

# Enapter White Paper

August 2020



## Introduction

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The world has reached a turning point in its understanding of energy. While clean sources of power were long driven by an environmental narrative, solar and wind have become the cheapest ways to generate power. The fossil fuel phase-out is already underway, and the future of energy generation will no longer involve the burning of fossil fuels.

Fossil fuels have always been at the beginning of the energy value chain. However, they are now being replaced by renewable energy generation assets. This implies a paradigm change for the entire energy system. Currently, electricity usage makes less than 20% of total global energy consumption. Major electrification efforts will certainly increase this share but, nevertheless, it is likely that a large part of global energy demand will need to be met by carbon-free fuels and gases.

Hydrogen is the only way to accomplish this goal and to decarbonise fuels at scale. Whether it is in industry, heating or transport/mobility, hydrogen made with renewable power via electrolysis (green hydrogen) is the only way to decarbonise liquid and gaseous fuel needs. Green hydrogen can therefore be considered as the oil of the 21<sup>st</sup> century.

Electrolyser manufacturers in the market are seizing the opportunity to scale their businesses to supply technology for the new oil rush. Enapter is an innovative energy technology company which is radically rethinking how to supply electrolysers to the market at speed. We capitalise on our patented anion exchange membrane (AEM) technology to disrupt and fast track green hydrogen scaling.

The solar panel disrupted the power utilities a decade ago. Solar reorganised power distribution as it created the prosumer and made decentralised supply structures possible. Similarly, Enapter leverages its AEM technology to close the circle with a modular product approach. Our electrolysers will provide fuels and gases on site, i.e. provide hydrogen for heating, cooling, fuel for transport, feedstock for industry but also electricity storage exactly where it is needed. AEM technology unlocks a pathway for the complete decarbonisation of energy beyond power in all sectors and for any system size.

Enapter is a fast growing, international and award-winning electrolyser manufacturer rooted in R&D. At the core of our company is a group of world-class scientists and engineers building the unique AEM electrolyser technology.

## Traditional (grey) hydrogen

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In the past decades, we have seen the traditional hydrogen market expand to approximately 70 million tons each year. Most of this hydrogen goes into the refining of petroleum products, fertilisers and other industrial feedstocks. This traditional hydrogen is predominantly created from fossil fuels via steam methane reforming or coal gasification, resulting in significant carbon dioxide emissions. It is known as grey hydrogen. Given the changes of sentiment towards fossil fuels in the political sphere, business and finance, it is only a matter of time until green hydrogen from water electrolysis is cheaper than grey hydrogen and replaces it. Grey hydrogen may temporarily be replaced by blue hydrogen, which is essentially grey hydrogen with CO<sub>2</sub> captured and stored. However, green hydrogen will ultimately prevail due to its lower costs and zero carbon emissions.

## Electrolyser manufacturers

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Water electrolysis has a long history in the chemical industry. Traditional alkaline technology (TA) is the incumbent water electrolysis technology and has been widely used for large-scale industrial applications since 1920. TA systems are considered durable and exhibit relatively low capital costs due to the avoidance of noble metals and relatively mature stack components. However, their low current density and operating pressure hinder reductions in system size and hydrogen production costs. On the other hand, proton exchange membrane (PEM) systems, first introduced in the 1960s by General Electric, were used mostly for mid-scale applications. Their key advantages are high power density, provision of highly compressed and pure hydrogen, and flexible operation. Disadvantages include expensive platinum catalyst and fluorinated membrane materials, a requirement for titanium, a high system complexity due to high pressure operation and water purity requirements, and a shorter lifetime than TA at present.

Alkaline manufacturers have been in the market for a century, while PEM manufacturers have existed for decades. Electrolysers were a niche business but manufacturers are aiming to leverage the new narrative and momentum around green hydrogen. Investments are being made by manufacturers to scale their output in the quest to reduce electrolyser capex. Across the full landscape of Enapter's competitors, the common denominator for scaling is increasing the stack/unit sizes of their electrolysers. Larger stacks and electrolysers are being developed both by TA and PEM manufacturers. The reason for this scaling approach is fundamental to both technologies. Alkaline electrolysers require a complex balance of plant that is cost-effective only at large scale; while PEM electrolysers need to offset high material costs. Building larger units is their recipe for driving down the cost of green hydrogen.

