

Developments in Hydrogen Production

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1. Introduction

Many have advocated a major role for green hydrogen in reducing greenhouse gas (GHG) emissions, and thus mitigating climate change. I posted the paper summarized and linked below a couple of months ago. In this paper I looked at the economics of green hydrogen vs. many applications that could reduce their GHG emissions by using this gas. This was a detailed review, and would be a good starting point for this paper.

On the Road to H2 in California: Sometimes, when looking at your past work, you feel that you have spending an inordinate amount of time on a given task, or in my case a subject for my posts. However, whether I'm really squandering my time would depend on (1) how important this subject is, (2) how timely it is, and (3) what are the net results. You can probably figure out what the subject of the above feeling is by looking at the title of this post.

I'm assuming most know how important it is for us to greatly reduce the amount of GHG we are emitting ASAP. What about timeliness? The key question: is hydrogen energy production in our distant future, or are imminent breakthroughs on the horizon? After going through recent posts, I now feel very strongly that we are getting really close to making some significant steps in the next year or two.

This paper will present the findings of recent posts and other related information. These should provide a summary of net results.

<https://energycentral.com/c/ec/road-h2-california>

Below we examine a breakthrough, as predicted in the above summary, however the E.U. company that made this breakthrough wasn't even on my radar when I wrote the above paper, so I think another paper is justified. Although the initial press release was over a year ago, I just came across it in a recent issue of Time.

Also, we will look at the major manufacturers of hydrogen electrolyzers, mostly those that are based in the U.S., and look at an advancement in proton-exchange membrane electrolysis that could greatly reduce the amount of a rare material it requires.

2. ThyssenKrupp Nucera alkaline electrolyzer tech

Dortmund, May 11, 2023 – ThyssenKrupp Nucera recently launched the new product name “scalum” for the highly efficient alkaline water electrolysis (AWE) modules for the production of carbon free hydrogen. The name “scalum” represents the AWE electrolysis module’s high level of scalability and precision¹

ThyssenKrupp Nucera has introduced a new product name for its innovative solution for the production of green hydrogen. This 20 MW module will henceforth be called “scalum”. The supplier of world-leading technologies for high-efficiency electrolysis plants announced this at the international industry trade fair “World Hydrogen Summit 2023” in Rotterdam.

¹ Rita Syre, Senior Media Relations Manager, thyssenkrupp nucera, <https://thyssenkrupp-nucera.com/2023/05/11/thyssenkrupp-nucera-the-electrolyzer-that-produces-green-hydrogen-is-now-called-scalum/>

The new product name is derived from the term “scale” and pays tribute to the module’s scalability, interconnecting multiple modules to very high plant capacities. Scalability plays a central role in the use of green hydrogen as a new, carbon-free energy source of the future. With the decarbonization of energy-intensive industry imminent, large-scale water electrolysis plants have to be used to produce this climate-friendly energy carrier using renewable energy. This will minimize the industry’s carbon footprint.

ThyssenKrupp Nucera is one of the few suppliers in the world capable of providing water electrolysis technology in the gigawatt power range. More than 2.5 gigawatts of capacity to produce hydrogen using renewable energy has already been sold to customers worldwide.

Alkaline water electrolysis (AWE) technology has proven itself with the longest track record in the green hydrogen production technology area. With several decades of experience, thyssenkrupp nucera’s chlor-alkali electrolysis technology is a strong base for their water electrolyzers. “scalum” from thyssenkrupp nucera stands out with low investment costs and convinces with its basis in a proven cell design with long runtime and high-performance history.

“To reliably represent capacities to produce green hydrogen on a scale of several hundred megawatts or even gigawatts of power, our equipment must guarantee a high degree of scalability and availability. Our product name ‘scalum’ reflects this quality promise that we make to our customers and by which we measure ourselves,” Dr. Christoph Noeres, Head of Green Hydrogen, says.

“Scalum” is the start of the new company-wide naming system for the AWE product family in thyssenkrupp nucera’s hydrogen division. The internationally understandable and meaningful name is intended to increase brand recognition and clearly express to customers that the AWE electrolysis technology is capable of a wide range of hydrogen production capacities. The focus is on differentiating product features that stand for the new era of energy supply with green hydrogen on an industrial scale to improve climate protection. Thus, the product name contributes to a unified and sharpened brand identity for thyssenkrupp nucera.

