse of WWTP Water for Hydrogen Electrolysis Power Plant on Bornholm

Assessing the technical, economic, environmental and regulatory aspects

Paulo Silva

01/04/25



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Reuse of WWTP Water for PtX on Bornholm

Project Context & Motivation *(Why are we doing this?)*

- Bornholm, like many regions, potentially faces **water scarcity and seasonal fluctuations** in water availability.
- Power-to-X (PtX) projects require **large volumes of ultrapure water** for hydrogen electrolysis.
- Wastewater reuse presents an opportunity to **reduce freshwater extraction** and create a **circular economy** in water management.
- Aligns with **Denmark's sustainability goals** and the **EU Green Deal**.

Scope of the Feasibility Study *(What does this study cover?)*

- Investigates whether **treated wastewater from a WWTP** can be reliably **cleaned via Reverse Osmosis (RO) and supplied to a PtX plant**.
- Evaluates **technical, economic, regulatory, and environmental aspects** of the project.
- Compares wastewater with other water sources like **groundwater and seawater**.
- Identifies **risks, regulatory barriers, and possible business models**.

Reuse of WWTP Water for PtX on Bornholm

Key Stakeholders & Relevance *(Who is involved & why does this matter?)*

- **Project Owner:** Bornholm Energi og Forsyning (BEOF) – Managing wastewater treatment & potential water supply.
- **Regulatory Authorities:** Danish Water Sector Act, Miljøstyrelsen, and the Danish Competition & Consumer Authority.
- **Technology Partners:** SILHORKO-EUROWATER (RO treatment), consulting firms (NIRAS, Rambøll, COWI).
- **Industry & Market Players:** PtX companies, hydrogen producers, and industrial off-takers.
- **Research & Development:** Collaboration with universities (e.g., DTU) and INTERREG WaterMan project partners.

Key Questions to Answer *(What will this presentation address?)*

- Is reclaimed water a **viable and cost-effective** source for PtX water supply?
- Can RO treatment **meet the required water quality,** for further treatment?
- How do **CAPEX, OPEX, and TOTEX** compare across water sources? With focus on the 0.8 GW surplus available for Ptx.
- What **regulatory challenges** exist in supplying reclaimed water?
- What are the **main risks & mitigation strategies**?

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Background & Theoretical Framework

Power-to-X (PtX) & Water Demand *(Why is water critical for PtX?)*

•What is PtX?

- PtX refers to technologies that **convert renewable electricity** into hydrogen or synthetic fuels (methanol, ammonia, methane).
- Hydrogen production via **electrolysis** requires ultrapure water to avoid equipment degradation and ensure efficiency.

•Water Consumption for PtX Hydrogen Electrolysis:

- **9 liters of ultrapure water per kg of hydrogen produced**.
- A **1 GW PtX plant** needs approx. **5–7 million m³/year** of ultrapure water.

•Why consider wastewater reuse?

- Reduces dependency on freshwater sources.
- Enhances sustainability by closing water loops.
- Aligns with circular economy and climate adaptation strategies.

(Freepik 2025)

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Background & Theoretical Framework

Wastewater Treatment Process & Reverse Osmosis (RO) ***(How do we turn wastewater into ultrapure water?)***

•**Stages of Wastewater Treatment:**

- **Primary Treatment** – Solids removal, sedimentation.
- **Secondary Treatment** – Biological treatment (activated sludge, MBBR, etc.).
- **Tertiary Treatment** – Advanced filtration (sand filters, UV disinfection, chemical polishing).

•**Reverse Osmosis (RO) for Ultrapure Water Production:**

- RO is a **membrane filtration process** that removes salts, bacteria, and organics.
- A typical system includes **pre-treatment**, **RO membranes**, and **post-polishing** **(EDI, ion exchange, UV sterilization)**.
- **Challenges:** Membrane fouling, energy consumption, brine disposal.

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Background & Theoretical Framework

Regulatory Landscape *(Who governs water reuse in Denmark?)*

- **Danish Water Sector Act:**
  - Defines two types of water suppliers:
    - **Wastewater Companies** – Primarily treat wastewater; **limited ability to sell reclaimed water**.
    - **Drinking Water Companies** – Can legally supply reclaimed/ultrapure water for industrial use.
  - BEOF must explore legal options to supply PtX water.

