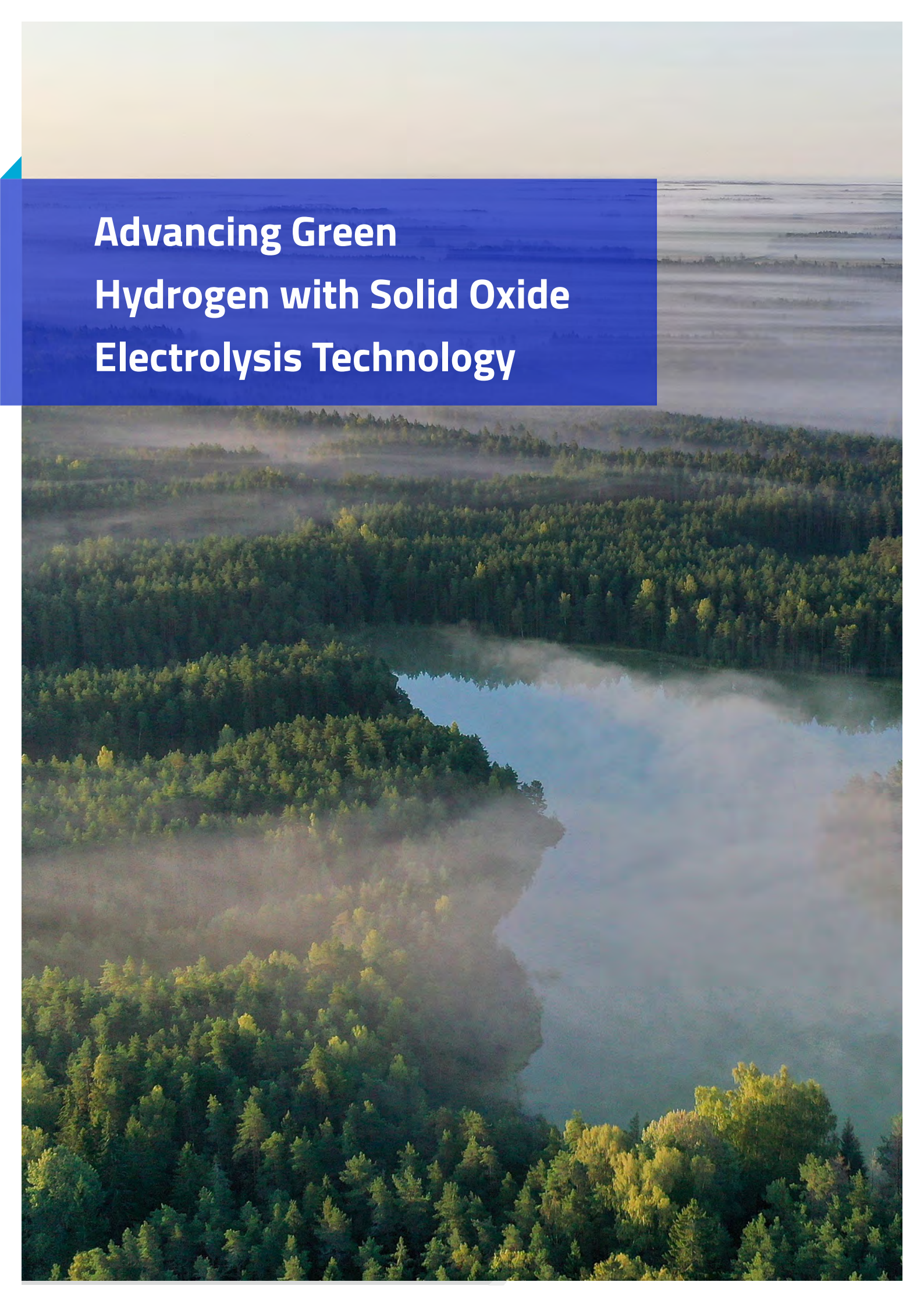
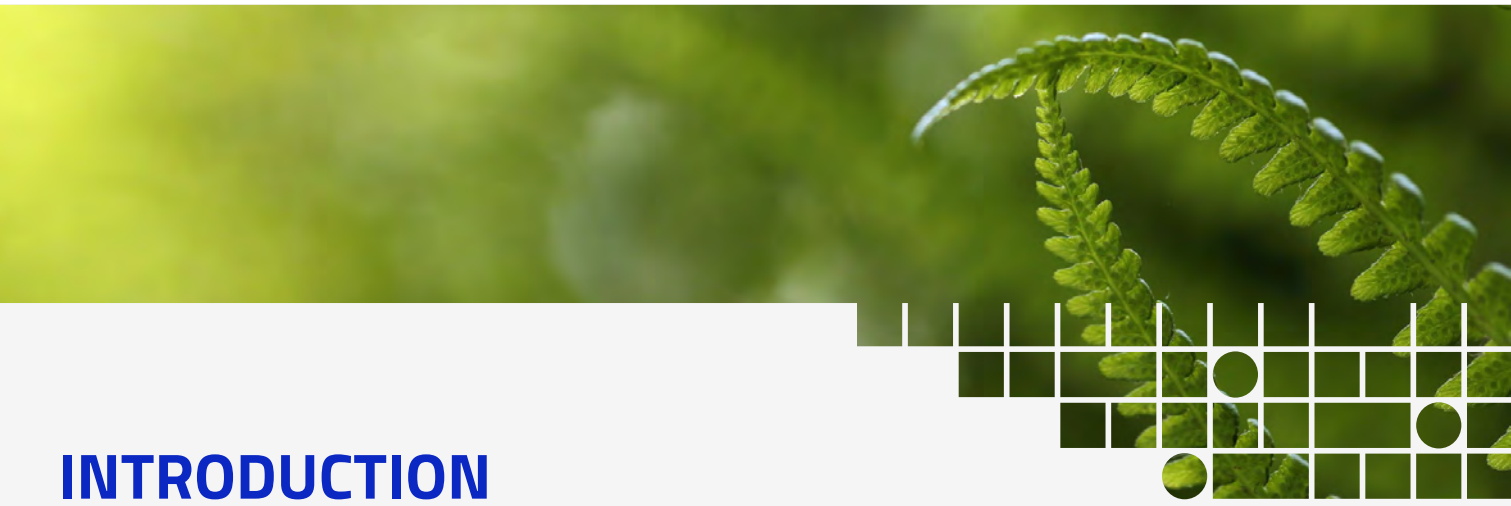


