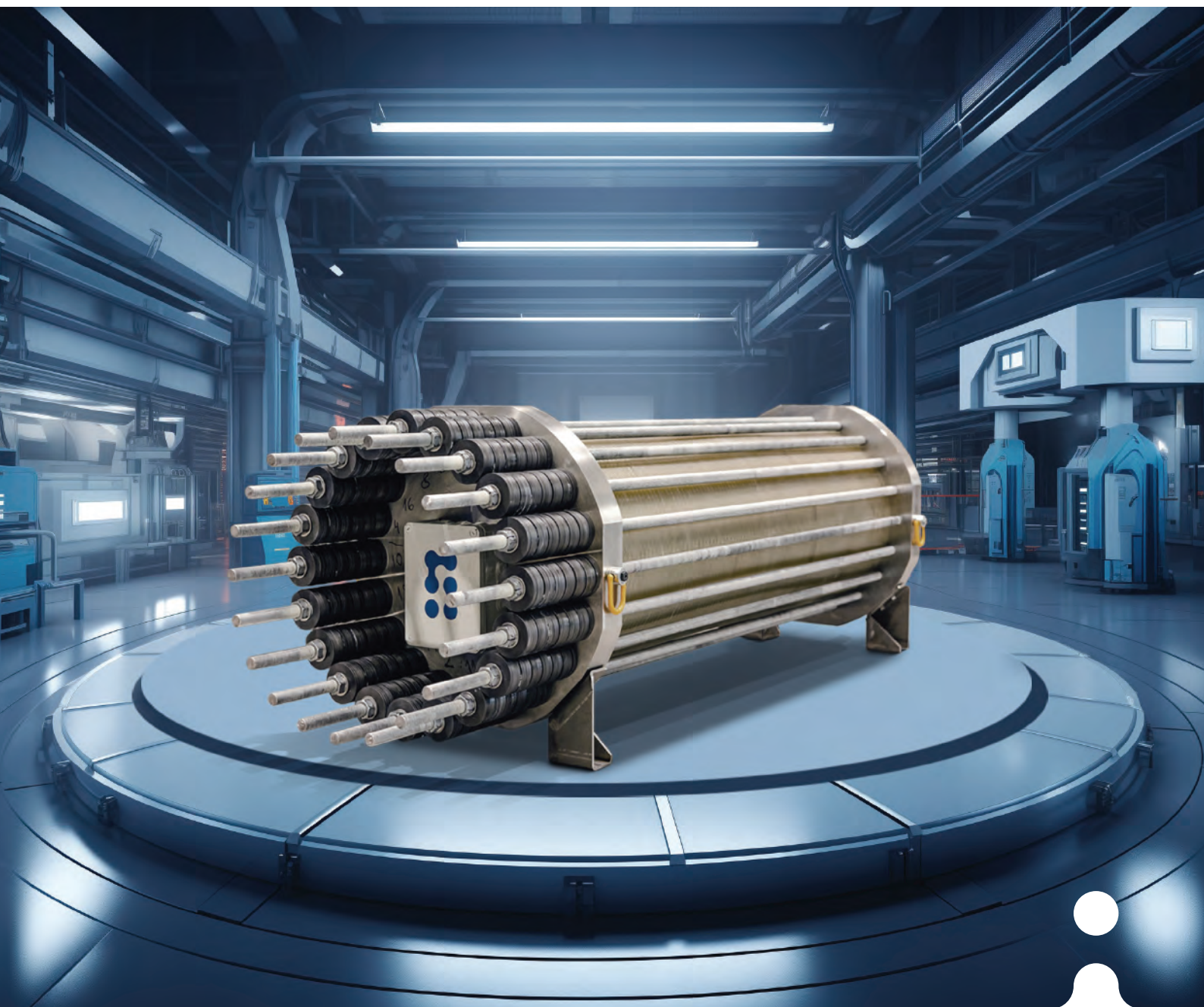


The Guide to Integration of Hydrogen Stacks

Make Informed Decisions to Achieve Optimal Efficiency.



The Guide to Integration of Hydrogen Stacks

Welcome to Stargate Hydrogen's comprehensive 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, to **help you navigate this transformative industry confidently.**

In this guide you will learn:

- **Page 02** - About Stargate Hydrogen.
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- **Page 08** - Economic considerations.
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About Stargate Hydrogen

The story of Stargate started in 2021 when the founders, knowing that to effectively combat climate change, electrification would not be enough, decided to **act and pursue affordable green hydrogen to reduce carbon emissions** in the hard-to-abate sectors such as steelmaking, fertilizer and chemical industries.

