stargate hydrogen

V2

The Integration Guide for Hydrogen Stacks

Make Informed Decisions to Achieve Optimal Efficiency.

MADE IN EUROPE

Alkaline electrolysers for enabling the industry of tomorrow.

www. stargatehydrogen.com

The Hydrogen Stacks' Integration Guide

Welcome to Stargate Hydrogen's guide on integrating hydrogen systems. This guide is **tailored for decision makers in engineering firms** seeking integration expertise. We will address critical considerations, from technology to team building and cost-efficiency.

In this guide you will learn:

About Stargate Hydrogen

Stargate Hydrogen was founded in 2021 to **make green hydrogen affordable for hard-to-decarbonise industries** like steel, fertilisers, and chemicals. Our focus: improving electrolyser efficiency and cutting costs using novel ceramic catalysts and patented stack design.

Tested by renowned independent research institutes such as ZSW and Fraunhofer, our electrolysers are reliable and cost-effective. With €50M+ in funding from strong investors and IPCEI status we're capable of producing 140 MW worth of electrolysers annually.

Our customers include Fortum, Utilitas, ABB, Rockfin, and others across Europe, Turkey, and India. They all receive extensive engineering support while integrating our products into their operations. We deliver real results through efficient and scalable hydrogen solutions. Together, we enable the industry of tomorrow.

"Success in our industry hinges upon the careful selection of partners for stack integration. Our ability to deliver **cutting-edge, efficient,** and reliable technology depends on collaborating with experts. Choosing partners who share our commitment to innovation and quality ensures seamless integration and paves the way for a **sustainable Green Hydrogen future."**

Marko Virkebau
The CEO of Stargate Hydrogen

Choosing the Right Technology

Electrolyser stacks, are the heart of any Electrolyser production system. These stacks are a **simple, yet intricate assembly of components** designed to facilitate the electrolysis of water, splitting it into its constituent elements, hydrogen and oxygen, using electricity.

Selecting the appropriate stack technology is paramount to success. In this section we'll compare the four most prominent technologies for hydrogen production: **Alkaline, PEM, AEM,** and **SOEC** technologies.

Next you will learn about each technologie's suitability for various applications and performance. Understanding their efficiency, scalability, and compatibility with your operational needs will **guide your decision-making process**.

Alkaline Electrolysis

As one of the earliest methods, Alkaline Electrolysis showcases robustness and reliability in hydrogen production.

Utilizing cost-effective materials and an alkaline electrolyte solution, **this technology offers a compelling cost advantage over other methods.**

Its straightforward design make it an economically sound choice for industries seeking a reliable and proven approach to hydrogen generation.

PEM Electrolysis

Employs a solid polymer electrolyte membrane, allowing for compactness, fast start-up, and efficiency. **The PEM electrolyser is compact and best suitable for small-scale applications.**

Nonetheless, PEM systems are relatively expensive due to the need for precious metal catalysts, such as platinum, and are sensitive to impurities in the feedstock.

Choosing the Right Technology

AEM Electrolysis

Similar to PEM, utilizes a polymer membrane, but in this case, it permits the transport of negatively charged ions. AEM technology seeks to mitigate the high cost associated with PEM systems while maintaining some of their advantages, like operational flexibility and efficiency.

AEM Electrolysis can be more tolerant of impurities, but challenges remain in developing scalable, stable and durable membranes.