“Even in our technically oriented B2B market, we have to deal with the increasing importance of consistent brand experiences. That’s why we are continuously developing our brand identity, which includes the development of meaningful product names“, says Katharina Immoor, thyssenkrupp nucera’s Head of Communication & ESG.

The launch of the new product name marks the next milestone in the long-term development of the thyssenkrupp nucera brand. At the beginning of last year, the electrolysis specialist unveiled its brand identity with the new company name thyssenkrupp nucera. It symbolizes the dawn of a new era of innovation, transformation and green energy as a decisive contribution to climate neutrality.

3. ThyssenKrupp Nucera, The Company

The following is from the thyssenkrupp nucera corporate brochure.

With a history spanning over 60 years, we bring together the collective expertise of three renowned global leaders in the field of electrolysis: thyssenkrupp’s electrolysis division in Germany, the Italian electrochemical specialist UHDENORA, and the former electrolysis unit of the Japanese Mitsui group.

Today, we proudly offer cutting-edge technologies and innovative solutions for efficient chlor-alkali and green hydrogen electrolysis. Our offerings are a testament to our extensive experience and worldwide partnerships, solidifying our position as leaders in the field.

Timeline:

1960: Founding of thyssenkrupp Uhde's Electrolysis division.

1973: Founding of Chlorine Engineers Corporation Ltd. (Japan)

1984 – 1994: Uhde's first BM single element membrane technology and Chlorine Engineers' first product of the BiTAC family with zero-gap technology lay the foundations for becoming a global market leader in chlor-alkali membrane electrolysis.

1995: Opening of the chlor-alkali R&D test stand in Gersthofen². More than 50 references already obtained for the new Single Element technology.

2001: The newly formed joint venture UHDENORA leads to innovative, power saving products (NaCl-ODC (oxygen-depolarized cathode), HCl-ODC electrolysis).

2003: Establishment of first industrial energy-saving hydrochloric acid recycling plant.

2013: NaCl-ODC market entry - 25% energy saving electrolysis technology

2018: Research and development for hydrogen production with electrolysis continues at our Carbon2Chem 2 MW green hydrogen demonstration plant in Duisburg.

Who we are: Driven by chemical engineering innovation, thyssenkrupp nucera pioneers high-efficiency electrolysis technology with 50+ years of experience. Throughout our journey, we have developed two strong portfolio segments that create synergies and provide innovative solutions for industrial progress and green value chains: chlor-alkali and green hydrogen.

We build state-of-the-art electrolysis plants worldwide that harness the power of solar, wind and water energy to produce hydrogen, leaving no harmful greenhouse gas emissions behind. We believe, by producing green hydrogen at commercial scale, we enable sustainable transformation and provide our customers with access to clean, renewable energy that will last for generations to come. Safety anchors our pursuit of high-tech breakthroughs, embracing challenges with resilience.

Global Presence:



² Gersthofen is a town in the district of Augsburg, in Bavaria, Germany.

Recent US Development: *The US Department of Energy (DOE) has selected thyssenkrupp nucera USA Inc. for a \$50 million grant under the Bipartisan Infrastructure Law's investment in clean hydrogen and electrolyzer manufacturing. With this funding from the U.S. government, thyssenkrupp nucera aims to expand its footprint in the North American hydrogen market...*³

4. Two Different Electrolyzer Technologies

*Alkaline water electrolysis (AWE) is a long-known technology for hydrogen production through water splitting into hydrogen and oxygen using electrical energy. In the last decades, research has become more focused on proton-exchange membrane electrolysis (PEMEL), as higher current densities are achievable. However, PEMEL electrodes require precious metals like platinum and iridium, while steel and nickel are favored materials for AWE. Hence, the research for the enhancement of AWE has intensified in the last years. With a higher share of renewable energy in the power grid, AWE may be essential for load-balancing and large-scale hydrogen production. However, the large-scale application demands low cost and high effectiveness. Therefore, every component of an AWE system needs to be optimized...*⁴