- **Environmental & Health Regulations:**
  - **PFAS and micropollutants removal** is a key challenge.
  - Discharge of **brine waste** from RO systems must meet environmental limits.

- **EU Renewable Energy Directive:**
  - Promotes hydrogen production from renewable sources.
  - Supports sustainable water management in industrial applications.

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Background & Theoretical Framework

Comparison of Water Sources for PtX on Bornholm *(Which sources are available, and how do they compare?)*

Water Source	Advantages	Challenges
Groundwater	High availability, lower treatment cost	Limited capacity, potential over-extraction
Brackish water (Baltic Sea)	Abundant, stable source	High energy cost for desalination, low-medium recovery rate
Treated Wastewater	Sustainable, reduces freshwater use	Requires advanced treatment, regulatory barriers

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Methodology

Main approach:

- **Assessment Criteria** (Technical feasibility, Cost analysis, Risks, Environmental impact)
- **Data Sources** (WWTP water quality data, supplier quotes, regulatory requirements)
- **Comparison of Water Sources** (Wastewater vs. Groundwater vs. Brackish water)

Stakeholder Analysis

Key Stakeholders:

- **Regulatory Authorities:** Miljøstyrelsen, Bornholm Kommune, Danish Competition and Consumer Authority.
- **Industry Partners:** PtX companies, SILHORKO-EUROWATER.
- **Consulting Firms:** NIRAS, COWI, Rambøll.

Objectives of Stakeholder Analysis:

Identify **decision-makers** and key technical contributors.
Ensure **regulatory compliance** (e.g., legal ability of wastewater companies to supply reclaimed water).
Develop **engagement strategies** to align interests and secure collaboration.

Risk Management & Feasibility Assessment

Key Risks Identified:

- **Regulatory Barriers:** Compliance with Danish and EU water supply laws.
- **Financial Viability:** CAPEX, OPEX, and cost per m^3 of reclaimed water.
- **Technical Uncertainties:** Water quality fluctuations, membrane fouling, brine disposal.

Approach to Risk Mitigation:

- **Internal & External Feasibility Studies** to evaluate financial and technical sustainability.
- **LCA Study** to assess environmental benefits of reclaimed water over conventional sources.
- **Sensitivity Analysis** to evaluate impact of cost fluctuations and technology performance.

Key Findings & Results: Technical Feasibility – NIRAS report

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	Power-To-Hydrogen (PtH)		
Plant size Hydrogen production (t/year)	1 - 50 MW 90 - 4.500	50 - 200 MW 4.500 - 18.000	200 MW - 1 GW 18.000 - 90.000
Ultrapure water Annual water volume (m^3/year) Hourly water volume (m3/hour)	750 - 37.000 0,15 - 7	37.000 - 150.000 7 - 30	150.000 - 750.000 30 - 140
Potential water source(s)	Public water supply Field drilling Surface water	Public water supply Contaminated groundwater Treated wastewater Surface water	Contaminated groundwater Treated wastewater Seawater
Electricity supply Wind Sun Net	Local electricity supply X X X	Local X X X	 X (X) X
Desalination Technology [1]	Reverse Osmosis, Ion Exchange	Reverse Osmosis, (Ion Exchange)[2]	Reverse Osmosis

Table. Overview. Grouping of Power-To-Hydrogen (PtH) plants based on size, potential water source and clean water technologies, and electricity supply. Data based on market dialogue, and key figures for the PEM electrolysis process. Key figures used: specific energy consumption of 5.8 kWh per m3 of ultrapure water. Operating time of 5,300 hours per year (61% of the time). Hydrogen density at standard conditions of 0.09 kg per Nm3, density of water at 8°C of 999.9 kg/m3

