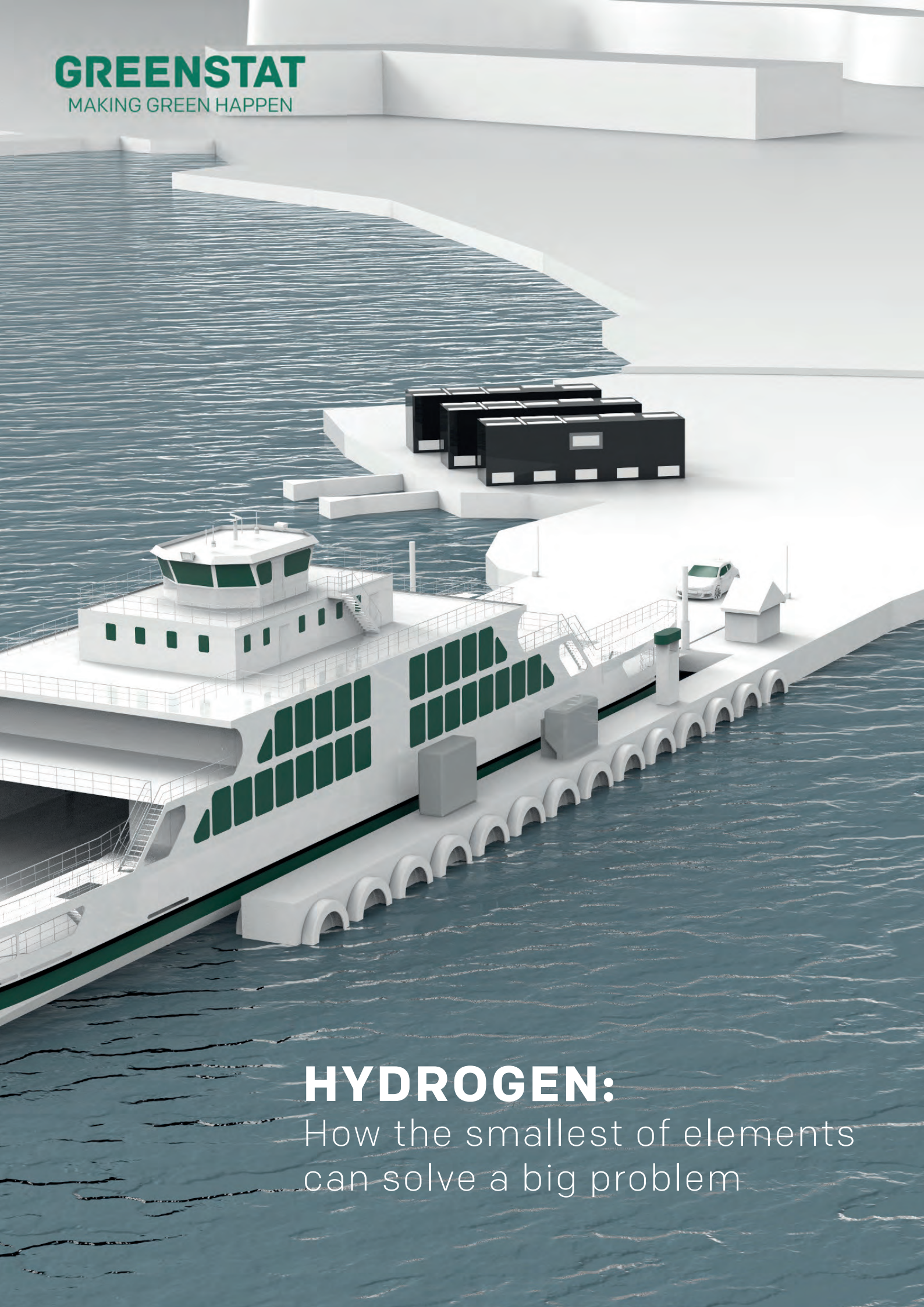
GREENSTAT
MAKING GREEN HAPPEN



HYDROGEN:
How the smallest of elements can solve a big problem

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Vegard Frihammer the visionary leader of Greenstat, turns the spotlight on the fascinating area of hydrogen and reveals how the smallest of elements can solve a big problem

With a planet consisting of 71% water, the advantages of using the sea for transportation of goods and passengers are obvious. You can transport larger volumes or number of people than by land transport or planes, it makes even the most remote port accessible, it connects countries, cities and villages and it can also be quite enjoyable and comfortable.