We believe that the price of **green hydrogen is key** for unlocking widespread industrial use and thereby significantly reducing emissions.

In order to make this happen, we understood that we need to increase the efficiency of the electrolysis process and bring down the capital cost of the green hydrogen production equipment. We do this by **developing novel catalyst materials, based on ceramic materials**, which we proudly call Stardust.

As a result of this, our technology can achieve **high efficiency with very low capital cost** and as an additional benefit, our products face no critical raw material availability issues.



Marko Virkebau
The CEO of Stargate Hydrogen



“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.**”



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 electrical energy.

Selecting the appropriate stack technology is paramount to success. We'll delve into Alkaline, PEM, AEM, and SOEC technologies, outlining their suitability for various applications and performance. Understanding their efficiency, scalability, and compatibility with your operational needs will **guide your decision-making process.**

The four most prominent technologies for hydrogen production include Alkaline Electrolysis, Proton Exchange Membrane (PEM) Electrolysis, Anion Exchange Membrane (AEM) Electrolysis, and Solid Oxide Electrolysis Cells (SOEC).

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** capable of conducting anions effectively.

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 paramount, Alkaline Electrolysis might be 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 medium-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.



What Makes a Good Stack?

Understanding **the nuances of a superior 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 paramount 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 these 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.



A 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 stack for your Balance of Plant (BOP) 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, 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.

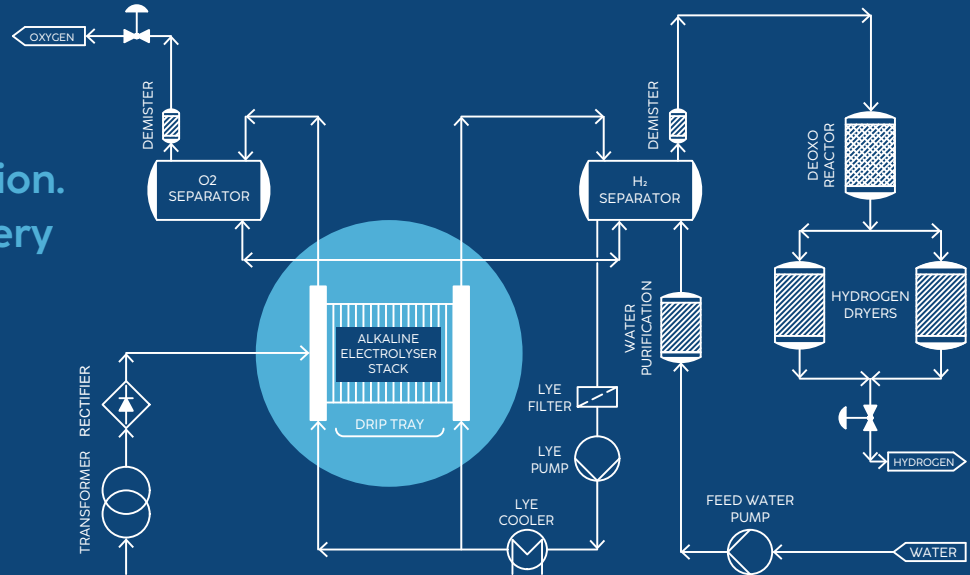
While it is important that the materials and design of your installation match the expected pressure, temperature, and corrosion requirements, it is worth noting as well that during normal operation, different subsystems will have to interact and act in an integrated way to maintain these parameters 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
- H₂ 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.
- H₂ in O₂ sensor and O₂ in H₂ sensor.
- H₂ 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**. This section will 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 for the system.

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 30% to 40% of the cost is for the purchase of the Stacks, the remaining 60% to 70% 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 hour.



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) or 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:**

$$\text{LCOH} = \frac{(\text{Investment} + \text{Maintenance} + \text{Operational} - \text{Revenue})}{\text{Hydrogen output}}$$



Achieving Optimal Cost-efficiency

Comparing Scenarios

Analysing two scenarios with the same **1MW Electrolyser System** will help you to get a better understanding of how different sources of energy affects the LCOH.

SCENARIO 1



Source of electricity - Solar PV
Operating hours - 2500h per annum
Cost of electricity - 4 cents/kWh

SCENARIO 2



Source of electricity - Grid
Operating hours - 8400h per annum
Cost of electricity - 18 cents/kWh

X

Energy Source	Discount Rate	LCOH	Lifetime
Solar PV	5%	5.76 €/kg	20 yrs
Grid	5%	11.34 €/kg	20 yrs

Key Takeaways

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 in 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 chemical reactions and other unit operations involved in the electrolysis process. 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 (and oxygen) 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.