An aerial photograph of a calm lake surrounded by a dense forest. The sun is low on the horizon, creating a soft glow and reflecting on the water's surface. A blue rectangular box is overlaid on the top left of the image, containing white text.

Advancing Green Hydrogen with Solid Oxide Electrolysis Technology



INTRODUCTION

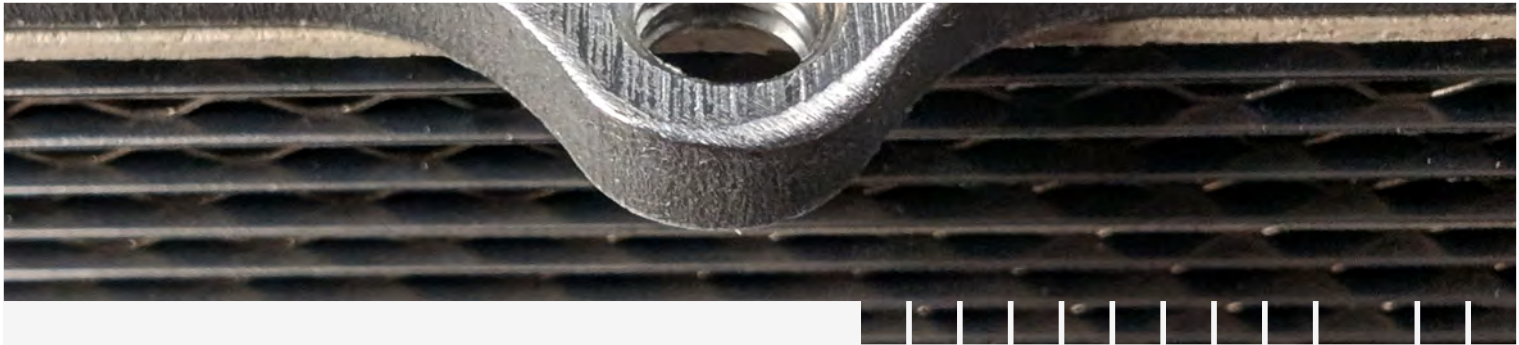
Elcogen's Solid Oxide Electrolysis Cell (SOEC) technology enables highly efficient green hydrogen production. Unlike conventional methods, SOEC reduces electricity needs and supports renewable energy storage. This whitepaper highlights how Elcogen's solution drives decarbonisation across industries like steel, chemicals, and fuels - supporting a more sustainable, cost-effective hydrogen economy.



