SCALING UP TO MEET ANTICIPATED DEMAND

Todd Cartwright, Nel Hydrogen, discusses why electrolyser equipment needs to range from small containerised systems to large capacity plants in order to meet varying market needs.

According to Custom Market Insights in a report published in November 2023, the global water electrolysis market is expected to grow significantly from now until 2032, with a compound annual growth rate of almost 8%.[1] Currently, 98% of hydrogen production is based on fossil feedstocks. Most hydrogen from the mid-20th century through today has been 'grey' hydrogen, produced from natural gas, methanol and coal sources – all with a high carbon dioxide (CO_2) emissions burden. The remaining percentage of the hydrogen is produced via an electrolysis process, and of that, 25% is made by water electrolysis specifically. Water electrolysis makes it possible to generate hydrogen from water using electricity with no CO_2 emissions at all at the point of generation. 'Green' hydrogen normally refers only to hydrogen produced by water electrolysis using renewably-generated electric power, while 'clean' hydrogen includes green hydrogen, as well as hydrogen produced through other low-carbon pathways.

While hydrogen made via water electrolysis is currently a very small percentage, that is expected to increase exponentially as the push for green hydrogen production using renewable energy sources is adopted as a way to achieve net-zero emissions. Indeed, the International Energy Agency (IEA) has been suggesting over the last few years to all stakeholders in the green hydrogen movement to start scaling up technologies and bring down costs to allow hydrogen to be used more widely.[2] Carbon taxes and laws in Europe and Asia are driving hydrogen and derivative users to lower carbon emitting supply approaches. While the US does not yet have federal carbon emissions taxes or restrictions, various state regulations and environmental, social and governance (ESG) considerations are having a similar effect of promoting the use of a lower carbon footprint hydrogen. Even more specific to hydrogen, Europe, the US and Canada have all passed laws to promote investments in green or clean hydrogen. The final rules relating to these laws are still under development and the details are creating uncertainty in the hydrogen investment climate. In particular, the initial proposed rules from the US Treasury relating to the 45V Hydrogen Tax Credit are under scrutiny as key stakeholders in the field consider the proposed qualifications too limiting.

There are both current and prospective market needs for hydrogen. Those in the future category will depend on new hydrogen economics and/or new hydrogen applications. Markets and uses that meet current and near-term hydrogen demands are continuing to multiply. Clean hydrogen technologies are winning an increasing percentage of these supply opportunities. The markets and projects that are most acutely delayed and otherwise negatively affected by 45V and other types of rulemaking and interpretation, are the prospective projects.

As examples of current markets and uses, there are pilot projects well underway in various sectors using water electrolysis to generate hydrogen. As such, electrolyser equipment manufacturers are among the stakeholders in the clean and green hydrogen initiatives and are stepping up production as the market drives demand. Certain market sectors – sustainable aviation fuel (SAF), ammonia, and hydrogen fuelling, for example – are moving more quickly, and making larger investments in water electrolysis for their hydrogen needs than other industries, although others, such as the steel industry, are also making notable strides. As such, these 'first movers' are first in line to procure electrolysers. These more active market sectors are creating sufficient demand for new electrolyser manufacturing plants to be built, which will aid all the markets as the green hydrogen evolution continues

Figure 1. Nel containerised PEM electrolysers are capable of producing 500 m^3/h of hydrogen or over 1 tpd. The unit above is located at a Constellation Energy nuclear plant in upstate New York, US.

Figure 2. The 20 MW PEM plant at the Iberdrola-Fertiberia facility in Puertollano, Spain, is the largest electrolysis plant currently in operation providing green hydrogen for green ammonia production.

and demand for electrolysers increases. For instance, Nel Hydrogen is building a new electrolyser equipment manufacturing plant near Detroit, Michigan, US. When fully developed, the Michigan plant alone will have an annual production capacity of up to 4 GW alkaline and proton exchange membrane (PEM) electrolysers.

According to Recharge, a global news and intelligence service for the energy industry, the cost of green hydrogen is expected to fall to US$1.50/kg by 2030 as electrolyser capacity increases.[3] It reports that more than 100 GW of electrolysers will be manufactured each year by 2030, up from 2 GW in 2020.

