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“Power-to-X”

# Decarbonizing Energy with Green Hydrogen: Technology Available and Proven in Production Today

**Decarbonizing the world’s economy is possible today by coupling its different sectors to maximize the use of renewable energy resources. The key enabler is Proton Exchange Membrane (PEM) electrolytic technology for generating “green hydrogen” from water at an industrial scale. The hydrogen can then be used as a zero-emissions fuel or combined with other elements as a molecular component in core industrial feedstocks.**

With a nearly unanimous consensus of the world’s climate scientists, greenhouse gases — carbon dioxide and methane, chief among them — are causing climate changes that threaten Earth’s viability for humans and must be massively reduced as quickly as possible.

The scale of that imperative cannot be met without the fundamental decarbonization of global power generation, industry, buildings, and transportation by shifting from fossil fuels to renewable energy sources. Together, these sectors account for 95 percent of global $CO_2$ emissions, which exceeded 33 billion tons in 2018, according to the International Energy Agency (IEA).[1]

While the deployment of renewable energy sources (especially wind and solar) are rapidly rising, they are proving insufficient in reducing global $CO_2$ emissions. As the IEA sees it, the use of renewables must grow much faster if the world is to realize its long-term climate goals.

*"... the share of renewables in the power mix needs to rise from one-quarter today to two-thirds in 2040. In the provision of heat, renewables need to rise from 10% today to 25%. In transport, renewables need to rise from 3.5% today to 19%, including both direct and indirect use, e.g. renewable electricity for heating and electric vehicles."*[2]

To achieve these goals, the world needs what's called "sector coupling." This enables renewable energy to be transferred to other energy-consuming sectors in the global economy, effectively decarbonizing them, too.

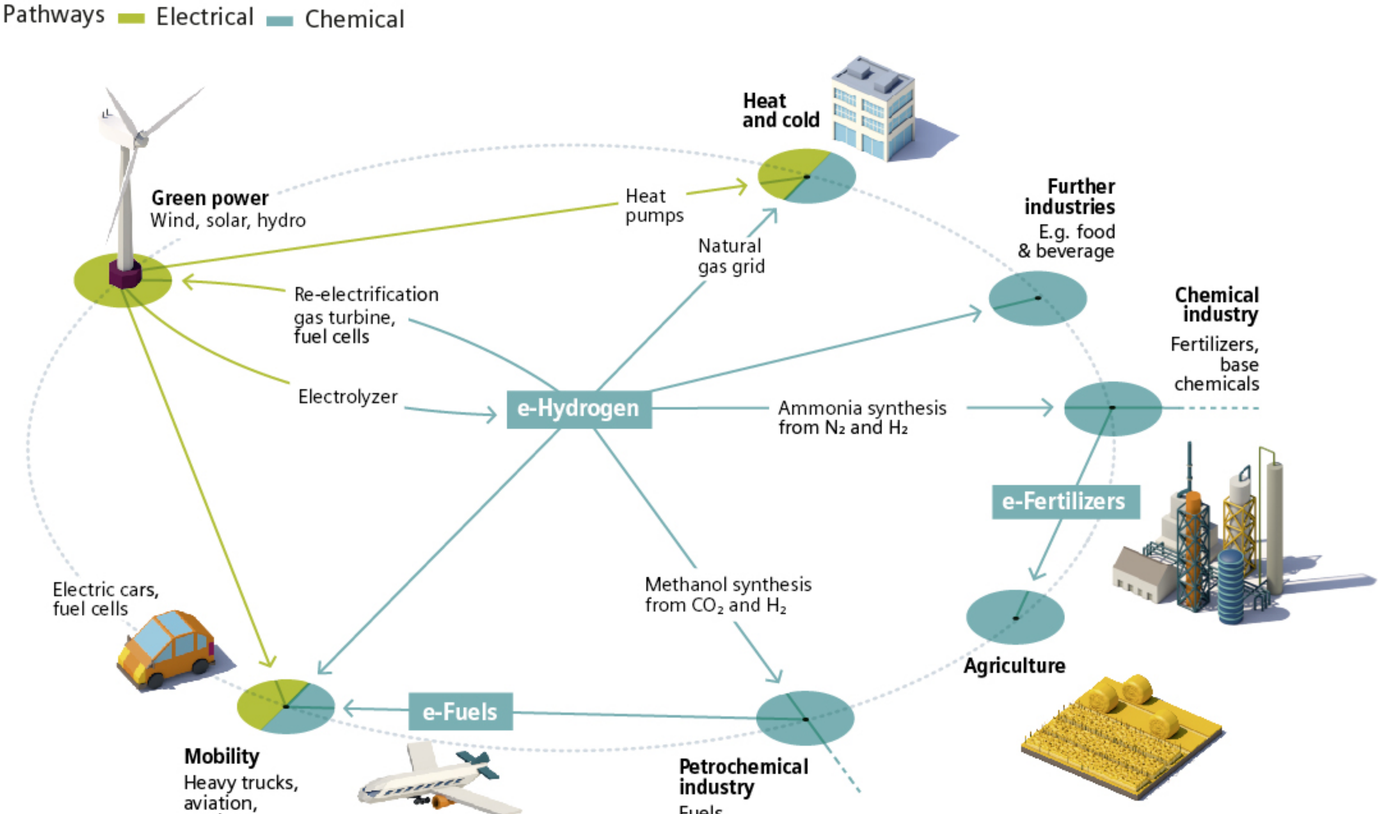
Sector coupling is especially critical to the decarbonization of the world. Renewable energy is making an impact on the power sector; however, the power sector only makes up 40 percent of global $CO_2$ emissions. The remaining 60 percent must also be addressed. One way to accelerate the decarbonization of the other industries is through coupling the use of excess green electricity from renewable energy sources to convert various compounds into industrial feedstocks, as well as to displace fossil fuels in other heavy industries and sectors, known as sector coupling.