Highly efficient clean hydrogen production with solid oxide technology

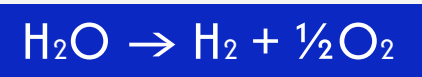
Clean hydrogen produced by electrolysis from renewable energy sources is set to replace fossil-based hydrogen production methods. Today, hydrogen is needed in vital application areas of our modern society: for the synthesis of chemicals, fuel refining and the production of fertilisers. Clean, green hydrogen, produced with minimal carbon footprint is a fundamental ingredient in the future sustainable energy ecosystem, replacing fossil-derived grey hydrogen. Green hydrogen is also expected to play a pivotal role in reaching zero carbon emissions in hard to abate sectors such as steel production.

Green hydrogen is produced by splitting water into hydrogen and oxygen using a process called electrolysis. Today, 80% of the cost of green hydrogen can come from the electricity needed to split water molecules into hydrogen and oxygen. Solid oxide electrolysis (SOEC) technology, owing its superior electrical efficiency compared to all other electrolysis technologies, will be a game-changer in the industrial green transition. Elcogen's SOEC technology provides the potential for significant energy savings over other available technologies and is beneficial in all applications areas.



Technology Fundamentals

The fundamental process used to produce green hydrogen is known as electrolysis. In electrolysis, electricity is used to split water into gaseous hydrogen and oxygen according to the below reaction:



Water splitting occurs in an electrolysis cell using two electrodes separated by a membrane. Hydrogen is produced at the cathode, and oxygen at the anode, and the

product gases are separated by a membrane. Membranes or solid electrolytes are used to separate the product gases and to facilitate the transport of ions necessary for the electrochemical reactions. Hydrogen production capacity is increased by bundling electrolysis cells electrically in series to form a stack. Today, there are three main electrolysis technologies: Low temperature polymer electrolyte membrane (PEM), alkaline water electrolysis (AWE), and high temperature solid oxide electrolysis (SOEC).

Electrolysis Technology	PEM - Polymer Electrolyte Membrane	AWE - Alkaline Water Electrolysis	SOEC - Solid Oxide Electrolysis Cell
Electrolyte	Hydrogen ion conducting polymer membrane	Alkaline liquid solution	Oxygen ion conducting solid ceramic
Operating temperature	50°C - 80°C	60°C - 95°C	500°C - 900°C

PEM and AWE technologies are comparatively well developed, and the low temperature of operation makes the manufacturing and operation of cells, stacks and the electrolyser system straightforward. Nevertheless, both PEM and AWE technologies suffer from major inherent disadvantages that constrains large-scale deployment in the long run. The electrochemical reactions are intrinsically slow at low temperatures and require high