AWE uses an aqueous potassium hydroxide solution as the electrolyte at the typical operating temperatures between 50 and 80 °C. A separator is placed between the electrodes to prevent the direct mixing of the product gases inside the electrolysis cell. Asbestos was used as a diaphragm until this material was banned. The development of new porous separators was needed. Since 1970 new materials have been evaluated to replace asbestos. Promising results were achieved with materials based on polysulfone and polyphenylene sulfide. However, those materials are only slightly hydrophilic, and therefore the wettability of the pore system with the electrolyte solution is low. Thus, other hydrophilic compounds like ceramics or other polymers are added to enhance the overall wettability. Such composite materials combine the chemical and mechanical stability of the base materials with the beneficial properties of the functionalized materials. The most commonly known porous separator uses zirconium dioxide (ZrO_2) on a polymeric basis and is marketed under the name Zirfon™ (Agfa-Gevaert N.V.). Currently, Zirfon™ is one of the most used separators for AWE. While this material is known to provide low gas contamination and high ionic conductivity, the overall performance is strongly dependent on the detailed geometrical structure and the chemical composition. Thus, further optimization of such porous separators is possible. Additionally, the conventional manufacturing process of separators requires specific solvents, which may be replaced by more environment-friendly alternatives.

When comparing AWE with PEMEL, the most obvious difference between the technologies is the requirement of liquid electrolyte management for AWE, while PEMEL can use deionized water for operation. Hence, many researchers try to eliminate the need for a highly concentrated electrolyte while maintaining the usage of non-precious metals as electrode materials. This can be realized by the development of a suitable anion-exchange membrane (AEM), with high ionic conductivity at dilute electrolyte or even pure water. Furthermore, the membrane must provide a high crossover barrier despite a low thickness.

³ <https://www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/thyssenkrupp-nucera-selected-for-dollar50-million-grant-from-the-u.s.-department-of-energy-252256>

⁴ Jörn Brauns, Jonas Schönebeck, et al, Electrochemical Society, “Evaluation of Diaphragms and Membranes as Separators for Alkaline Water Electrolysis,” Jan 27, 2021, <https://iopscience.iop.org/article/10.1149/1945-7111/abda57>

AEM development is an ongoing research field, and no material developed to date clearly satisfies all requirements in terms of performance and stability.

A Proton Exchange Membrane (PEM) electrolyzer is an advanced and highly efficient electrolysis technology that plays a vital role in the production of green hydrogen, a sustainable and eco-friendly energy source. Utilizing a solid polymer electrolyte, or proton exchange membrane, the PEM electrolyzer facilitates the conversion of water into hydrogen and oxygen through a process known as electrolysis. As the world grapples with climate change and seeks alternatives to fossil fuels, the PEM electrolyzer has emerged as an essential component in the quest for sustainable energy solutions. Its unique features, such as compact design, rapid response time, and ability to efficiently produce hydrogen at high pressures, make it particularly well-suited for integration with renewable energy sources like solar and wind. As a result, the PEM electrolyzer not only helps to advance the production of green hydrogen but also contributes to the broader goal of transitioning to a low-carbon, sustainable energy future.

Author's comment: as pointed out above, "...PEMEL (a.k.a. PEM) electrodes require precious metals like platinum and iridium, while steel and nickel are favored materials for AWE" In the long run, this could limit its potential in a market with huge growth potential like green hydrogen production. Note that reference 1 and reference 4 used different acronyms for alkaline water electrolysis, and I edited this to use "AWE" for both.

5. Major Electrolyzer Manufacturers in the U.S.

Source: Blackridge, Global Top 20 Hydrogen Electrolyzer Manufacturers.⁵

The bad news is that there are only four Manufacturers that are based in the U.S. ThyssenKrupp Nucera (Section 2) is also on this list, albeit at number 20. Also, my former employer (Siemens) is on the list (number 17). Both of these EU-based manufacturers have a presence in the U.S., especially Siemens, who is a major supplier in many U.S. energy industries.

Bloom Energy: Bloom Energy's primary product is a fuel cell that can use either hydrogen or natural gas, the latter directly without (externally) refining it into hydrogen. They also make a high-temperature solid oxide electrolyzer. This electrolyzer technology is a third type (in addition to AWE with PEMEL). The following text is from Bloom's website, and is referenced below.