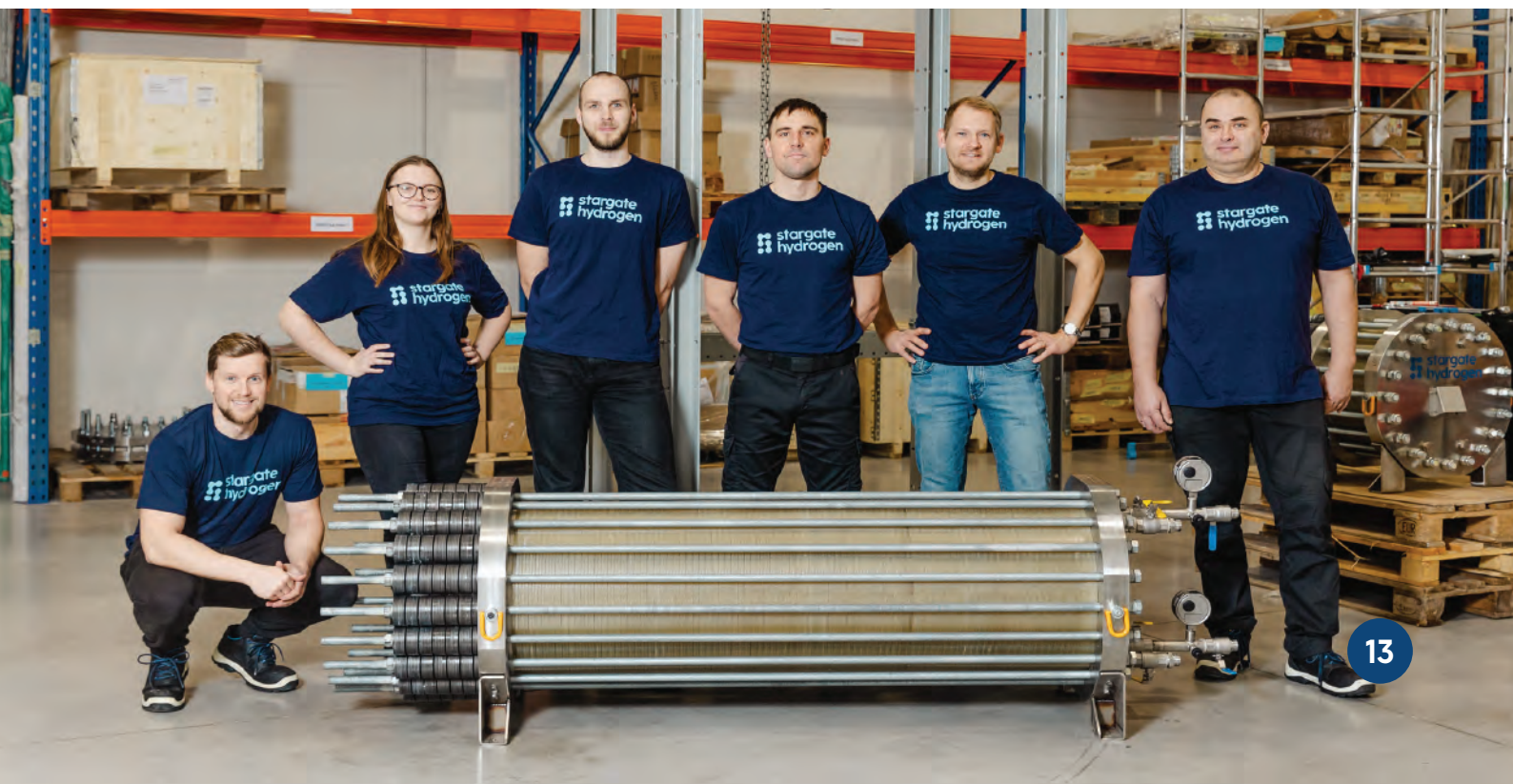
Building your Team

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 chosen equipment aligns seamlessly 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

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 - H₂ 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.

Case Study: Rockfin

In this section you will get a glimpse of a real-world case study featuring Rockfin. Here we will showcase the successful integration story. Learn from their experiences, challenges faced, and the strategies implemented to achieve seamless hydrogen system integration.

About Rockfin

Rockfin sp z.oo is a world-leading engineering company specializing in the design, manufacture, testing and servicing of oil and fuel systems for gas turbines, steam turbines, generators, compressors and high-pressure drives and control systems. In 2022 Rockfin started its journey towards becoming an alkaline electrolyser system integrator, and chose Stargate pressurised alkaline stacks as the heart of their electrolysis systems.