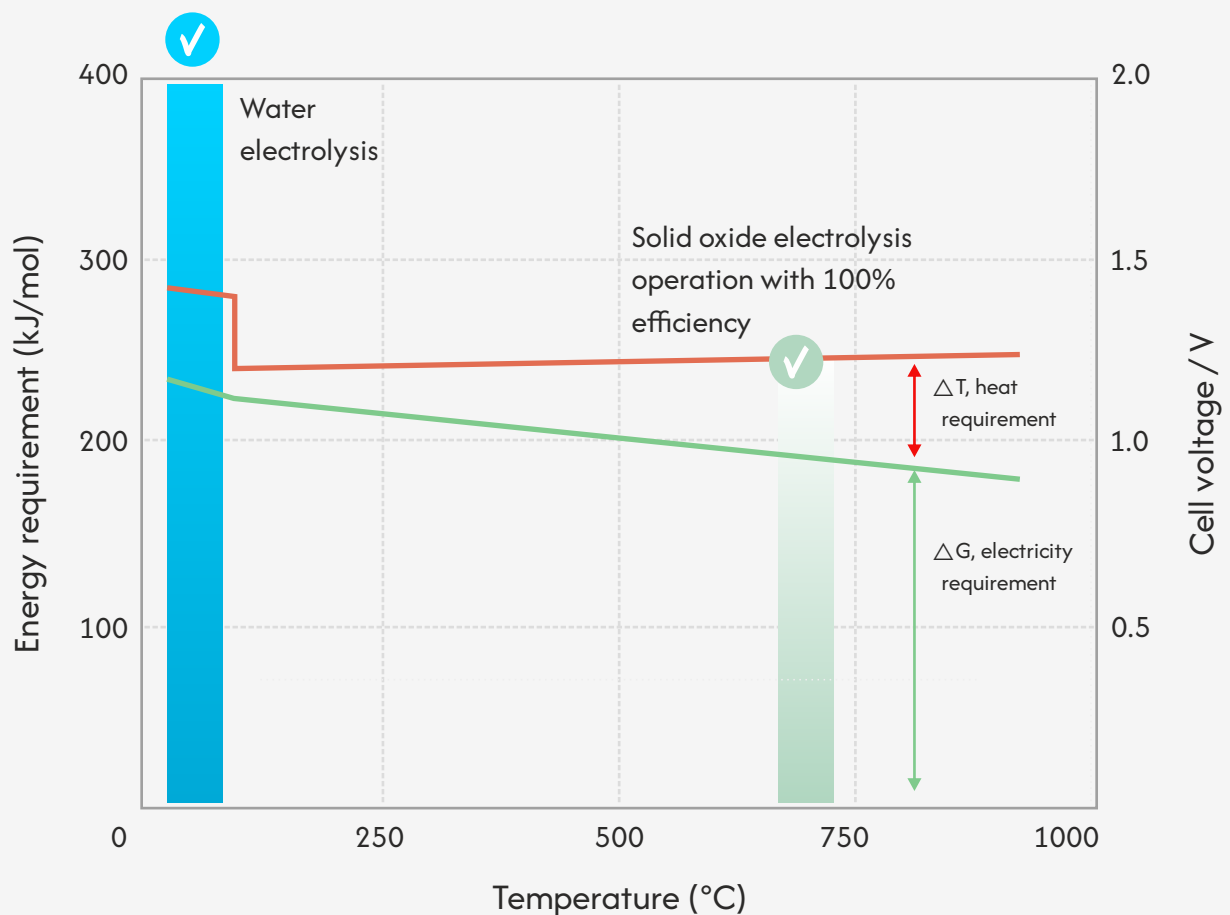
operating voltages, which leads to high electricity consumption, poor efficiency and considerable amounts of low-grade waste heat. Precious metal (e.g. platinum, iridium) can be used as catalysts to speed up the electrochemical reactions but even with these high-cost materials with limited availability, water electrolysis technology comes with a fundamental problem of poor efficiency leading to wasted electricity.



Unlike low-temperature water electrolysis technologies, SOEC operates at significantly higher temperatures and steam (evaporated water) is supplied as feedstock to the solid oxide electrolyser. The high temperature operation and inherent faster reactions reduce losses and operating voltage in SOEC compared to low-temperature electrolysis technologies, making the entire process more efficient for hydrogen production and reducing the demand for renewable electricity.

In addition, lower voltage and less electric energy are needed to drive the electrolysis as the temperature increases (ΔG in picture X),

and the heat from irreversible losses can be absorbed directly in the solid oxide cell to meet the heat requirement of the reactions ($S\Delta T$ in picture). Due to these unique and fundamental properties, Elcogen's solid oxide technology can be operated at so-called thermoneutral voltage, where the heat produced by irreversible losses of the SOEC matches exactly the heat demand of the electrolysis reaction, making it possible to achieve 100% electrical efficiency.