## AEM technology: the electrolysis game changer

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We started Enapter in November 2017 in a unique position, having received the core technology and patents from ACTA Spa, an Italian R&D company with a 10+ year track record in AEM electrolyser technology.

AEM technology produces hydrogen at high purity in cells using a solid polymeric anion exchange membrane. The stack is made up of multiple cells connected in series, each of which has a cathodic half-cell separated from an anodic half-cell by an anion exchange membrane. The anodic half-cell is filled with dilute KOH (alkaline) electrolyte solution. The cathodic half-cell has no liquid and produces hydrogen by electrolysis from water that permeates through the membrane from the anodic half-cell.

Oxygen evolves from the anodic side and is transported away by the circulating electrolyte. Hydrogen is produced under pressure (typically 35 bar) and is already extremely dry and pure (~99.9%). Enapter's ancillary dryer module can increase hydrogen purity to >99.999%. As hydrogen is generated, the anodic half-cell side is topped up with purified water. Completely deionised water is not needed.

AEM electrolysis technology is recognised by a leading independent scientific review<sup>1</sup> and the US Department of Energy for its distinct position in the field of electrolysis<sup>2</sup>. AEM water electrolysis combines the advantages of PEM and TA electrolysis, making it best positioned to meet green hydrogen cost reductions<sup>3</sup>:

### PEM vs AEM

- ✓ Platinum group metals (PGM) catalysts → PGM catalysts not needed
- ✓ Titanium bipolar assembly → steel bipolar assembly
- ✓ Nafion® perfluorinated membrane → hydrocarbon membrane

### TA vs AEM

- ✓ Corrosive alkaline solution → dilute alkaline solution
- ✓ Low gas purity → high gas purity
- ✓ Low current density → high current density

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<sup>1</sup> Journal of Electrochemical Science and Technology; 2017; page 265 <https://www.jecst.org/journal/view.php?doi=10.33961/JECST.2017.8.3.183>

<sup>2</sup> [https://www.energy.gov/sites/prod/files/2014/11/f19/fcto\\_2013\\_market\\_report.pdf](https://www.energy.gov/sites/prod/files/2014/11/f19/fcto_2013_market_report.pdf)

<sup>3</sup> See the similar finding in a study of the Los Alamos National Laboratory (commissioned by the US Department of Energy): [https://www.hydrogen.energy.gov/pdfs/review19/p158\\_chung\\_2019\\_o.pdf](https://www.hydrogen.energy.gov/pdfs/review19/p158_chung_2019_o.pdf)

AEM is a game changer in the electrolysis industry with its potential to “offer >75% stack cost reduction”.<sup>4</sup> AEM electrolyzers are low-cost but high-tech and could be viewed as advanced PEM 2.0 technology. Our internal calculations, as well as those of the research community, show that an AEM stack will produce hydrogen at a significantly lower cost than PEM stacks. AEM electrolyzers can address the distributed hydrogen market competitively today, but when scaled, they will outcompete even larger PEM electrolyser stacks by 2022/23. The modularity of the Enapter system provides huge advantages over competing alternative systems in terms of redundancy, resilience and cost. This can be delivered across large and small systems, regardless of size.

Enapter has a growing patent portfolio. At the core is a strong patent family based on AEM electrolysis with a dry cathode. There is no other producer of AEM electrolysis on the market today. While the industry is aspiring to catch up, their attempts have not made it beyond a research-focused level.<sup>5</sup>

## Rethinking electrolyser concepts with AEM

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In May 2020, oil prices on the WTI exchange went negative for the first time in history. This showed the limits of our current energy supply chain and not just from a sustainability point of view. The COVID-19 pandemic highlighted substantial changes that are occurring across society, especially in the energy sector. Independence and resilience of the energy supply system have become the centre of attention. With its modular approach to hydrogen production, the AEM electrolyser provides a key solution in this context. It joins forces with major developments such as digitalisation, cognification and the tech-fuelled exponential growth of renewables, which are all based on distributed networks. These innovations rely on decentralised structures which allow us to manage previously unimaginable complexities while making nodes more capable. The global megatrend is therefore to move away from centralised systems.