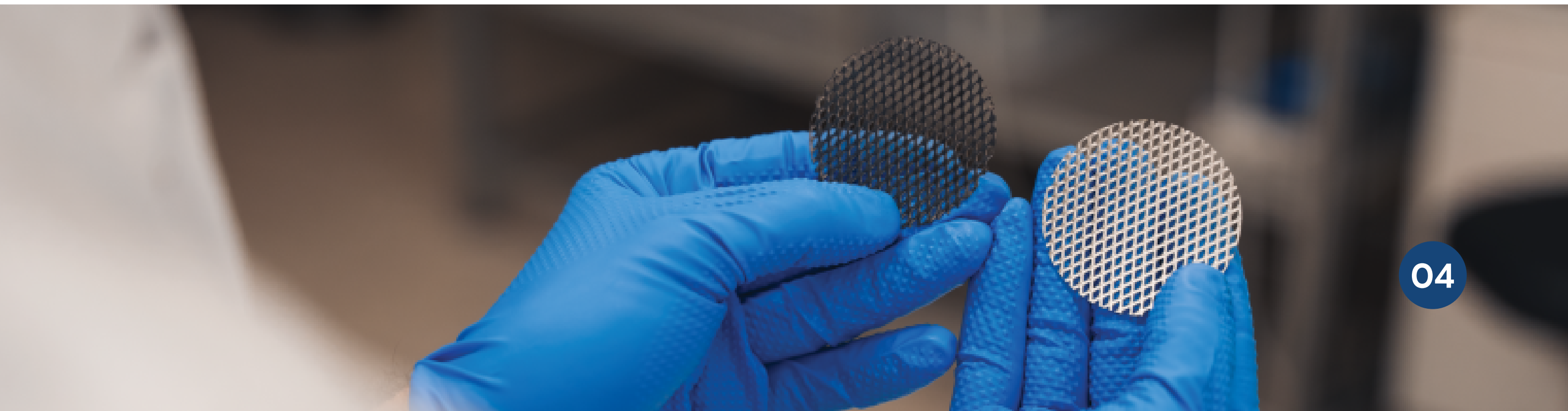
Solid Oxide Electrolysis

SOEC operates at high temperatures, improving reaction kinetics and enhancing process efficiency. Additionally, the high operating temperatures allow for the utilization of waste heat from industrial processes or other sources, increasing the overall energy efficiency of hydrogen production.

But the technology is still in development and struggling with reaching multi-megawatt scale.

Key takeaways about technology

For high reliability in large scale hydrogen production where cost-effectiveness is needed, Alkaline Electrolysis is preferred. PEM Electrolysis suits applications requiring compactness, but that comes with a cost and uncertainty on long term use. AEM Electrolysis is an evolving technology seeking to bridge the cost-efficiency gap between Alkaline and PEM systems, suitable for small-scale applications but its track record is limited. Finally, SOEC technology's efficiency in high-temperature processes and adaptability makes it an intriguing option and could in the future unveil new opportunities as the landscape evolves.

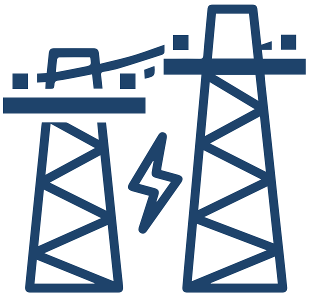


The Nature of the Power Supply

The mode of operation — **constant, variable, or intermittent** — significantly influences the performance and longevity of hydrogen production systems. While constant operation offers optimal efficiency and durability, variable and intermittent operations introduce challenges that require strategic mitigation.

Advancements in electrolyzer technology, control systems, and integration strategies are essential to enhance the viability of hydrogen production under less stable conditions.

Main Power Supplies Comparisson



Constant

The electrolyzer operates at a stable, continuous power input—typically close to its rated capacity—with little to no fluctuation.

Variable

The electrolyzer runs under changing power input levels within an operating range, but do not involve frequent stops or full shutdowns.

Intermittent

The electrolyzer operates sporadically, frequently starting and stopping depending on the availability of power.

Ignoring proper mitigation strategies for variable or intermittent hydrogen production can reduce efficiency, damage equipment, and increase costs. Without adaptation, electrolyzers face faster wear, lower output, and reliability issues—especially when powered by unstable energy sources.

The Nature of the Power Supply

Summary Comparison Table

The following table highlights the key differences between constant, variable, and intermittent operation modes, focusing on power stability, efficiency, equipment stress, and suitable applications. It provides a quick reference to understand how each mode affects hydrogen production performance and system design requirements.

Attribute	Constant	Variable	Intermittent
Power Stability	High	Medium	Low
Hydrogen Output	Predictable	Fluctuating	Sporadic
Efficiency	Optimal	Slightly reduced	suboptimal
Equipment Stress	Minimal	Moderate	High
Power Sources	Grid, hydro, nuclear	Buffer renewables	Unbuffer renewables
Control Required	Low	Moderate	High

Mitigation strategies for Alkaline Electrolysers

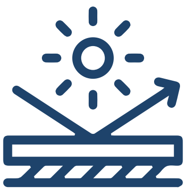
To effectively operate alkaline electrolyzers with variable and intermittent energy sources, key mitigation strategies include integrating energy storage systems—such as batteries or supercapacitors—to buffer power fluctuations and ensure smoother input. Implementing advanced control systems can optimize load response and minimize thermal stress during power changes. Preheating mechanisms and intelligent start-stop protocols can reduce wear during frequent cycling.