Source: NIRAS report "*Process Wastewater Treatment*", 2024

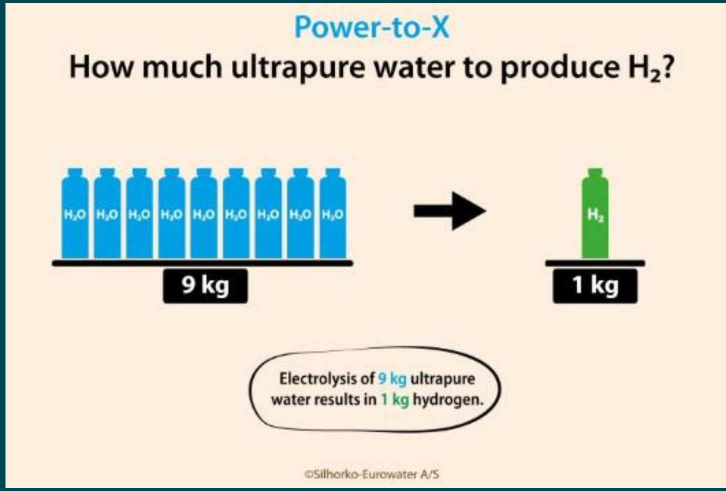
Key Findings & Results

Technical Feasibility (RO treatment performance, required infrastructure)

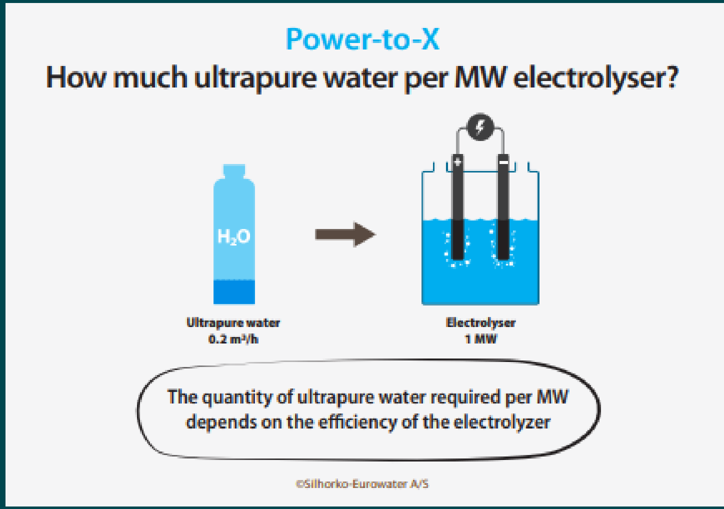
- RO treatment achieves water quality suitable for delivery to Ptx. But post-polishing is required for ultrapure water (out of scope).
- Pipeline network to transport reclaimed water from the WWTP to the PtX plant.
- Storage solutions to handle fluctuations in water demand.
- Brine disposal system to comply with environmental regulations.

	0,6GW PTX	0,8GWPTX
Required UPW quantity	120 m3/h	160 m3/h
Feed water quantity required at 70% recovery rate	170 m3/h	230 m3/h
Feed water quantity required at 80% recovery rate	150 m3/h	200 m3/h
Rønne, Nexø and Boderne (summer)	~275 m3/h	
Rønne (summer)	150-160 m3/h	

Rønne WWTP does not have sufficient wastewater, but the centralized system would suffice.



(Silhorko-Eurowater A/S 2024)



(Silhorko-Eurowater A/S 2024)

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Key Findings & Results: Economic Feasibility - Niras report, costs section summary

	Demands and efforts	CAPEX		OPEX		TOTEX (10 years)		Ultrapure water	
		50 MW My. Kr.	1 GW My. Kr.	50 MW My. Kr.	1 GW My. Kr.	50 MW My. Kr.	1 GW My. Kr.	50 MW kr./m3	1 GW kr./m3
Treated wastewater									
	Clean water systems	45	210	3,5	16	7,5	37	105	27
1	Wastewater treatment plants: Special PFAS challenges in the catchment area	8	40	1,5	10	2,5	15	32	10
2	Wastewater treatment plant: Diffuse PFAS input from the catchment area	6,5	28	1,5	7,5	2	10	29	7
Groundwater									
	Clean water systems	35	155	2	15	5,5	30	75	22
3	Wastewater treatment plant: No specific groundwater contamination	5,5	13	0,7	3	1,2	4	16	3
Surface water									
	Clean water systems	42	195	3	15	7	35	100	25
4	Wastewater treatment plant: Diffuse PFAS input from the catchment area	6,5	24	1,5	5	1,5	7	21	5
Seawater									
	Clean water systems	85	350	7	35	16	70	220	52
5	Purifiers	7	33	0,6	5,5	1,1	8	16	6
Economic uncertainty: >50%			Economic uncertainty: 30-50%				Economic uncertainty: 30%		

Table. CAPEX (Capital Investment), OPEX (Annual Operation) and TOTEX (Total Annual Costs) of 50 MW and 1 GW installations for alternative water sources and technology trains, as well as prices per m3 of ultrapure water. The economic uncertainty is colour-coded, as shown at the bottom of the table.