Bloom Energy has begun generating hydrogen from the world's largest solid oxide electrolyzer installation at NASA's Ames Research Center, the historic Moffett Field research facility in Mountain View, Calif. This high-temperature, high-efficiency unit produces 20-25% more hydrogen per megawatt (MW) than commercially demonstrated lower temperature electrolyzers such as proton electrolyte membrane (PEM) or alkaline.⁶

This electrolyzer demonstration showcases the maturity, efficiency and commercial readiness of Bloom's solid oxide technology for large-scale, clean hydrogen production. The 4 MW Bloom Electrolyzer™, delivering the equivalent of over 2.4 metric tonnes per day of hydrogen output, was built, installed and operationalized in a span of two months to demonstrate the speed and ease of deployment.

⁵ <https://www.blackridgeresearch.com/blog/list-of-global-top-hydrogen-electrolyzer-manufacturers-companies-makers-suppliers-in-the-world>

⁶ <https://www.bloomenergy.com/bloomelectrolyzer/>

Cummins Inc.: *At the heart of Cummins' hydrogen generation technology is electrolysis, a highly efficient electrochemical reaction using electricity to break down water (H₂O) into its constituent elements, hydrogen (H₂) and oxygen (O₂).⁷*

Cummins uses an PEM design: *the core components of an electrolyzer are cell stacks containing two electrodes through which electricity enters and exits the system, separated by a membrane across which the current passes. When electricity is applied to the system, hydrogen is formed at the cathode, oxygen at the anode. The membrane effectively keeps the gasses separate while they are harvested. Hydrogen can be captured as a gas at extremely high purities, leaving oxygen that can be used for other purposes including industrial and medical uses. The hydrogen gas can be easily stored as a compressed gas or liquid.*

Ohmium International, Inc.: *Ohmium's PEM electrolyzers use 100% renewable energy to safely produce green Hydrogen, a flexible resource that has the capacity to decarbonize industries worldwide.⁸*

Ohmium's headquarters is the SF Bay Area: 39672 Eureka Drive, Newark, California 94560. They appear to manufacture in India.⁹

Plug Power Inc.: Like Bloom, Plug Power (a.k.a. Plug) manufactures both fuel cells and electrolyzers. The text below is from their web site, and referenced.

Plug's electrolyzer products utilize PEM stack technology with nearly 50 years of operational experience in applications demanding extremely high reliability, including mission critical life-support in nuclear submarines and NASA spacecraft.¹⁰

Plug offers plug-and-play electrolyzer products, as well as custom-engineered, built-to-order integrated solutions to meet any type of demand. Plug's output instantaneously adjusts based on electrical input, creating a perfect pairing with intermittent renewable resources.

Plug Power's Headquarters are at 968 Albany Shaker Road Latham, NY 12110. They manufacture in Rochester, NY. Also see the article below.

Ammonia is a fundamentally crucial fuel source serving as the key input for nitrogen fertilizers used in food production.¹¹

Just how important is ammonia? The International Energy Agency (IEA) has concluded that about 70% of the production of it, a chemical compound combining nitrogen and hydrogen into NH₃ via the Haber-Bosch process, is used as fertilizer inputs for crops such as wheat and corn globally. In the U.S., that figure is even higher at 90%.

⁷ <https://www.cummins.com/sites/default/files/2021-08/cummins-hydrogen-generation-brochure-20210603.pdf>

⁸ <https://www.ohmium.com/our-product>

⁹ <https://www.ohmium.com/contact>

¹⁰ <https://www.plugpower.com/hydrogen/electrolyzer-hydrogen/electrolyzer-products/>

¹¹ Plug Power, "The Potential of Plug's PEM Electrolyzers: Decarbonizing Ammonia Production," April 27, 2023, <https://resources.plugpower.com/electrolyzer-hydrogen-production/the-potential-of-plug-s-pem-electrolyzers-decarbonizing-ammonia-production>

But though a lynchpin for putting food on the table, ammonia producers also currently rely heavily upon natural gas to churn it out. And ammonia resultantly currently outputs 1.3% of all CO₂ emissions, as well as 2% of global energy consumption. To understand why, here are some basics about how ammonia production works.

Ammonia production via Haber-Bosch, the process utilizing a metal catalyst under high temperatures and pressures, is fueled by natural gas. So much natural gas consumption takes place within that process that it totals 3 to 5% of the world's natural gas production and 1-2% of the world's energy supply at-large, according to a 2021 study published in the journal Joule.