What Makes a Good Stack?

Understanding **the nuances of a hydrogen stack** is crucial in establishing an efficient and reliable hydrogen production system. This efficiency is expressed through the electrical-to-chemical energy conversion ratio.

Durability

A longlasting stack is a must for commercial applications. A good stack must exhibit **stable performance over long life time** ensuring a predictable and reliable rate of hydrogen production.



Robustness

Is a key factor, considering the demanding conditions hydrogen stacks face, The ability to **withstand harsh conditions over a wide window of operation** over an extended period of time without significant degradation is essential in a quality stack.

Flexibility

Is a crucial feature for industries with fluctuating hydrogen demands. An ideal stack should offer **scalability to meet changing production needs** without requiring excessive modifications.

Safety

Is of utmost importance in any hydrogen production process. A reliable stack should **incorporate safety features**, including robust seals to prevent gas leaks or potential hazards.

Low-maintenance

Is highly desirable, reducing downtime and operational costs. An effective stack design should **minimize the need for frequent servicing and part replacements**.

Specifications of the Ideal BoP Configuration for Stargate's Stack

Determining the ideal Balance of Plant (BOP) for Stargate Hydrogen's Stack is crucial and integrating it following the best practices is a complex task. The theory behind the BOP specification seems quite straightforward but ensuring that all the parts work together reliably and for long periods of time can be quite challenging.

The process of developing a low temperature alkaline electrolysis system is very straightforward at its basis, as these are systems with a very long track record in terms of industrial implementation. For this type of process, the conditions that must be met to guarantee the maximum performance of your hydrogen production, based on the requirements of the alkaline stack, which are:

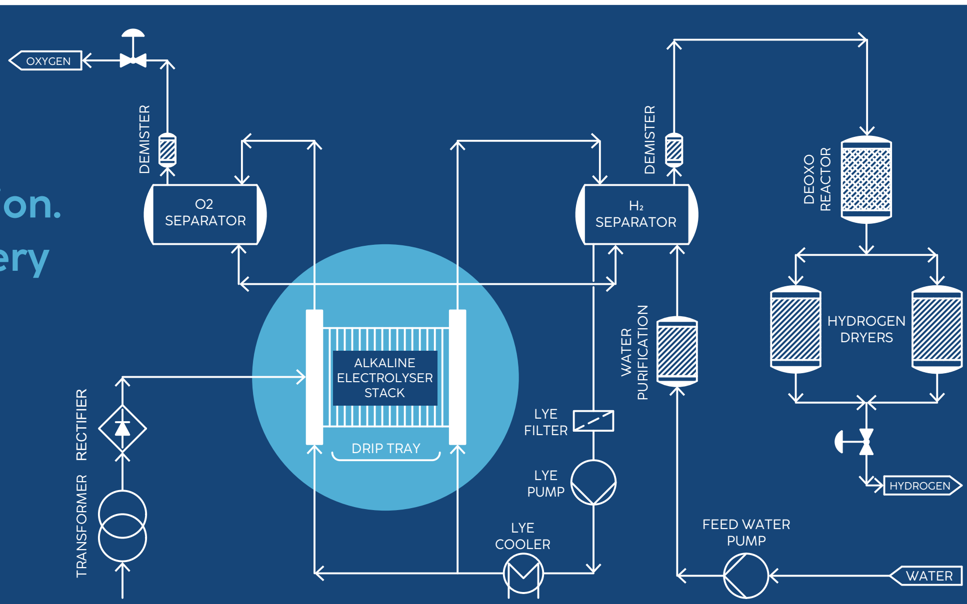
- Operational temperature of 80 to 90 degree Celsius.
- Electrolyte mixture of 30% potassium hydroxide (KOH) in water.
- Constant supply of demineralized water.
- Electrolyte recirculation that adapts to stack current density.
- Working pressure between 30 and 34 bar.

While it is important that the materials and design of your installation match the expected pressure, temperature, and corrosion requirements, it is worth noting as well that during normal operation, different subsystems will have to interact and act in an integrated way to maintain these parameters within the desired range.