### Decarbonization at scale is economically viable and operational today

Different energy storage technologies, such as capacitors, flywheels, and batteries, may offer energy portability — especially important for vehicle, marine, and aviation transportation — but they have their limitations in terms of storage duration, scalability, and, in the case of batteries, weight.

Fortunately, there is an alternative energy storage option that shows much promise because of its high energy density, portability, and storability: *hydrogen*. More specifically, we are referencing "green hydrogen" that is produced using renewable energy sources via advanced electrolysis without carbon emissions.

## Sector Coupling and Power-to-X




Source: Siemens

Hydrogen is the most basic and plentiful element in the universe and powers the sun. By itself or as the basis of synthetic, carbon-based (but neutral) fuels, hydrogen can be integrated into the world's energy-delivery infrastructure much more easily than other energy storage technologies. Although more work is needed in this area, safety concerns can be addressed with enhanced safeguards added to those used to protect people, property, and the environment from the dangers of flammable fossil fuels today.

To generate green hydrogen at the scale needed to decarbonize the world's energy, Siemens and key partners have invested for the past decade in generating hydrogen from water, using Proton Exchange Membrane (PEM) electrolysis technology. Simply put, the PEM process uses low-cost renewable energy sources to split water — $H_2O$ — into its constituent elements without generating carbon emissions.

Traditional methods of producing hydrogen, such as natural gas reforming (also known as steam-methane reforming) and charcoal gasification, use fossil fuels and therefore generate carbon emissions. In fact, steam methane reforming (SMR) methods using natural gas as feedstock can generate 8–10 kg of $CO_2$ for each kilogram of produced hydrogen.

In contrast, the PEM process produces green hydrogen, which can be used as an electrolyzed fuel (i.e., "e-fuel") by itself or, combined with $CO_2$ via methanation, it can produce e-fuels such as methane ($CH_4$) or methanol ($CH_3OH$) for use as an industrial feedstock. Hydrogen can also be combined with nitrogen to form ammonia ($NH_3$) as another important industrial feedstock.

What's more, green hydrogen produced by PEM electrolysis can be converted into electricity again as an admixture with natural gas or in pure form to fuel gas turbines. In 2019, as part of its commitment toward environmental sustainability, Siemens signed a European industry agreement that promised our new gas turbines can be operated with 20 percent hydrogen (mixed with natural gas) by 2020 and 100 percent hydrogen from 2030 onwards.

Parts of these commitments have already been fulfilled, as much of the Siemens gas turbine portfolio can use fuel mixtures with hydrogen levels of 30 percent or higher, and even up to 100 percent in some turbine models.