Alkaline electrolysis and PEM electrolysis are the two types of electrolysis systems that are generally considered commercially mature right now. There are other types in development which also show promise. Alkaline technology has historically been used for large capacity hydrogen plants. Alkaline cell stacks cost fewer capital dollars on a per kW basis because they do not use precious metals as catalysts like PEM does. Alkaline equipment has also reduced in cost to a great extent, having been commercially deployed for almost a century. Alkaline electrolysis is being used at green steel projects in Sweden such as Ovako; HYBRIT (a joint venture between SSAB, LKAB, and Vattenfall); and H2 Green Steel. Iron making and steel making sites are typically large – most of them are expected to accommodate multiple electrolyser 'trains' to accommodate generation in the 100 MW to 500 MW range that might be required at full scale. Another concept being explored is establishing separate green hydrogen generation plants – complete with co-located off-grid renewables, companion storage facilities, and transport fleets – to deliver the green hydrogen to nearby iron and steel locations. For example, the Hy Stor Mississippi Clean Hydrogen Hub project features underground salt caverns for storage. Hy Stor's goal is to develop a green hydrogen generation, storage, and transportation hub in the US. The first phase of the project is expected to be commissioned in 2025.

Conversely, PEM electrolysers are compact, and can ramp up quickly to cope with variable energy sources or changing hydrogen demand. They can be supplied to produce a range of quantities of hydrogen, from a few kg per day to hundreds of tons per day. PEM electrolysers have been working commercially in the field for approximatley 50 years. PEM is well suited to space constrained sites and offers a simple, low-maintenance process that reduces the requirement for downstream compression or gas purification.

It is this equipment, Nel believes, that will be used for the initial stages of the SAF market, which is expected to take off in the near future. According to the International Air Transport Association, the global aviation industry is set to require 120 million tpy of clean hydrogen by 2050, with 100 million t to produce SAF and 20 million t for hydrogen-powered aircraft. 100 million tpy of clean hydrogen for SAF by 2050 equals 274 000 tpd of hydrogen production. Carrying this maths through, 274 000 tpd of hydrogen would entail approximately 685 GW of electrolysis for hydrogen production.

Currently, Nel's PEM containerised systems are capable of producing up to 1 tpd of hydrogen. Taking the same PEM stack technology and packaging it innovatively, Nel will offer plug and play cell stack subsystems that can produce 4+ tpd.

Electrolysis begins with the electrolyser's cell stack, the core of the electrolyser, akin to the chip in a computer or the engine in a truck. Each cell stack is made up of many electrolytic cells, each of which is an electrochemical reactor. Add water (either pure water or in an electrolyte solution) and DC power, and the cell stack creates hydrogen and byproduct oxygen. Cell stacks can be arrayed to increase production in a number of different configurations.

Nel's PEM stack modules (PSM), which are containerised cell stack systems, can be aggregated to achieve larger plant designs without the need for a building. The advantages of containerised PEM electrolysis are several, including

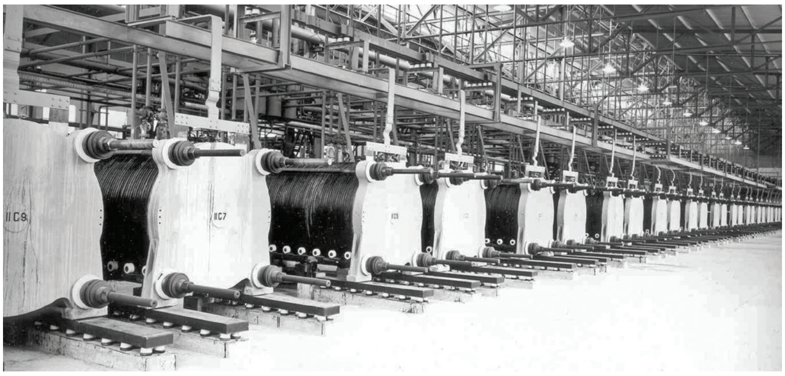

Figure 3. The 135 MW alkaline plant from Nel Hydrogen in Glomfjord, Norway (1953 - 1991) was used to create up to 30 000 m^3/h of hydrogen for ammonia production.

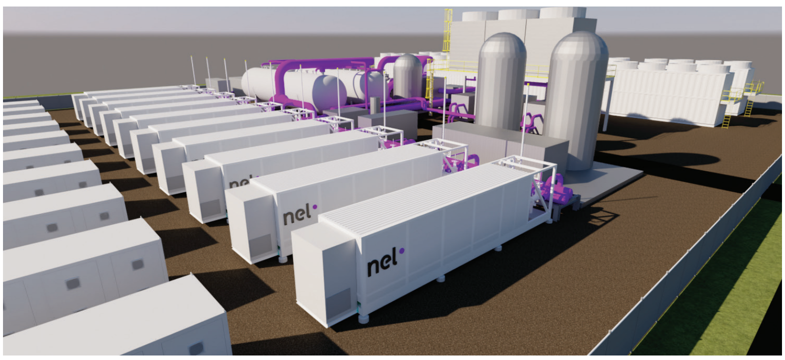

Figure 4. Nel's 10 MW PEM stack modules (PSMs) are containerised cell stack systems that offer a plug and play subsystem for larger electrolyser plants, shown here in a 100 MW plant configuration.