Electrolyser Components

Below we are specifying the list of components you will need when integrating a **Stargate Hydrogen Alkaline stack.**

From stack to seamless integration. We're with you every step of the way!



Components list

- Stargate's Alkaline Stack
- Liquid / Gas Separation System
- Electrolyte Recirculation System
- Hydrogen Purification System
- H_2 Quality Control & Measurement System
- Power Supply - Transformer & Rectifier
- Control & Safety Instrumentation Systems
- Auxiliary Cooling Systems
- Water Treatment and Supply System
- Nitrogen Purge System
- Compressed Air Supply Unit
- Gas Venting System

Safety sensors list

- Stack voltage, stack current.
- KOH temperature at stack inlet.
- KOH/gas temperature at stack outlet.
- KOH level sensor.
- Pressure sensors.
- H_2 in O_2 sensor and O_2 in H_2 sensor.
- H_2 room sensor for detecting leaks.
- KOH sensor for detecting leaks
- Water conductivity sensor
- KOH flow rate sensors
- Cooling water temperatures
- Water top-up flow rate

Further technical details can be provided by the Stargate team upon request.

Economic Considerations

Understanding the cost implications of Stack and BoP integration is key. We'll provide insights into the economic factors affecting these systems, **including initial investment costs, operational expenses, for long-term viability**. Find here aid in budget allocation.

The first steps towards building a Hydrogen production system is defining the following points:

1st – Define your utilization scenario.

2nd – Determine the annual, monthly, and daily operational hours under full load.

3rd – Specify the optimization criteria for the system.

- If optimizing for high efficiency, consider the significant impact of operational costs.
- If prioritizing low capital expenditure (capex), ensure maximum system operation hours are achieved.

It is crucial to consider the specific optimization goals for the system, as each scenario requires a tailored approach to maximize return on investment (ROI).

Economic Considerations

Implementation costs

Estimating investment costs is a task where many variables must be taken into consideration. But it depends first and foremost on the size of the stacks needed for the project. Usually, a rough estimation of the costs for the system considers that 20% to 30% of the cost is for the purchase of the Stacks, the remaining 70% to 80% are for covering the costs of all other parts and systems such as the rectifier, the container itself, pipes, pumps, vents etc...

Operational costs

The main factor driving the operational costs is electricity. Therefore, it is important to keep in mind that the operating cost will vary according to the electricity price. The operational cost can be estimated by assuming an energy price (Euros/kWh) and multiply it by the stack capacity in kW. The result of the equation will be a cost estimation in Euros per hour. As an example, if the price of energy is 3 cents per kWh and the stack efficiency is 51.07 kWh/kg the estimated operational cost will be 1.53 Euros per kilogram.

Maintenance costs

Estimating the maintenance costs will depend on the optimization of the system as we discussed in the paragraph above, besides that it will include different aspects, but if the owner of the system follows all the necessary recommendations such as visual inspections daily, weekly and monthly besides replacing the KOH every 3 years we can estimate the average maintenance expenses should be around 3% of the capital cost of the equipment annually.

Achieving Optimal Cost-efficiency

While the initial cost of a hydrogen stack is a consideration, the cost-effectiveness should be evaluated taking into consideration various factors such as efficiency, durability, and maintenance costs over the stack's lifespan.

Levelised Cost of Hydrogen (LCOH) serves as a crucial metric, encapsulating the total cost of producing hydrogen over its entire lifecycle, making it a fundamental tool for decision-making and investment strategies.

Understanding the LCOH is imperative for companies across various industries aiming to integrate green hydrogen into their operations. **This metric accounts for the entire cost spectrum involved in hydrogen production**, encompassing capital costs, operational expenses, maintenance, and the cost of the energy source used for hydrogen generation.

Calculating LCOH involves factors such as equipment depreciation, energy input, efficiency losses, and operational lifespan. It offers a comprehensive overview, aiding companies in assessing the viability and competitiveness of green hydrogen against traditional energy sources such as grey or black Hydrogen.