### "Power-to-X" can fight global climate change with proven, scalable technology

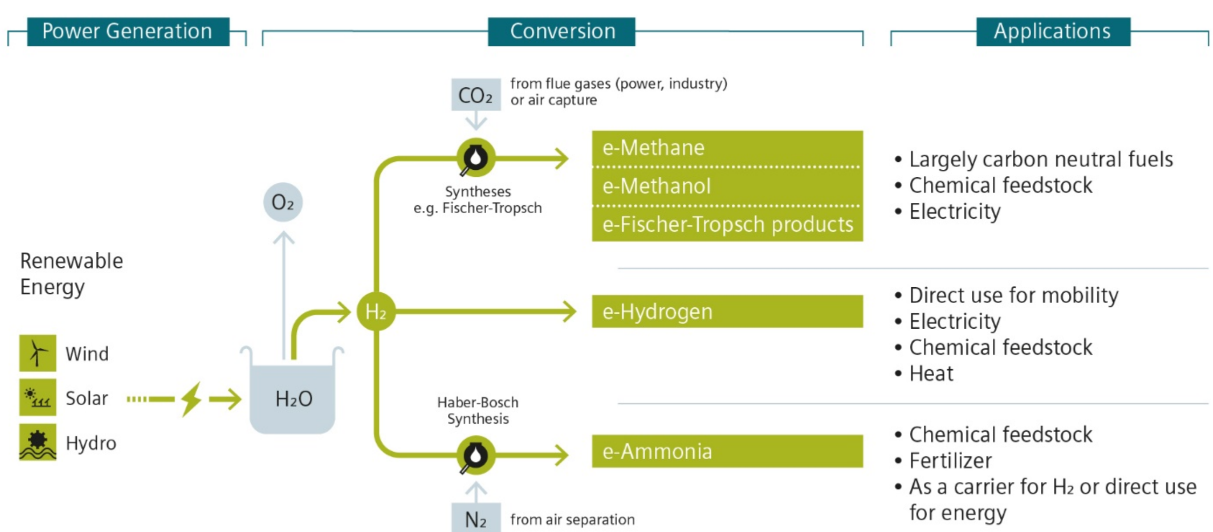
Siemens has long supported a concept related to the PEM electrolysis approach known as "Power-to-X." It's often abbreviated as "PtX," with "X" relating to the fuel-type that's ultimately produced. So, readers may see variations on this naming convention, such as:

- PtG: Power-to-Gas (gaseous e-fuels, including hydrogen itself or admixed with natural gas)
- PtL: Power-to-Liquids (liquid synthetic e-fuels and industrial feedstocks)
- PtC: Power-to-Chemicals (chemicals for industrial use)
- PtH: Power-to-Heat (via resistance heating or heat pumps)
- $PtH_2$: Power-to-Hydrogen (via PEM electrolysis)
- PtP: Power-to-Power (using PtG or PtL outputs to generate electricity)

In fact, as one of the many activities to decarbonize the world's energy production and use, Siemens is active in the "Power-to-X for Applications" Working Group at the Mechanical Engineering Industry Association (VDMA), which has 3,200 member companies and is Europe's largest

## Three pathways of Power-to-X

Electricity based molecular hydrogen, methanol and hydrocarbons as well as ammonia




Source: Siemens

mechanical engineering organization. Our involvement with VDMA is part of Siemens' commitment to social and environmental responsibility.

Green fuels can replace fossil fuels, lowering the carbon emissions from their expended energy by as much as 90 percent (or more, in the case of using clean-burning, green hydrogen, with water as the benign by-product of its oxidation). They can also replace biofuels, such as ethanol, which now consumes considerable farmland to grow its main feedstock, corn. This can resolve the food-versus-fuel debates on the use of increasingly valuable farmland and return acreage to food production or non-crop uses, such as nature preserves, recreation areas, and residential developments.