No data found — it's challenging to estimate the cost per m³ of wastewater treated by RO. Perhaps the KWB LCA study can offer reliable figures on this.

Source: NIRAS report "*Process Wastewater Treatment*", 2024

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Risks – What Could Go Wrong?

Framing Risks as Obstacles:

- **Political**: Changes in environmental policies, subsidies, or water sector regulations.
- **Economic**: Cost fluctuations in infrastructure, energy, and operational expenses.
- **Social**: Public perception and acceptance of wastewater reuse.
- **Technological**: Failures in treatment technology or new regulatory standards requiring adjustments.
- **Legal**: Compliance with the Danish Water Sector Act and other regulatory barriers.
- **Environmental**: Potential brine disposal challenges and water scarcity issues.

(Freepik 2025)

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Risk Analysis

Sample of full risk list

What Can Go Wrong	Consequence (1-5)	Probability (1-5)	Risk Score (C × P)	Preventive Actions	Mitigation Actions	Responsible
Water quality & composition issues	4	3	**12 (High)** **Prevent- Plan B**	Real-time monitoring, advanced treatment controls	Emergency polishing, alternative water sources	Technical team
Dependence on a single customer	5	2	**10 (High)** **Prevent- Plan B**	Market diversification, contractual agreements	Flexible supply agreements, alternative off-takers	Business Development
Equipment failure	3	3	**9 (Medium)** **Plan B**	Preventative maintenance, redundancy systems	Rapid repair protocols, spare parts inventory	Technical Operations
Fluctuations in operational costs	3	3	**9 (Medium - high)** **Plan B**	Long-term supplier agreements, cost forecasting	Budget reserves, price adjustments	Finance Team
Staff shortages	2	2	**4 (Low)** **Monitor**	Workforce planning, cross-training employees	Temporary staffing solutions	HR & Operations
Supply chain risk (chemicals & equipment)	2	2	**4 (Low)** **Monitor**	Multiple suppliers, inventory management	Emergency procurement	Procurement Team

Risk mitigation strategies:

- **Technical Mitigation**:
  - Routine RO system testing and backup systems.
- **Regulatory Mitigation**:
  - Monitoring legislative changes and adapting.
- **Market Mitigation**:
  - Engaging with stakeholders to evaluate market shifts.

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Conclusion – Key Takeaways

- **Technical Feasibility:** Reclaimed wastewater can be effectively treated to ultrapure water using **Reverse Osmosis (RO) and Ion Exchange**, ensuring water quality for hydrogen electrolysis. BEOF secures reclaimed water up to RO.

- **Economic Feasibility:** uncertain with RO wastewater price. But significant **cost reduction at scale**, with ultrapure water costs dropping from **DKK 135/m³ (50 MW) to DKK 35/m³ (1 GW)**.

- **Regulatory Considerations:** The wastewater company's ability to supply PtX companies depends on compliance with the **Danish Water Sector Act** and coordination with the **Danish Competition and Consumer Authority**.

- **Sustainability Impact:** Using **reclaimed water instead of groundwater or seawater** improves environmental sustainability, aligns with **EU renewable energy goals**, and reduces overall water stress.

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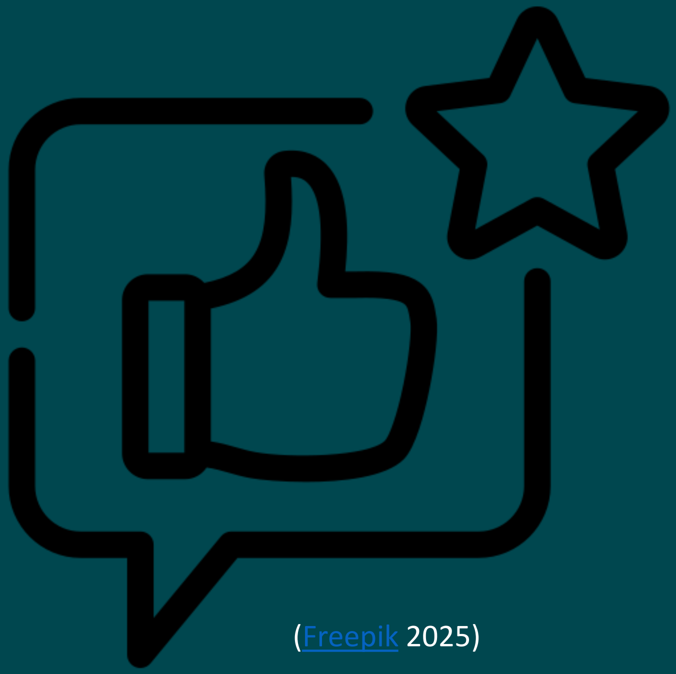
Recommendations