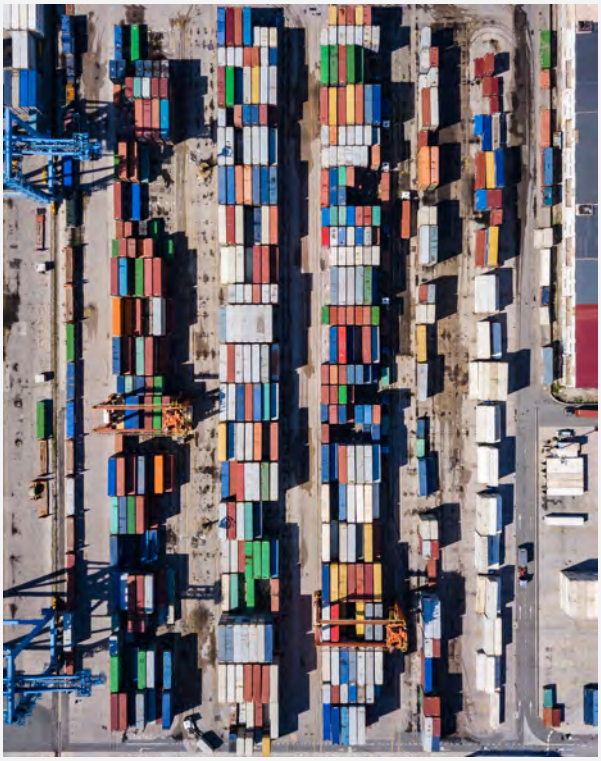


Photo Mauro Licul

But shipping is also a large emitter of greenhouse gases, with just above 2% of global emissions of CO_2-equivalents, according to the United Nations International Maritime Organization (IMO). In order to reach the goals from the Paris Agreement of reducing emissions by 40% in 2030 – compared to 1990-levels, the shipping industry needs to be part of the solution.

And while a structural change has yet to occur, things are already on the move. In March 2018, IMO adopted an initial strategy on the reduction of greenhouse gas emissions from ships. By 2050, the goal is to reduce emissions by 50% compared to 2008-levels and at the same time pursue efforts to eliminate emissions entirely.

The overwhelming majority of emissions from shipping stems from the fuel, whether it is heavy fuel oil, marine diesel oil, marine gas oil or liquified natural gas, albeit with different amounts of emissions.

So, what is the alternative?

Greenstat strongly believes that hydrogen can replace fossil fuels in the maritime industry. While not a fuel, but an energy carrier, it can be utilised together with a fuel cell converting the hydrogen to electricity and a battery, to provide propulsion. Hydrogen can be produced in several ways. By splitting water, using electricity, in a process called electrolysis you get hydrogen and oxygen. If the source of electricity is renewable, for example excess hydropower in areas with a poor electricity

grid or an intermittent energy source like wind power, you have an emission-free product.

It is also possible to achieve close to emission-free hydrogen using natural gas as the input source, which is the main production method today, and combines it with carbon capture and storage to handle the CO_2-emissions. However, the CCS-part of the equation is still at a very early stage, just a handful of production plants capture the CO_2 and even fewer have adequate storage.

Hydrogen has a higher specific energy per unit than fossil-fuels, but a lower energy density per unit. In short, it takes up more space than the current solutions. However, hydrogen can be liquified by reducing its temperature down to minus 253 degrees Celsius, and in the process decrease the volume needed for storage. Still, an important area of development is larger storage tanks, suited for long distances. On the flipside, fuel cells have a higher efficiency than combustion engines, reducing the amount of energy needed.