## PEM electrolysis is proven high-efficiency hydrogen production technology

PEM electrolysis uses a cathode-anode cell that features a solid polymer electrolyte that conducts protons, separates water into hydrogen and oxygen, and protects the cell's electrodes. Developed as a more efficient alternative to traditional alkaline water electrolysis, PEM electrolysis has three main advantages:

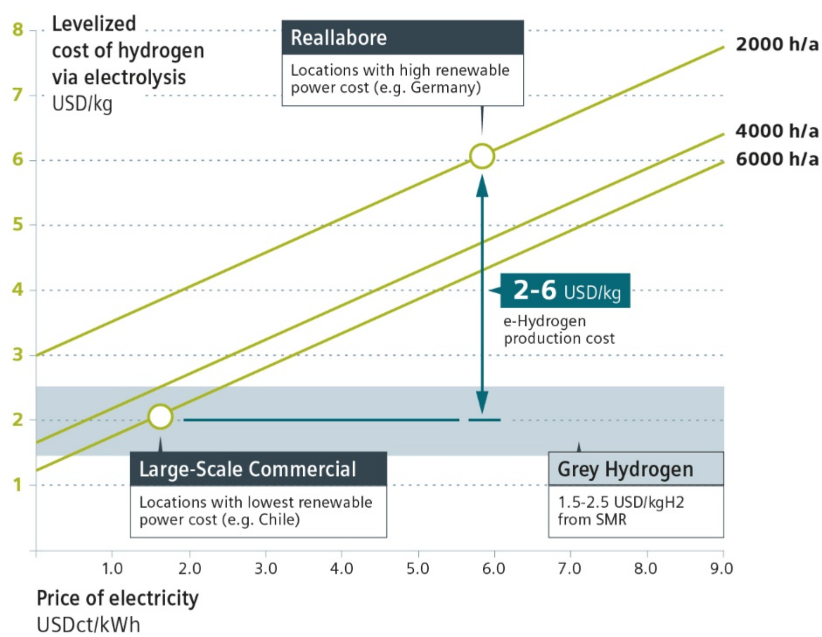
- **Responsive and flexible.** PEM electrolysis can be coupled directly to renewable energy sources. It has black-start capabilities, which means it doesn't need an external power source to restart from a partial or total shutdown. With an extended operating range, PEM technology can ramp up to 10 percent or more in its operating capacity in less than one second. It can operate from 5 – 100 percent of capacity, providing exceptional operating flexibility.
- **Inherently clean in operation.** With only water, green hydrogen, and oxygen in a PEM electrolysis system, the technology requires no aggressive chemical electrolytes, such as the potassium hydroxide (KOH) electrolyte required by alkaline electrolysis systems. In addition, it produces hydrogen that is more than 99.9 percent pure — without any $CO_2$ emissions.
- **Economically competitive.** Compared to the alkaline electrolytic systems, PEM electrolysis has a smaller footprint, and it requires low maintenance, resulting in lower operating expenses and total cost of ownership.

While 95 percent of today's global production of hydrogen is done via SMR and coal gasification methods[3] — with both generating $CO_2$ emissions — PEM electrolysis can produce "green" hydrogen at competitive prices when electricity from renewable sources cost less than $0.04/kWh.

In the past, only geothermal and hydroelectric could deliver such low-cost power, but wind and solar costs have fallen rapidly. In fact, a 2019 report comparing different costs of power generation via renewables shows that onshore wind costs of $0.03-0.04/kWh are now possible with the latest generating technology. And, thanks to advancements in photovoltaic efficiencies, new solar PV projects are lowering the costs of electricity to as little as $0.03/kWh.[4]

## Hydrogen from electrolysis becomes competitive

Highly available, low-cost renewable power already generates green e-hydrogen at costs of conventional hydrogen from steam methane reforming (SMR)




Source: Siemens

Main impact by WACC; electrolyzer_ CAPEX, OPEX, electrolyzer efficiency, lifetime

### Siemens makes PEM electrolysis cost-effective and scalable

In September 2015, Siemens became the first global industrial company to commit towards carbon neutrality by 2030. To this end, Siemens is one of the world's leading companies in developing and commercializing PEM electrolysis as a cost-effective and scalable technology to drive PtX initiatives.

Not coincidentally, in 2015 Siemens deployed the Silyzer 200, a large-scale, commercial version of PEM electrolysis that is one of the world's largest PtG plants in Germany. Today, the company has taken that technology into its third generation with the deployment of the Silyzer 300 at the H2FUTURE project, in partnership with VERBUND Solutions GmbH, voestalpine Stahl GmbH, K1 MET GmbH and the Austrian Power Grid AG.