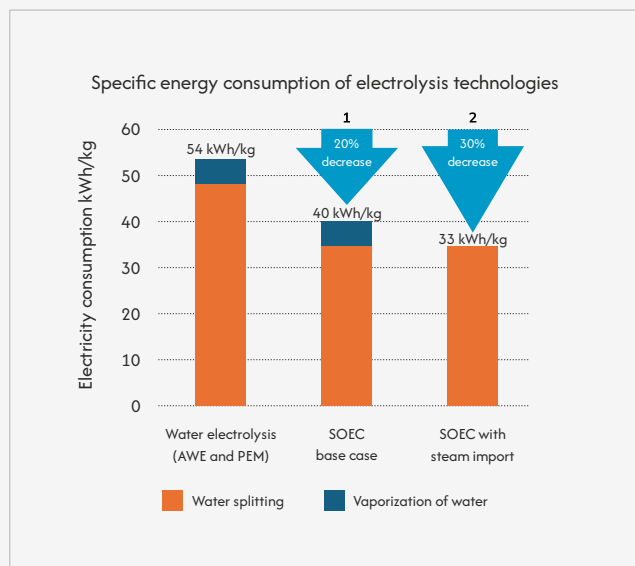




Benefits Over Other Electrolysis Technologies

Thanks to its fundamental advantages, solid oxide technology offers energy saving potential in green hydrogen production that is beyond the reach of low-temperature water electrolysis technologies.

Inherently higher efficiency: Thanks to operation at thermoneutral voltage, the operating voltage and energy requirements of SOEC will always be lower than those of water electrolysis technologies. Even in business cases where water is evaporated into steam with electricity, the combined specific electricity consumption for SOEC electrolysis and steam generation is only 40 kWh/kg hydrogen, compared to the typical 50 kWh/kg with water electrolysis. In other words, SOEC can consume up to 20% less electricity (see figure below)



than typical water electrolysis technologies, enabling huge savings in the electricity bill of a green hydrogen plant.

Utilising industrial waste heat: Further reduction of electricity consumption is possible when low-grade waste heat from industrial processes or renewable sources is available. The waste heat can be used to generate steam for SOEC, enabling hydrogen production at 33 kWh/kg H₂ in the SOEC stack, or at 100% efficiency, resulting in up to 30% lower electricity consumption compared to water electrolysis technologies (SOEC with steam import in Arrow 2). Utilisation of steam generated from low grade waste heat reduces the electricity requirement further providing even more renewable energy savings.

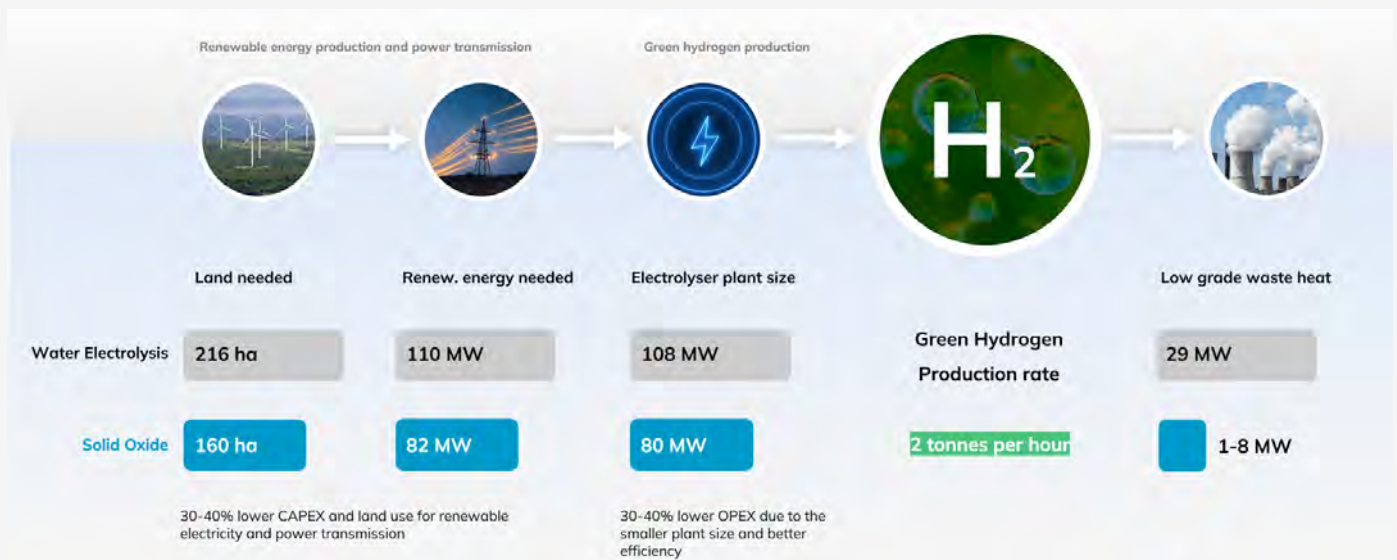
Minimal waste heat from electrolysis: Thanks to inherently high efficiency, SOECs produce little or no waste heat in the electrolysis reactions compared to water electrolysis technologies, which can waste up to 30% of electricity as low-grade heat. The heat has very little value and often becomes waste that requires cooling systems to be discharged into the environment. This leads to more expensive utility needs but also has a negative impact on the environment (e.g. warming of surface water or noise and local warming).