With 70% of all ammonia currently being made from natural gas, and the rest coming from coal, production under the status quo fuels climate change. The EIA has surmised that non-green ammonia is “twice as emissions-intensive as crude steel production and four times that of cement, on a direct CO₂ emissions basis.”

But Plug Power, via its Proton Exchange Membrane (PEM) electrolyzers, can mitigate the greenhouse gas emissions currently embedded in ammonia production and make the vital food-making ammonia fertilizer more sustainable. With stakeholders pushing for industrial actors to green their production processes, Plug's technology capably aids producers in decarbonizing the chemical compound into green ammonia.

Plug's electrolyzers use electricity to produce hydrogen from water molecules in a process called electrolysis. The only byproduct in this process is oxygen, compared to traditional steam-methane reformation (SMR), which splits out hydrogen from natural gas and yields significant greenhouse gas emissions.

Contrasting with the SMR ammonia production process, Plug's electrolyzers are not only better for the planet, but also will cut costs in the future as the forecasted commodity price of natural gas continues to rise as those of renewables fall.

The opportunity is a major one for green hydrogen and green ammonia, with 43.5% of all global hydrogen consumption currently taking place in producing ammonia. And as global prices have risen, driven by geopolitical pressures, adoption of green ammonia has also increased.

U.S. Energy Information Administration data from May 2022 show the price of ammonia in the U.S. had risen by a factor of six times in the two years prior due to the international natural gas markets price shock.

These pricing dynamics have exhibited a willingness by buyers to purchase green ammonia as an alternative.

For instance, green ammonia made via electrolysis receives a per ton offer price of more than six times that of conventional ammonia from a CF Industries-owned Louisiana facility. Yara Fertilizers, too, has recently stated global natural gas prices have prompted several plant closures. American farmers have also mulled crop-switching to lower the pricing burden.

In addition to cost-savings, hydrogen generated from Plug's electrolyzer products is pressurized upfront to reduce downstream compression demands. This pressurization alone reduces energy consumption required for green ammonia production by 2-5% while lowering power consumption by roughly a factor of two, further reducing compression costs. This cuts costs and emissions simultaneously.

Overall, using green hydrogen in ammonia production can lower the agricultural sector's CO₂ emissions by nearly 90%, Yale Environment 360 reported in 2022. As a whole, the agriculture sector currently contributes 11% of U.S. greenhouse gas emissions and 18.4% of the global inventory.

Put succinctly, to cut costs and carbon, green ammonia produced from Plug's electrolyzers is the way to go.

From another article (referenced):

Plug Power Inc. manufactured 122MW of Plug's 1MW electrolyzer stack platform in Q1 2023, an all-time high for the Company and the industry for PEM electrolyzers. Additionally, Plug shipped nearly 1,000 stacks for specialty applications, ranging from a few hundred watts to 150kW, totaling 5.7MW. Plug is on track to ramp its 2.5GW gigafactory in Rochester, NY to 100MW per month in mid-Q2 2023, with plans to further increase output in Q3 2023.¹²

6. Material Breakthrough

The following post from a week ago, in section 2, describes a development on how to greatly reduce the consumption of a rare element currently used in electrolyzers.

New Materials for Tomorrows Energy Industry: Many of my posts start with a new material that accelerates an application. This is one of those posts. However, this post started by an Editorial in the May 17 issue of Science pointing out the need for new materials, so that is where we will start.

The decreasing cost of electricity worldwide from wind and solar energy, as well as that of end-use technologies such as electric vehicles, reflect substantial progress made toward replacing fossil fuels with alternative energy sources. But a full transition to clean energy can only be realized if numerous challenges are overcome. Many problems can be addressed through the discovery of new materials that improve the efficiency of energy production and consumption; reduce the need for scarce mineral resources; and support the production of green hydrogen, clean ammonia, and carbon-neutral hydrocarbon fuels. However, research and development of new energy-materials are not as aggressive as they should be to meet the demands of climate change.

<https://energycentral.com/c/ec/new-materials-tomorrows-energy-industry>

¹² <https://www.ir.plugpower.com/press-releases/news-details/2023/Plug-Announces-Record-Production-of-PEM-Electrolyzer-Stacks-in-Q1-2023-On-Track-to-Meet-100MW-per-Month-Target-in-Q2/default.aspx>