The Silyzer 300 consists of 24 PEM electrolytic modules that together draw 17.5 MW of power to produce up to 750 pounds (340 kg) an hour of virtually pure hydrogen with no $CO_2$ emissions. The system operates at 75 percent efficiency, which helps cut hydrogen's production cost by 40 percent compared to SMR and coal gasification processes, both heavy $CO_2$ emitters.

The Siemens Silyzer development roadmap targets fourth-generation hydrogen plants that by 2023 can draw more than 100 MW of power for hydrogen production at ever-greater efficiencies. By 2030 and beyond, Siemens envisions building 1,000 MW, fifth-generation plants.

As a leading developer of PEM electrolysis technology, Siemens complements this capability with leadership in the carbon capture and utilization (CCU) technology required for many parts of PtG and PtL processes. For example, Siemens can offer the CCU industry a wide range of electrification, automation, and digitalization products from its vast portfolio, plus global domain expertise and experience, to assist its operators in this regard.

Another key element is the Siemens portfolio of advanced gas turbines, which can effectively recycle the stored hydrogen into electricity by using it as fuel. As mentioned, Siemens is committed to making its gas turbines able to run 100 percent on hydrogen by 2030.

Importantly, Siemens had decades of expertise in the design, engineering, construction, commissioning and lifecycle management of complex power generation and process technology plants. This expertise includes the ability to integrate and bundle most of all the required technologies — especially PEM and CCU — into solutions tailored for a customer's specific project need.

In addition, Siemens technologies can help operators drive continuous improvements in system efficiencies and product costs, especially when using volatile solar and wind energy. Finally, Siemens has both the financial resources and global footprint of direct sales and support to be the world's catalyst for the massive decarbonization needed to successfully fight climate change.

### On the road to an economically and environmentally sustainable future

The idea of the "greenhouse effect" goes back to 1824, when French scientist, Joseph Fourier, hypothesized that the atmosphere traps some of the sunlight's radiant energy much like a greenhouse does. Then in 1896, Swedish chemist, Svante, observed that $CO_2$ was adept at trapping heat radiation and the massive amounts released by burning coal could warm the planet.[5]

So, while climate change concerns may seem relatively recent, they aren't. However, more recently there has been an increase in the urgency of warnings from the climate science community that the world must intensify decarbonization of its energy use in the coming decades to prevent irreparable harm to Earth's climate that could have dire (if not grave) consequences for all living species.

For this reason, Siemens has made strategic priorities out of its involvement in the PtX sector-coupling movement and further development of its Silyzer PEM electrolytic technology for hydrogen production at ever-greater scale.

Although Siemens has considerable technical expertise to help drive both technological and industrial initiatives, the effort to decarbonize the world's energy use will require the commitment and assistance of both the public and private sectors.

The former needs to develop relevant regulatory and tax incentive frameworks to spur greater participation by the latter. Siemens welcomes both to join in the global effort needed to curtail further heating of the planet and contain the consequences for humanity that are already appearing in the form of extreme weather events and mass migrations of people.

The good news is that the world has a consensus on the causes of climate change, and Siemens has solutions to put it on the road to an economically and environmentally sustainable future. Now we need the widespread support of the private sector to reach our needed destination: a *fully decarbonized energy model worldwide*. ■

[1] "Global Energy & $CO_2$ Status Report." The International Energy Agency. https://www.iea.org/geco/

[2] IBID

[3] Louis Brasington. "The Role of Green Hydrogen in Global Decarbonization." Cleantech Group. December 13,2018. https://www.cleantech.com/the-role-of-green-hydrogen-in-global-decarbonization/

[4] Dominic Dudley. "Renewable Energy Costs Take Another Tumble, Making Fossil Fuels Look More Expensive Than Ever." Forbes. May 29, 2019. https://www.forbes.com/sites/dominicdudley/2019/05/29/renewable-energy-costs-tumble/#1dec040be8ce

[5] "Harbingers of doom: a brief history of climate change warnings. " BBC History Magazine. 2005. https://www.historyextra.com/period/modern/climate-change-warnings-history/

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