By evaluating the LCOH, companies can make informed decisions, strategize investments, and determine the feasibility of incorporating green hydrogen technology within their infrastructure. **Here is a simple formula you can use to calculate LCOH:**

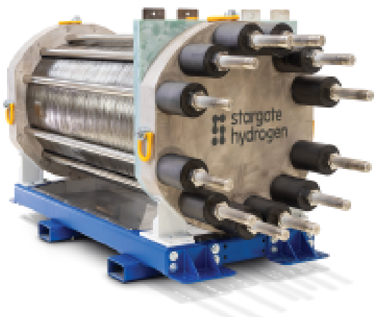
$$\text{LCOH} = \frac{(\text{Investment} + \text{Maintanance} + \text{Operational})}{\text{Hydrogen output}}$$

Achieving Optimal Cost-efficiency

Comparing Scenarios

Analysing two scenarios with the same **0.5MW Electrolyser Stack** will help you to get a better understanding of how different efficiency rates affects the LCOH.

SCENARIO 1



Stack Efficiency - 51 kWh / kg H_2
Operating hours - 5000h annum
Cost of electricity - 10 cents/kWh

SCENARIO 2

Stack efficiency - 55 kWh / kg H_2
Operating hours - 5000h annum
Cost of electricity - 10 cents/kWh

Efficiency	Electricity cost	Lifetime	LCOH
51 kWh / kg H_2	10 cents	10 yrs	**6.9 €/kg**
55 kWh / kg H_2	10 cents	10 yrs	**7.5 €/kg**

Important to notice:

Cheap green electricity is essential. The cost of electricity is directly related to the LCOH, therefore as the cost of renewable energy goes down, so does the cost of Green hydrogen. The reduction of the cost of green electricity is a trend we can see in Northern Europe, where due to the early adoption of renewable sources of energy the current price of energy can be as low as 2.9 ct/kWh is some regions.

Building your Team

Here is what you need to know when assembling an engineering team for integration and maintenance to ensure system longevity and operational efficiency. Insights into skill sets required, team composition, and training will be provided. The set of skills for an integration and maintenance team is quite specific, but a strong engineering team is an important prerequisite for successful stack integration projects.

The job titles and skills you should look for:

Process engineer

Process engineers lead the definition of requirements for the componets, such as pipes for fluid flow, separation, drying. This task will primarily involve the detailed design of the auxiliary systems for the conditioning of the electrolyte loop (including the cooling system, recirculation pump, adding of makeup water, etc.), but also the definition of the requirements and processes needed for purifying the produced hydrogen gas.

Automation Engineer

The automation team will have the task of developing the subsystems for the operation of the electrolysis system under the intended conditions and always within the safety parameters. Therefore, the automation engineering team will lead the design, writing, and implementation of the control loops that ensure the correct operation of the electrolysis system under all foreseen scenarios. For the implementation of the automation system, they will have to work closely with the process engineers for the specifications and selection of the instruments to be included in the process.

Electrical Engineer

Ensuring that the power supply to the stack and to the rest of the systems is steady and according to the specified requirements of the components is their main task. Their responsibility is focused on the selection and implementation of the transformer and rectifier systems for the DC power supply to the stack, including the electrical connection and the development of the grounding concept for the electrolysis system.

Building your Team

Mechanical Engineer

The mechanical integration of all components within the assembly represents a crucial undertaking, necessitating the collaboration of a specialized team in mechanical engineering. This multifaceted activity includes the design and manufacturing of structures that will support the final system. Additionally, it involves a meticulous 3D design of the assembly, considering the equipment placement and the intricacies of piping and electrical connections. It is imperative for the individual leading this effort to collaborate closely with process engineers, ensuring that the equipment aligns with real-world implementation constraints and does not exceed spatial limitations.

Certification Engineer

Regarded as the safety specialist within the project, the certification engineer plays a crucial role in executing essential risk assessment procedures to guarantee the secure operation of the system. Furthermore, they oversee the acquisition of all pertinent information required to ensure the certification of the assembly aligns with the requisite directives and standards. This responsibility extends beyond the design phase, including continuous involvement throughout the entire operational lifespan of the plant.

Certifications & Safety in Europe

Navigating the regulatory landscape and understanding certifications and safety measures are imperative. This section will highlight the necessary compliance standards and safety protocols to adhere to for a secure and legally compliant system.

To ensure hydrogen safety in production, storage, and transportation, various international and national safety codes and standards have been established. These guidelines provide a framework for the design, operation, and maintenance of hydrogen facilities, ensuring that risks are minimized, and safety is prioritized.