Lower investment in electricity infrastructure:

Compared to water electrolysis, SOEC consumes significantly less renewable electricity per unit of hydrogen produced. The potential of the high efficiency of SOEC can result in significant savings across the entire electricity production value chain, as water

electrolysis technologies can require 35% more renewable electricity production for the same amount of hydrogen produced. Smaller land areas for renewable power become possible, and pressures to invest in and increase transmission capacity within the power grid are also alleviated (see Figure X).

Advantages of SOEC electrolysis



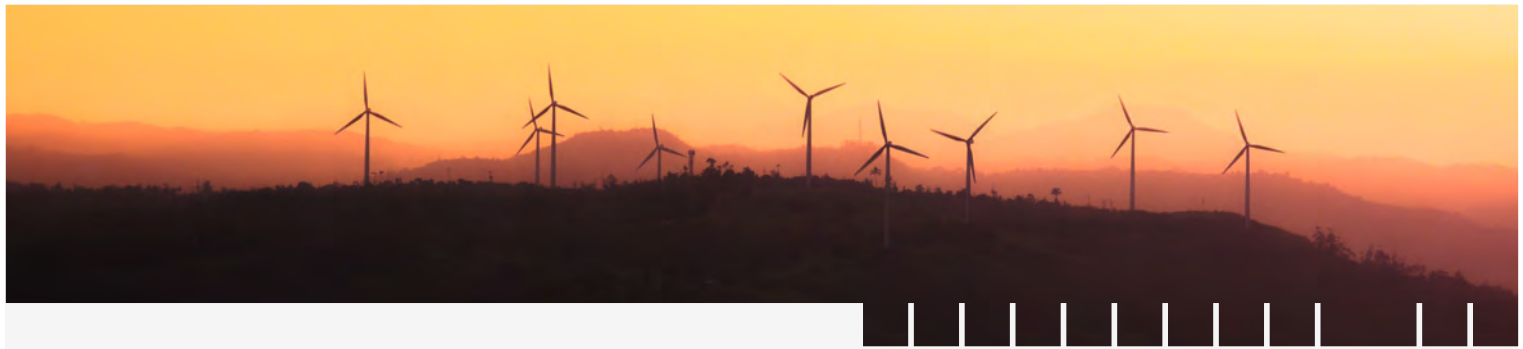
Broad and flexible operating capabilities:

Elcogen's SOEC stacks can be operated from zero to maximum without any risk of gas cross-over. This enables full modulation of hydrogen production over its operating window. It also demonstrates superior robustness during thousands of instantaneous start-stop cycles. This feature allows flexible operation and makes our technology inherently suitable when load following capabilities are needed. This is especially important to optimise the use of electrolyser assets when directly powered by intermittent renewable electricity production. It also allows potential to tailor operation according to fluctuating electricity prices.