With its AEM technology, Enapter is in a unique position to leverage this paradigm shift. While the competition is scaling by building larger electrolyser systems, we are following a different path. We build a standardised, scalable and flexible system that supplies hydrogen on site at the cheapest possible cost. It will be the universal building block for any energy system. The CE-certified device is digitally enabled by our Energy Management System (EMS). As a microwave-sized product, it can be easily stacked to achieve the hydrogen production output required. Unlike its peers, AEM technology attains huge cost reductions with compact, modular units. This allows us to conceptualise the electrolyser as a simple product that can be used in any application. Meanwhile, the competition will continue building electrolysers as industrial plants.

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<sup>4</sup> Ebd.

<sup>5</sup> EU Commission recognizing AEM potential and encouraging research: <https://cordis.europa.eu/project/id/875088>



*The EL 2.1 is the latest version of the modular and stackable AEM electrolyser. The standardized form factor allows for easy integration in 19" racks. It marks the beginning of Enapter's platform-based technology offering.*

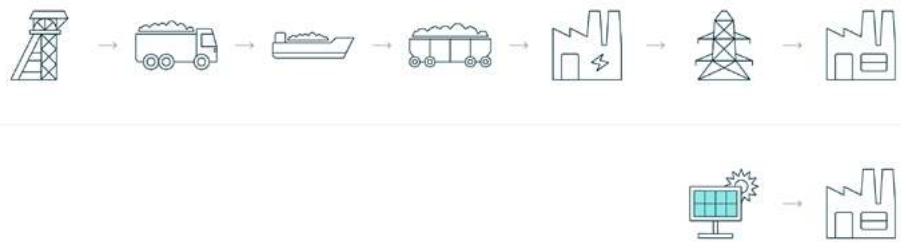
Nothing has experienced more rapid cost reductions in economic history than mass-produced commodities. Enapter's approach can be well understood by drawing an analogy between the electrolyser industry today and the IT industry in 1980. Today's manufacturers of large-scale electrolysers are developing systems comparable to the IT industry's early "mainframes". Each system is designed as an individual project, demanding highly sophisticated engineers and intricate planning. The PC was an innovation that came as a small, modular and standardised product. While ridiculed by many at first, it allowed for scaling and it outpaced the mainframe in its development. Today's data centres are largely made of blade server structures, which have stripped down computers even further, with a modular design to minimise the use of physical space and energy.



*From mainframe to PC to blade servers*

Due to the unique characteristics and cost advantages of AEM, we follow a similar approach. While our competition is increasing the size of their units, we are making small, standardised and adaptable products. Standardisation and a compact footprint are key prerequisites for mass production. Our numbers prove that mass produced modules will make cheaper electrolyzers.

We aim to replicate for hydrogen production, what the solar panel has been to electricity production. Twenty years ago, solar was the most expensive energy generation technology. Mass production has commoditised the solar panel and today it is by far the cheapest energy generation technology. The solar panel created a new paradigm in the energy industry. It empowered the energy consumers (residential, commercial, and industrial) to become prosumers. Distributed energy production was unheard of before solar (along with wind and bioenergy) started a victory march within the energy sector. Incumbent players, the energy utilities, were slow to respond and almost tumbled. Structural change was consequential and the business model of centrally producing electricity and transporting it to the periphery fundamentally changed. Solar allows users to cut the supply chain and produce it on site. Today, not using solar to offset your energy bill is imprudent for any homeowner, business, or factory.



*What solar did to electricity supply chains*

A modular electrolyser, that can be stacked to achieve any hydrogen production rate (from a kw range to multi megawatts), is poised to complete the energy system disruption. It is the same principle as the solar panel: a small unit that can be used individually, in small numbers or reach gigawatt size, if many modules are combined. Less than 20% of our energy is consumed in the form of electricity today. The remainder (heating, transport, industry) is almost entirely reliant on fuels and gases. The impact of being able to create the clean fuel/gas needed on site, next to the solar or wind installations in any size (not only megawatt scale) will send shockwaves through the energy sector.