The European Union issues directives and regulations that member states must implement to ensure green hydrogen safety. These relevant directives for green hydrogen safety include those related to industrial safety, environmental protection, and transportation of dangerous goods. The key EU directives regarding safety applicable to an electrolyser system are:

- Low Voltage Directive (2014/35/EU)
- Electromagnetic Compatibility (2014/30/EU)
- Pressure Equipment Directive (2014/68/EU)
- ATEX Directive (2014/34/EU)
- Machine Directive (2006/42/EC)
- ISO 22734:2019 - H_2 generators using water electrolysis

These are not all the safety codes and standards in the EU, they are part of the broader framework governing industrial safety. It's crucial to consult the official documents and regularly check for updates to ensure compliance with the latest safety standards and regulations related to hydrogen independent of where you are planning to start a hydrogen project.

Tests During Comissioning

Pre-Test requirements

- Confirmation of correct mechanical and electrical installation.
- Availability of Utilities (Power, Demin water, N2, Pressurised Air etc.).
- Commissioning checklist completed.
- Safety inspection and HAZOP available.
- Communication with SCADA / Control system stable, tested.

Visual inspection

- No physical damage.
- Components securely mounted.
- Cabling, piping correctly routed and mounted.
- Safety signs and markings in place.

Safety System Verification

- Emergency Stop functional.
- Gas leak detection functional.
- PRV tested / calibrated.
- Ventilation system operational.

Functional testing

- Start-up of the Stack (Pressure balance control).
- Hydrogen flow active and regulated.
- Safe and consistent venting possible.
- Demin water flow within specifications.
- Overall stable values within range.

Performance Verification

- Stack at nominal working conditions is performing according to promised performance.

Alarm & Interlock tests

- System reactions tests for over-pressure, Leakage of H_2, cooling pump failure.

Stack Maintanance CheckList

Recurring maintenance is vital to ensuring sustained performance, operational safety, and long-term durability of hydrogen production systems. It helps to detect early signs of wear, prevent costly downtime, and maintain optimal energy conversion rates.

Follow the below inspection plan to ensure proper system operation of Stargate Hydrogen stacks:

- **Weekly -** Visually check for any electrolyte leakages
- **Quarterly -** Compare the hydrogen in oxygen, and the oxygen in hydrogen concentrations at full loads with historical data to identify gases quality.
- **After first 100 operating hours -** Visual check, Compression check
- **After first 300 operating hours -** Visual check, Compression check
- **After first 500 operating hours -** Visual, Compression, and Performance check
- **After first 1000 operating hours -** Visual, Compression, and Performance check
- **After first 1500 operating hours -** Visual, Compression, and Performance check
- **Every 2000 operating hours -** Visual, Compression, and Performance check

NB! Upon purchase of a Stargate Hydrogen stack you will receive a detailed Operation & Maintanance Manual. This checklist is an overview of the necessary procedures.

Case Study: Turn-Key Hydrogen Production System for Mobility Fleet

In this section you will get a glimpse of a real-world case study featuring Utilitas where we will showcase the successful comissioning of a turn-key Hydrogen System. Learn from their experiences, challenges faced, and the strategies adopted to implement **the first full value chain demo project in the Baltic States.**

About Utilitas

Utilitas is a leading producer of renewable heat and electricity and provides district heating and cooling across Estonia. Offering solutions that are good for customers and the environment.

"Working with the Stargate Hydrogen team has been a collaborative and rewarding experience. Their team brought a high level of competence and professionalism to the table and consistently delivered on their commitments."

Aivo Lokk, Utilitas CTO

Case Study: Turn-Key Hydrogen Production System for Mobility Fleet

Why Stargate:

As Estonia's leading district heating provider, Utilitas is committed to future-ready, low-carbon infrastructure. When seeking a hydrogen partner, they prioritized a provider that could deliver a robust, reliable system under challenging conditions. Stargate Hydrogen was selected for its technical expertise, track record of trustworthy delivery, and ability to meet tight implementation timelines.