- Establish a Dedicated Water Company.
- Engage Early with Regulatory Authorities.
- Leverage Wastewater as the Primary Source
- Maximize Energy Efficiency (Ptx synergies).
- Plan/mitigate for Future Water Demand Fluctuations
- Invest in High-Efficiency Reverse Osmosis (RO)
- Conduct Detailed CAPEX and OPEX Studies (engage with consulting companies)



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Eurowater – Feedback

CAPEX and OPEX Estimates:
- Difficult to assess; depends on final water treatment system design. Engage with NIRAS
- Estimated cost: €1-3 million (excluding EDI).
- Additional costs for specialized wastewater processes (e.g., concentrated RO waste during dry summers).

Water Treatment Plant Area Requirements:
- Depends on design; compact units (e.g., standard RO unit ~5 m² footprint).
- Estimated need for multiple units.

Using Baltic Sea Brackish Water:
- Feasible with reduced pressure due to lower salinity.
- Technical advantages over wastewater; more experienced vendors.
- Brine management: easier with seawater, can blend with wastewater for reduced impact.

Brine Management Solutions:
- Eurowater does not include brine management (meaning mixers and distribution/discharge pipes) but solutions exist.

PFAS Removal:
- PFAS can be eliminated through incineration (e.g., pyrolysis).

New Treatment Plant on Bornholm:
- Opportunity to future-proof with PtX integration.
- Consider synergies (e.g., using PtX oxygen for wastewater treatment, CO2 from biogas).
- Maintain independent operation of wastewater system from PtX facility.

(Freepik 2025)

Source:
Henrik Tækker Madsen
Application Development Manager

EUROWATER
A Grundfos company

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Thank you!

Questions?

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2nd Peer & expert review session: Recommendations & conclusions

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- Clarify legal and regulatory frameworks for PFAS and brine management: determine whether PFAS removal is legally required for the brine produced during the further treatment of WWTP effluent, especially since current laws are ambiguous. At the moment there seems to be no equal treatment between discharge of WWTP effluent and brine from the RO process. Therefore BEOF should engage in regulatory dialogue and possibly lobby for exceptions or clearer guidelines for industrial reuse.
- The cost of cost for taking care of the brine is a crucial factor in cost-benefit analysis, and may have heavy impact on the economic viability of the whole process. Contact other projects in Denmark working on recycling water for PtX (e.g. treated WWTP effluent or polluted groundwater – incl. nitrates, pesticides, PFAS) to see how they solve this problem.
- Investigate the technical and legislative feasibility of mixing WWTP-treated water with brackish water. While it may optimize treatment (if you can blend both in a treatment train), it might also complicate treatment processes (different hardness of water) and fall under the wastewater treatment regulations.
- Finalize the Lifecycle Assessment (LCA) study to get information on environmental viability, cost-effectiveness, and the best water source (WWTP effluent vs. brackish water or a mix). This will be a key input for the PtX feasibility study due in September.

Access the „BSR Water Recycling Toolbox” here.
https://www.eurobalt.org/waterrecyclingtoolbox/

Interreg Baltic Sea Region

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SUSTAINABLE WATERS WaterMan

The „BSR Water Recycling Toolbox” was elaborated as part of the project “WaterMan - Promoting water reuse in the Baltic Sea Region through capacity building at local level”, The project is co-financed by the European Union (European Regional Development Fund) and implemented within the Interreg Baltic Sea Region Programme. More information:

eurobalt.org/WaterRecyclingToolbox
interreg-baltic.eu/project/waterman

WaterMan promotes a region-specific approach to water recycling, which intends to use the alternation of too much and too little water that has become typical in the Baltic Sea Region to make the local water supply more resilient, and supports municipalities & water companies in adapting their strategies.