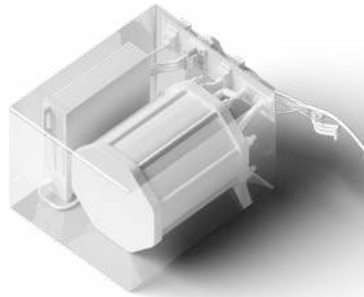
*What modular electrolysers could do to oil and gas supply chains*

## A platform-based approach to our technology roadmap

We are building our AEM technology solution using a platform-based approach. With a shared set of common design, engineering, and production efforts, as well as major components over a number of outwardly distinct models, product platforms allow for a reduction in costs and access to multiple market segments. Inspired by automotive platforms or Intel's microprocessor platform, a product platform approach allows us to increase our speed of product development, reduce development costs, and contribute to increasing product variety.

### The AEM stack module

At the centre of the AEM platform we are establishing the AEM stack module. It will be the building block for electrolyzers in different sizes. Standardising the AEM stack module allows us to quickly drive down the cost via mass production and easily apply it in various smaller and larger applications.



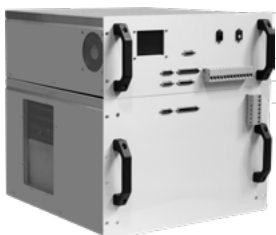
### Modular AEM electrolyser

The AEM electrolyser is a full electrolyser system built around an AEM stack. Our current product is the EL 2.1. The next generation models, the electrolyser EL 4.0 and T/X, will be smaller and lighter than previous models. However, they will continue to have one stack module with a production rate of 500 NL/h of hydrogen with ~99.9% purity at approximately 35 bar. It is an ideal solution for the decentralised market requiring small to mid-sized hydrogen generators. There is no technical limit to how many electrolyzers can be combined to reach higher production rates.

#### EL 500

Available in 2017

10 Units



#### EL 2.0

Introduced 01/2019

8 Units



#### EL 2.1

Introduced 02/2020

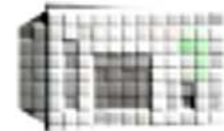
7 Units



#### EL 4.0

02/2021

6 Units



#### EL T/X

2022/2026



AEM electrolyser development stages

## Stacking the AEM electrolyser

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*Stackability: achieving small to midscale system sizes in racks / cabinets*

The current electrolyser can be easily stacked in standardised housings such as racks or cabinets.



*Stackability: achieving mid to large scale system sizes in containers*

For higher hydrogen production rates, stacking electrolysers in containers is a quick and easy way to provide larger flowrates using the same module but providing a solid enclosure.