predictable availability. The equipment is made in a factory; it is not assembled in the field. There are minimal technology and supply chain risks. There are also minimal infrastructure requirements in the field (the requirements are deionised water, electricity, the ability to dispose of waste water, and the customer hydrogen header pipe to take the produced hydrogen).Highly skilled tradespeople are not required to carry out field fabrication, and systems can be installed in any weather conditions or season. Because the systems are highly standardised, companies receive an assured level of support from manufacturers who have made hundreds of such systems. It is believed that PEM electrolysers, at least initially, will play the larger role when coupling to renewable energy grids because of their ability to respond instantly to electrical supply changes and downstream process needs.

Alternatively, the largest plants might omit containerisation and be placed in buildings using bare, uncontainerised cell stacks in groups of dozens to create even larger scale hydrogen production. As examples of larger PEM systems, several projects are underway around the world to ramp up green hydrogen and green ammonia supply. For instance, Iberdrola, a multinational electric utility company based in Bilbao, Spain, selected Nel Hydrogen to demonstrate the applicability of PEM electrolysers for green ammonia production.

Iberdrola and Nel have developed and deployed large-scale electrolyser projects to promote the green hydrogen supply chain in Europe and the US. Specifically, for green ammonia for fertilizer, the Iberdrola-Fertiberia alliance is producing green hydrogen for the Puertollano ammonia plant in Spain. The electrolyser solution is a 20 MW PEM system from Nel, the largest electrolysis plant for green ammonia production currently in operation. According to the Ammonia Energy Association, Fertiberia's low-carbon fertilizer has been successfully used in pilot programmes by Heineken and PepsiCo.[4] This green fertilizer has been used on barley and potato crops in Spain, significantly reducing overall agricultural emissions and paving the way for future supply chains. Both Heineken and PepsiCo are aiming to reduce agricultural emissions from their product supply chains and intend to scale up the use of green fertilizer based on the success of their 2023 pilot programmes.

Another company making strides in green hydrogen/green ammonia production for fertilizer is Yara International AS, who has also applied Nel Hydrogen's electrolyser technology to help achieve its mission to 'responsibly feed the world and protect the planet'. According to published press materials on its website, Yara has already removed half of its direct greenhouse gas (GHG) emissions over the past 30 years and is striving towards carbon-neutrality by 2050.[5]

Electrolysis enables the monetisation of excess and low-value electricity supplies, and this has encouraging potential for both stranded renewable energy and nighttime nuclear energy that is too expensive to sell at a profit. For example, there are periods of time in the middle of the afternoon when there is excess solar power. There is excess wind power on certain days, especially during the winter months when capacity factors are high and cooling loads are low. Nuclear plants contend with excess energy above grid needs almost every night. Electrolysis is uniquely compelling to the nuclear power economics by creating profitable nighttime electricity markets. Those plants can create hydrogen all night and feed the grid all day. In doing so, a nuclear power plant can serve two profitable markets.

Charting the energy grid supply and demand patterns, there is innovation happening right now for hydrogen-using companies to consider employing a blend of alkaline and PEM systems. For instance, if you wanted 100 MW of electrolysis capacity, lowest possible deployed cost, and the ability to ramp up and down to meet a certain amount of renewable energy, then you might deploy 70% alkaline and 30% PEM. That would give you the lowest deployed cost because alkaline systems are less expensive to buy and are slightly more electrically efficient. Meanwhile, the PEM portion of the plant can dynamically track the ups and downs of the electrical supply.

Equipment cost vs capacity scaling of water electrolysis projects follow different economic rules than older hydrocarbon-based technology because the approaches to capacity scaling differ. For instance, in steam methane reforming – the predominant means of hydrogen production from hydrocarbons – equipment costs grow at a decreasing rate as capacity is increased above a certain minimum level of 10 tpd, for example. This is because the reaction vessels and balance of plant can all be made larger in capacity to suit the desired production scale. Conversely, water electrolysis scales approximately linearly above a certain minimum level of, say, 50 tpd. This is because equipment capacity in water electrolysis is a function of the number of standard sized cell stacks deployed, rather than deploying ever larger cell stacks.

The 45V production tax credit rulemaking and subsequent interpretation of those rules will evolve with more clarity this year as all stakeholders in the clean and green hydrogen movement maintain focus on the virtuous outcomes: green hydrogen created from zero-carbon electricity; clean hydrogen replacing dirtier fuels/feedstocks in application where fuels are required; additional green hydrogen demand creating new demand for renewable electricity; additional green hydrogen production capacity, making it possible to maximise the value of all clean power on the grid – essentially creating a way to store electricity in the form of hydrogen.

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