The passion for electrolyser stack technology and the determination of the Stargate Team has been crucial to achieve this major milestone. We strongly believe in the long-term potential of hydrogen as a clean energy solution

Michał Wróblewski, Rockfin CEO

Overview and context:

Rockfin, a seasoned provider of skids and components manufacturer, with diverse assembly knowhow diversified its operations into the hydrogen production sector through the production of electrolysers utilizing Stargate's Stack. In 2022 Rockfin kicked off a demo project that leverages excess energy from photovoltaics to venture into green hydrogen production utilizing Stargate's alkaline stack.

Case Study: Rockfin

Why Stargate:

Rockfin explored multiple stack suppliers but could not find the ideal partner. Stargate's pressurized alkaline stack not only exhibited excellent compatibility but also provided comprehensive support since the first meeting and throughout the integration process. More over, the stacks configurability and the perspective of utilising in the future Stargate's novel catalyst called **STARDUST** influenced in Rockfin's decision.



Objectives

Rockfin aimed to showcase its electrolyser system capabilities, demonstrate commitment to hydrogen through an unsubsidized project, and contribute to the decarbonization of the industry.



Solution

Stargate offered its Stellar Light Stack along with engineering support, ensuring regular exchanges and meetings to guarantee successful integration.



Implementation

The implementation phase witnessed regular exchanges between Stargate and Rockfin, including mutual visits. These interactions defined milestones and established a joint project plan.



Case Study: Rockfin

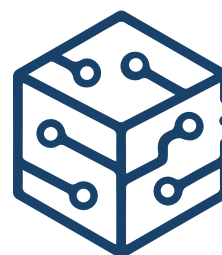
Outcome

The integrated system made its public debut at the Poznan Fair in Poland in May 2023. Rockfin successfully developed the Mini-Green box system, laying the foundation for future hydrogen production systems. The Mini-Green system is now available for sale, providing industries with an option to embark on their hydrogen journey.



Key takeaways

The partnership led to mutual growth. Stargate elevated its safety standards, while Rockfin gained valuable insights into electrolysis. The collaboration not only achieved its objectives but also set the stage for continuous innovation in the field of green hydrogen production.



The final result - Mini-Green Box

The Mini-Green Box system is now available for sale, providing industries with an option to embark on their hydrogen journey.



Stargate Hydrogen's Stack

With our pressurised alkaline electrolyser stacks you will be operational in a 6-month lead time with performance guarantee, a reliable choice for continuous hydrogen production. The stack's durability minimizes downtime and maintenance costs, contributing to the economic feasibility of green hydrogen.



Customizeable configurations



Performance guarantee



Full Integration support



Fast delivery
6 months lead time



Up to
100 Nm³/h



High Efficiency



Specification Sheet

stellar
SERIES

Next Generation alkaline electrolyser stacks.

Pressurised alkaline stacks for system integrators.



Customizable configurations



Performance guarantee



Full Integration support



Technical specifications

Product	Max Efficiency	Balanced	High Power
Hydrogen hourly production rate [Nm ³ /h]	100	100	100
Hydrogen daily production rate [kg/day]	215	215	215
Hydrogen pressure [barg]	32	32	32
Hydrogen purity [%]	>98%	>98%	>98%
Oxygen purity [%]	>98%	>98%	>98%
Stack Consumption [kWh/Nm ³]	4.59	4.74	4.84
Stack Consumption [kWh/kg]	51.07	52.74	53.85
Stack Operating temperature [°C]	80-90	80-90	80-90
Stack rated voltage - BOL [V]	227	189	160
Stack rated voltage - EOL [V]	264	213.4	178.2
Stack rated current [A]	2027	2507	3022
Stack minimum current [A]*	1150	1150	1150
Stack rated power - BOL [kW]	460	474	484
Stack rated power - EOL [kW]	535	535	539
Stack minimum operating point [%]*	55%	45%	38%
Stack efficiency (HHV) [%]	77.2%	74.7%	73.2%
Stack efficiency (LHV) [%]	65.2%	63.1%	61.8%

* Lower minimum load point on request.



Final Considerations

At Stargate Hydrogen, **we understand the intricacies of hydrogen integration** and aim to equip engineering companies with the knowledge and tools necessary for successful system integration.

Ready to embark on the hydrogen integration journey and revolutionize your engineering projects? Contact Stargate Hydrogen today to unlock tailored solutions and expert consultations for seamless system integration.

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