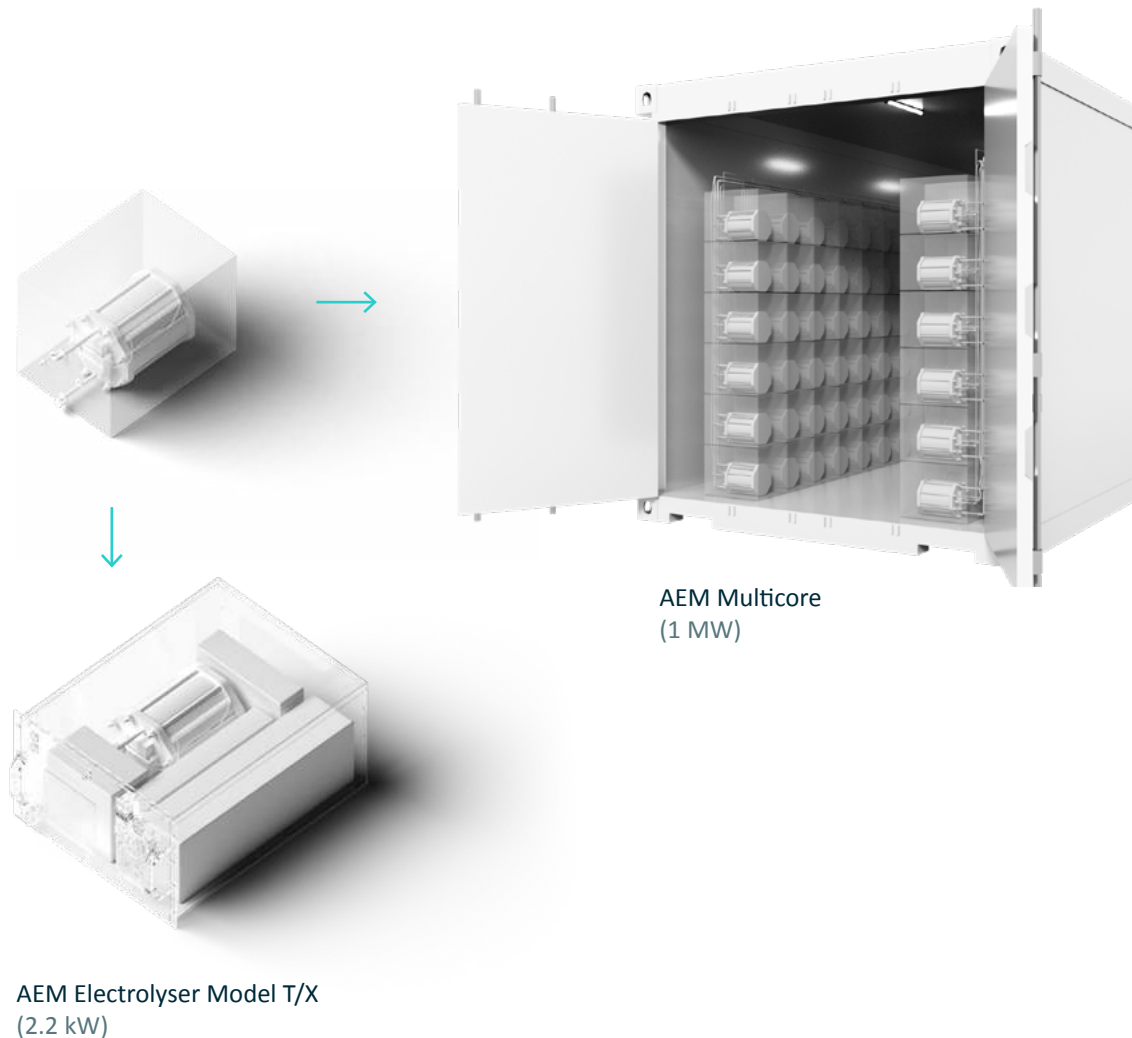


## AEM Multicore: growing to larger sizes

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The AEM Multicore concept is to apply our modular approach to megawatt sized electrolyzers. We can stack hundreds of our AEM stack modules and build one larger balance of plant (BOP) around it. This approach will allow us to economise on the BOP and reduce costs even further for larger systems.

The AEM Multicore will deliver large-scale electrolyzers with a similar compact footprint to the containerised solutions that competitors would offer. However, we will remain modular and our mass-produced AEM stack modules will be hot-swappable, providing an extremely high availability and built-in redundancy. It is worth noting that our current (not scaled!) stack costs at the single digit kW level are already quite competitive with singular large MW stacks of our competition today.



*The modular AEM stacks enable small and large solutions.*



The world is changing its approach from hardware to software-defined. A strong relationship between hardware and software is therefore essential for the success of future energy systems. Keeping in mind megatrends of digitalisation and cognitive services (that enable distributed networks to function efficiently, reliably and cost-effectively), Enapter enables its devices through powerful software.

Enapter's software-defined Energy Management System (EMS) is a decentralised energy system controller. It can configure, control and monitor both Enapter devices and third party devices, ultimately managing entire energy systems. The energy world is moving into the digital era where energy system functionality is driven by software logic. While there are limited manufacturer-independent and easy to use controllers for decentralised energy systems, software is vital to upgradable, adaptable and smart grids.