Reversible operation: Elcogen's solid oxide technology has the capability to operate in

both electrolysis mode and fuel cell mode. This feature opens unique opportunities to create solutions for renewable energy storage and grid balancing.

Safety: The SOEC stack operates at temperatures above the autoignition point of hydrogen, meaning that in the event of gas cross-over, the gases are oxidized within the SOEC cells. This prevents the formation of explosive gas mixtures in downstream processing equipment, ensuring higher level of operational safety. Therefore, Elcogen's SOEC technology is inherently safe with respect to gas cross-over hazard.



Moderate water purity requirement: Elcogen's SOEC is less susceptible to water contaminants that can cause performance loss through cell poisoning, compared to other electrolysis technologies. This reduces the need for complex water purification, resulting in lower CAPEX, reduced water consumption, and simplified wastewater handling.

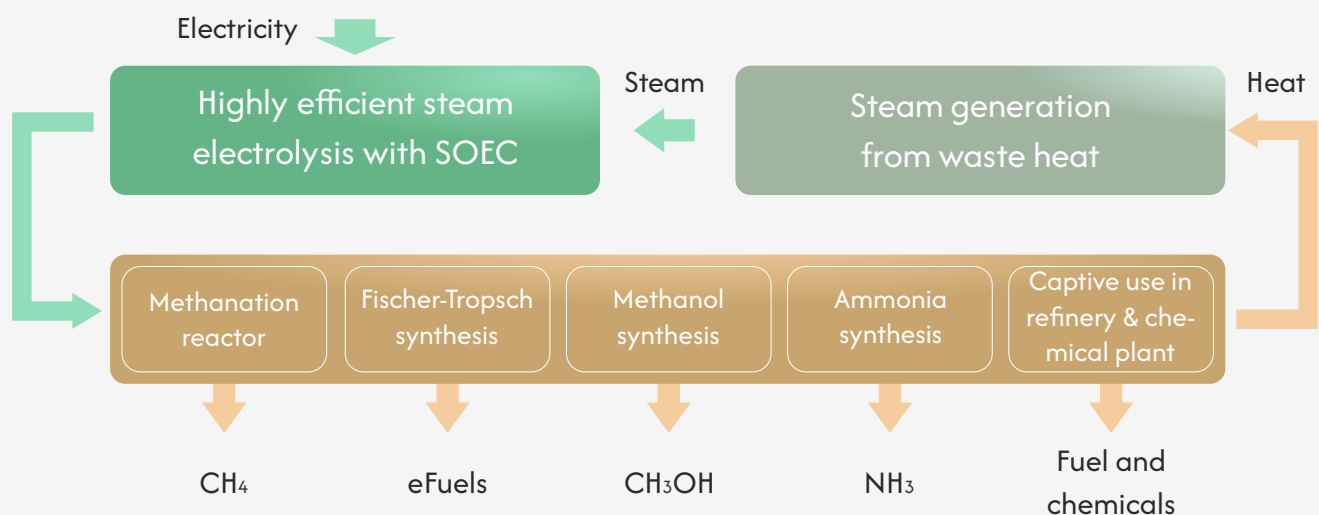
No use of precious or rare metals: Elcogen's SOEC technology is designed using readily available raw materials. No expensive or rare precious metals are used in SOEC and consequently the supply chain is less volatile in nature.

Main Application Areas

Reduced CO₂ emissions through green hydrogen production: Global hydrogen demand currently stands at around 100 million tons per annum [source IEA 2025] and almost all of it is produced from fossil fuels. Replacing this with green hydrogen produced via SOEC technology using renewable energy would significantly reduce CO₂ emissions, supporting the global goal of achieving carbon neutrality.

Integration into synthesis processes for green chemicals and synthetic fuels: The majority of synthesis processes for green chemicals and synthetic green fuels are exothermic, meaning they generate significant process heat as a by-product. This waste heat can be utilised for steam production, further improving the already high efficiency of hydrogen production using Elcogen's SOEC technology.