Objectives

- Support mobility applications by supplying hydrogen for vehicle refuelling
- Integrate a heat recovery system into the existing Tallinn district heating grid
- Demonstrate the viability of hydrogen-based energy integration in urban environments

Solution

Stargate Hydrogen delivered a containerised, turnkey hydrogen production system with 1MW capable of producing **432 kg of hydrogen per day.** The system includes:

- On-site hydrogen purification for fuel-cell grade output
- A heat recovery module connected to the Utilitas heating network, increasing overall energy efficiency
- Capability to fill multi-element gas containers (MEGCs) for off-site transpor

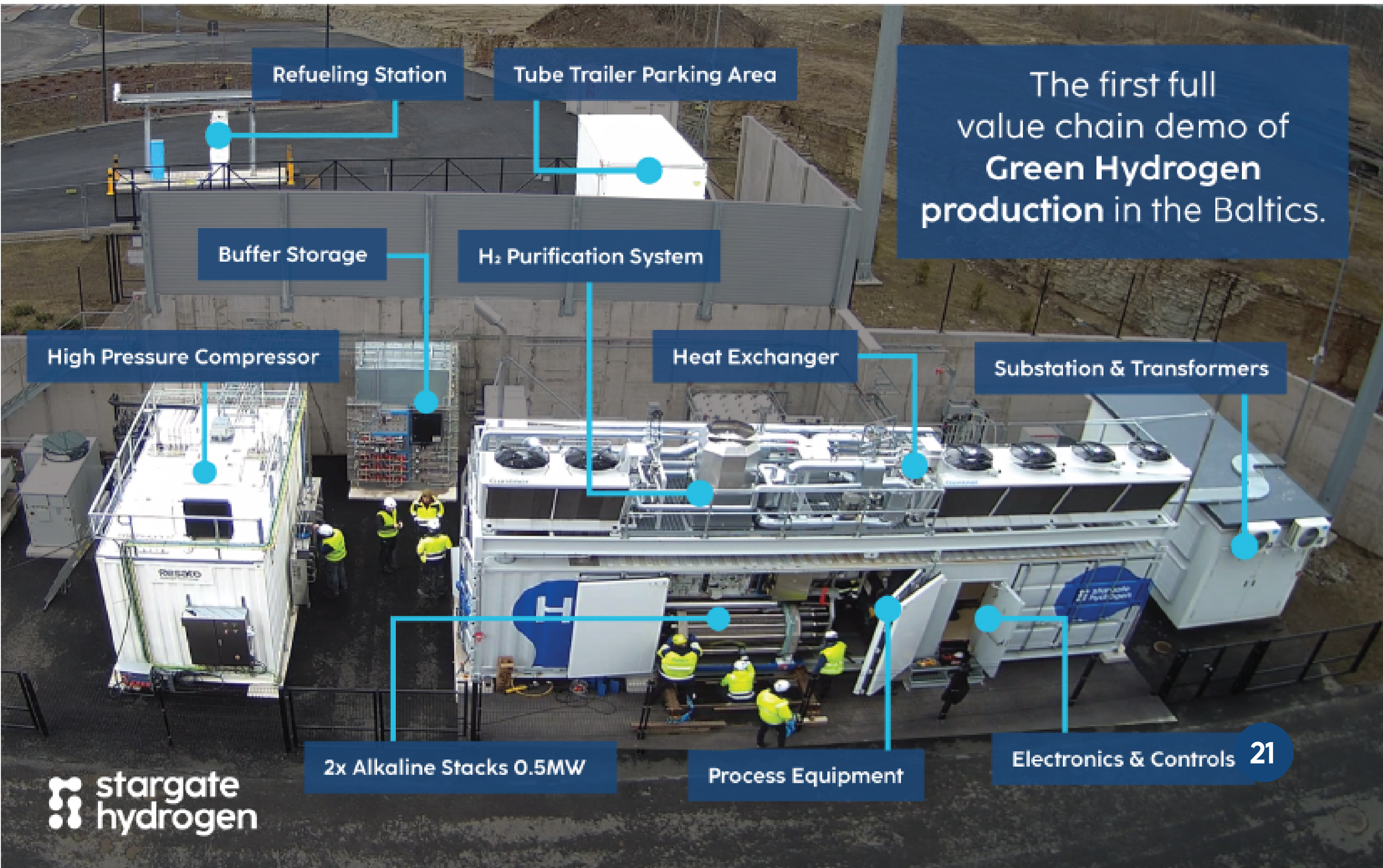
Case Study: Turn-Key Hydrogen Production System for Mobility Fleet

Challenges

- Tight urban site requiring compact design and precise logistics
- Harsh Estonian winter weather during system installation
- Complex coordination with external suppliers for system components and commissioning

Outcome

The system was delivered and commissioned and is now fully operational, with high-purity hydrogen production ongoing. The heat recovery integration is active, supplying clean thermal energy to local residents and improving Utilitas' system-wide efficiency.