The tech industry has led the world to realise the enormous value of big data. At Enapter, we are not interested in personal data of customers, but we see tremendous value in the thousands of hours of monitoring data that we collected from a few devices in the last year. The modular approach of mass-producing compact devices provides us with a foundation of data which we can leverage to rapidly develop our technology, allowing us to excel in predictive maintenance, AI, and intelligent energy systems.

Enapter's goal is to provide a modular energy management system to residential, commercial and industrial customers. We aim to integrate different communication protocols and avoid complicated and costly integration via programmable logic computers (PLC) or other limited systems. We are simplifying the setup, scalability, analysis and management of decentralised energy systems. In turn, we are simplifying the adoption of hydrogen systems in the market. Our philosophy for the EMS is to provide an "operating system" that offers core functionality to integrators, operators and developers. It can be easily amended and built upon to accommodate for individual needs via open collaboration tools and customisable frameworks.

Just like our customers and system integration partners, we utilise the Enapter EMS ourselves to optimise business operations. Our technology platform is used in our factory to automate all relevant processes such as final acceptance testing, production tasks, quality systems, R&D testing and customer support.

## Massive and rapid AEM production scaling

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Enapter is different from other electrolyser manufacturers. Instead of conceiving electrolysers as industrial projects, we follow a strategy to reduce costs using a modular mass-producible platform approach. We also control every aspect in the development and production of our core product. Starting from raw materials, we synthesise our proprietary catalysts, make our own electrodes and gas diffusion layers, produce our unique membrane electrode assemblies (MEA), assemble the stack according to in-house designs, build the entire balance of plant, and develop our own control system to operate the stack and entire system environment.

Enapter's advantages include the ability to fully leverage our intellectual property (IP) and keep internal critical knowhow, ensure quality of the overall product, and fully capitalise on seamless cost optimisation in every step of the value chain.

Enapter's next target is moving from serial manufacturing to automated production in order to leverage the AEM cost reduction potential. We will create blueprints of how to mass produce the AEM modules. The compact form factor, small size and weight of our stacks and electrolysers enable a quick and nimble setup.

Where others focus on giga factories, we apply decentralised concepts to our mass-production approach. Enapter's success is built around teams working closely together while being very flexible on location. We acquired the AEM core team and patents in Italy, set up a major pilot and office in Thailand, created a subsidiary in Berlin and located our software operations in St. Petersburg.

Scaling production is the ultimate priority for Enapter in driving down the cost of green hydrogen and leveraging the advantages of AEM. We approach scaling with agility and focus on the results. We will build capacities around the best resources wherever they may be. We will package development priorities and solve them with parallel teams where required.

Ultimately, we are planning to build the Enapter Campus to combine the best results of our teams and become a model and showcase for sustainable industrial production and R&D. Our goal is to develop the Campus with a "Life Cycle Zero CO<sub>2</sub> Impact" fully powered from renewables and full recyclability of our products. Producing AEM technology in this early stage requires world-class talent, suppliers, partners and support structures.

The Campus is not the end goal. It will act as a blueprint for the production of the AEM product palette. The future of global production will not be centralised. Instead, easy to clone production facility concepts are required. These will allow local owners and partnerships to quickly scale green hydrogen production globally. Eventually, we will be expanding production around the globe. With factory blueprints and high levels of automation, we will achieve gigawatts of production capacity across different locations.

## Strong partner network

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We are building an exceptional partner network to leverage mass production and introduce the universal AEM electrolyser into the many hydrogen use cases. By inspiring existing businesses to collaborate with Enapter, we are laying the foundation for green hydrogen's rapid market uptake.

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We work towards a big goal, laid out by the Hydrogen Council, where hydrogen is deployed at scale and provides a fifth of total final energy consumption by 2050. This reduces annual carbon emissions by about six billion tons compared to today and contributes roughly 20% of the abatement required to limit global warming according to the international goals.

Our big hairy audacious goal is that Enapter products provide 10% of global hydrogen production capacity by 2050.

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