SOEC technology integration capabilities to industrial waste heat sources

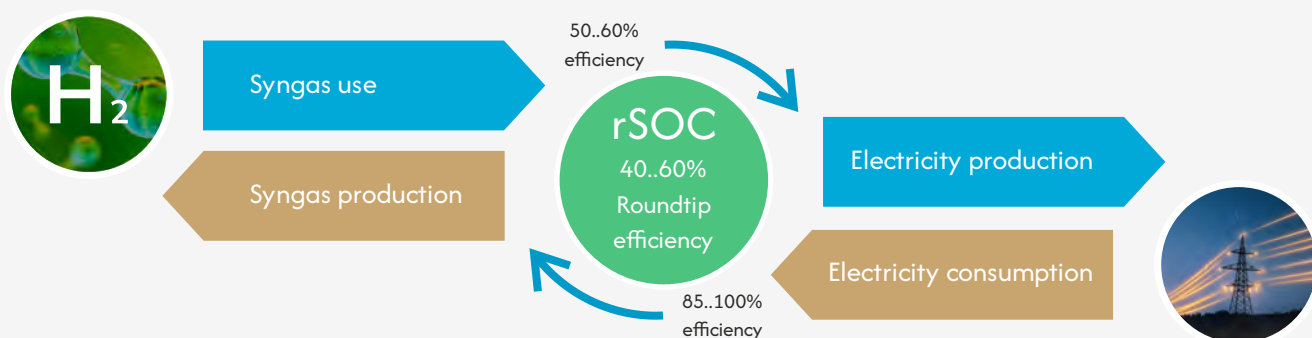




Integration to steelmaking – green steel:
Steelmaking industries contribute around 8% of global carbon dioxide emissions. Renewable hydrogen enables the decarbonisation of steelmaking through the introduction of novel process concepts, such as Direct Reduction of Iron with hydrogen, or by replacing natural gas with hydrogen in furnaces used for annealing and other downstream processes following melting.

The waste heat of furnaces and flue gases can be used to produce steam for Elcogen's SOEC technology-based steam electrolyzers, radically decreasing the need for electricity in hydrogen production and enabling ultimate energy optimisation potential for carbon-neutral steelmaking processes.

Energy Storage: The unique ability of Elcogen's SOEC technology to operate both in electrolysis and fuel cell modes provides potential for long-term storage of renewable energy in gas storage facilities or the existing gas grid infrastructure, offering one solution to cope with seasonal changes and the intermittency of renewable wind and power sources. Production of hydrogen or syngas is carried out during the summer or other periods when there is an abundance of renewable electricity, by operating reversible solid oxide (rSOC) systems in electrolysis mode. In winter, or during periods when the grid is experiencing a shortage of renewable electricity, the stored gas can be used to generate electricity with high efficiency by using the same rSOC system in fuel cell mode.



Hydrogen production with waste heat:
The unsurpassed efficiency of SOEC when coupled with waste heat sources makes it the prime candidate for hydrogen production in all applications where waste heat is available at low cost. The SOEC can be coupled to existing refineries or chemical plants with a surplus of

waste heat, or to nuclear or geothermal waste heat sources, providing unique opportunities for sector integration by transforming low-value waste heat into high-value hydrogen – either for feedstock to the hydrogen grid or for direct off-take at a chemical site.



How can we help you?

Founded in 2001, the company has its registered office in the UK, its main headquarters in Tallinn, Estonia, and R&D centers of excellence in both Estonia and Finland. Serving a growing global customer base, Elcogen's cells, stacks, and modules are integrated into third-party systems across sectors where decarbonisation is essential, including steel, fuels, shipping and energy infrastructure.

In addition to the supply of components, we offer comprehensive services to support technology integration, ensuring seamless adoption and optimal functionality of our solutions in various applications. We offer pre-sales and integration support covering consultancy on process and system design, advice on Balance of Plant (BOP) component and material selection, simulations,

and process calculations with consultation on testing and operation procedures, including HAZOP studies. Our after-sales services include onsite support for testing, commissioning, first start-up, first shutdown cycle and stack replacements. We also offer stack performance simulations, process reconciliations, and consultancy on practical operational procedure optimisation. Everything you need to succeed.

If you are interested in learning more, get in touch with us!

elcogen.com