Stargate Hydrogen's Stack

stellar
EDGE

Our pressurised alkaline electrolyser stacks are available with a 6-month lead time and come with performance guarantee. The stacks are build for long operational lifespans, which makes them **a reliable choice for continuous hydrogen production**.

This durability aims to minimize downtime and maintenance costs, contributing to the economic feasibility of green hydrogen. The technology has been validated by Fraunhofer, and our stacks have been tested by ZSW.

Performance guarantee

Full Integration support

Fast delivery 6 months lead time

Up to 100 Nm³/h

High Efficiency

Specification Sheet

stellar
EDGE

Next Generation alkaline electrolyser stacks.

Pressurised alkaline stacks for system integrators.

Technical specifications

Hydrogen hourly production rate [Nm^3/h]	100
Hydrogen daily production rate [kg/day]	215
Hydrogen pressure [barg]	32
Hydrogen purity [%]	>98%
Oxygen purity [%] **	>98%
Stack Consumption [kWh/Nm^3]	4.59
Stack Consumption [kWh/kg]	51.07
Stack Operating temperature [°C]	80-90
Stack rated voltage - BOL [V]	227
Stack rated voltage - EOL [V]	264
Stack rated current [A]	2027
Stack minimum current [A]*	1150
Stack rated power - BOL [kW]	460
Stack rated power - EOL [kW]	535
Stack minimum operating point [%]*	40%
Stack efficiency (HHV) [%]	77.2%
Stack efficiency (LHV) [%]	65.2%

* Lower minimum load point on request.

* * Crossover purity (wet) at stack outlet given that all operational conditions for the stack are maintained within their respective limits.
The final dry hydrogen purity depends on the separation and purification systems which are part of the Balance of Plant (not included).

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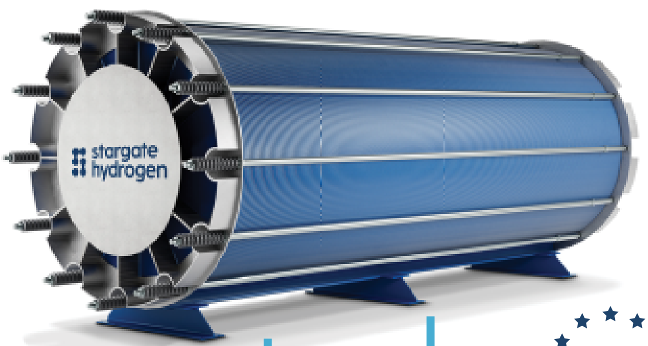
Electrolyser for larger projects

The Starbase Electrolyser Stack for green hydrogen production is Stargate Hydrogen's biggest Stack. A a skid-mounted 5MW pressurised alkaline stack that combines reliability with innovation to deliver a high efficiency solution. Designed and made in Europe, Starbase comes with a complete balance-of-stack, clear documentation and full integration support. Starbase is the perfect solution for engineering companies with system integration capabilities.

THE STARBASE

Alkaline Electrolyser **STACK**



5MW

Innovative proprietary single STACK design with unparallel **light weight** for easy transportation and on site instalation.

MADE IN EUROPE

PRESSURE

Output hydrogen pressure is **compatibal with most of industrial use** cases of hydrogen

ENGINEER SUPPORT

Full engineering support providing a **smooth, reliable process** from site acceptance testing all the way to initial hydrogen production.

CLEAR GUIDES

Detailed documentation package with battery limits and clear guidelines for **easy stack integration** in larger electrolyser inustrial plants.

Final Considerations

We hope this guide has helped you to navigate this transformative industry confidently. At Stargate Hydrogen, **we understand the intricacies of electrolyser stacks integration**, and that is why we are the right partner to equip your company with the knowledge and necessary tools for a successful integration.

Ready to embark on the electrolyser stack integration journey? **Contact Stargate Hydrogen today to unlock tailored solutions and expert consultations.**

contact us

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