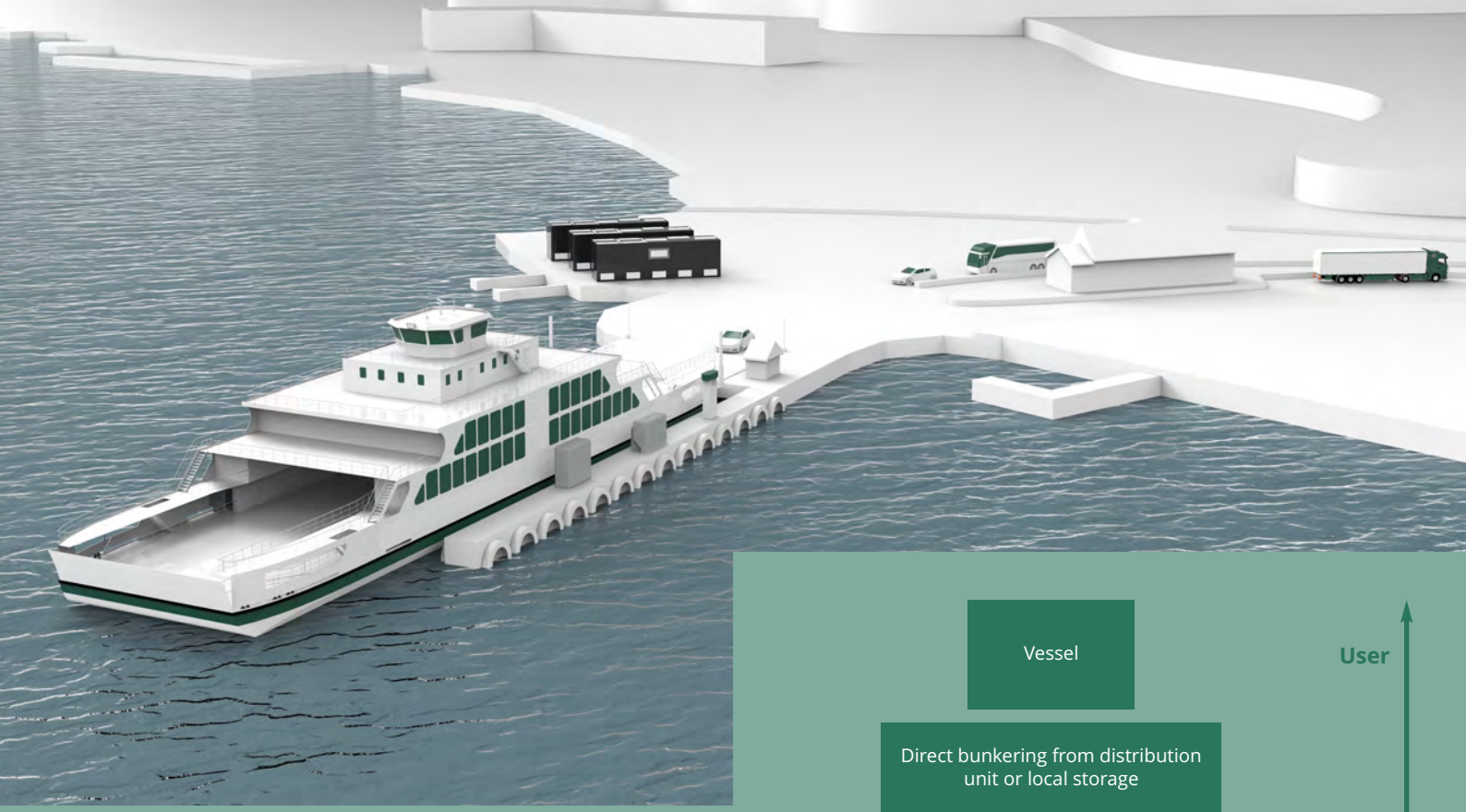
Often compared to the far greater energy efficiency of battery electric systems, it is important not to pit the two solutions up against each other. They serve different purposes, both being equally important solutions to a common problem: fossil-based transportation. For shorter distances battery electric solutions are preferable, but for longer distances or higher speed a fuel cell system, is far lighter than the battery packs needed to cover long distances or express route.

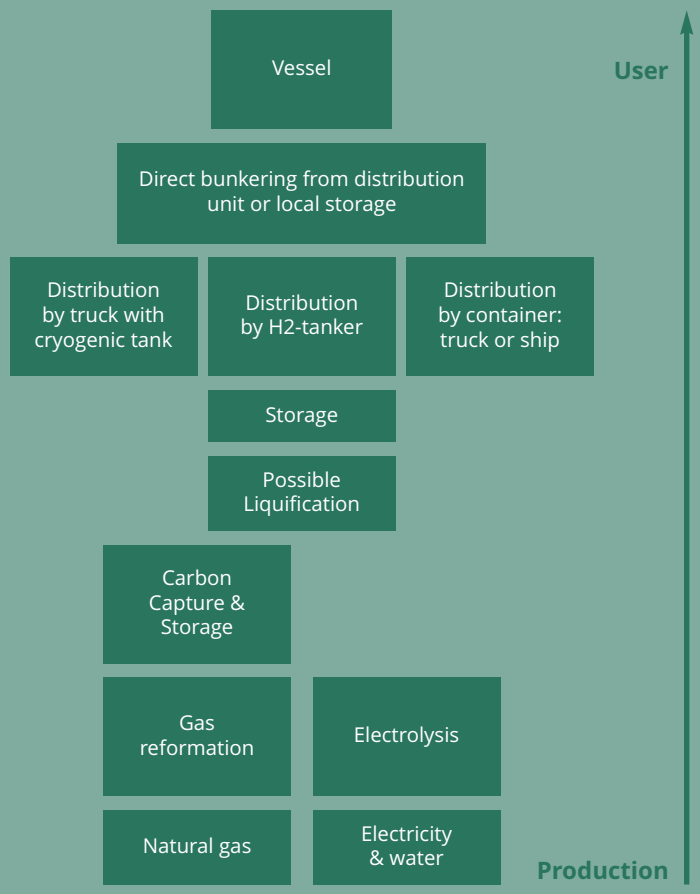
Is hydrogen an important solution?

So, if hydrogen is an important solution, let us examine the present state of the maritime hydrogen value chain from the production phase, through storage and distribution before ending up at the end-user.

In a market-driven economy, it is our belief that ship owners are the most important player. Therefore, the development of hydrogen-powered vessels is the triggering cause.

The production of hydrogen has been done at a large scale for decades for other industries, such as ammonia production and refineries, but we need maritime users of hydrogen to get a complete maritime value chain.





A maritime hydrogen value-chain

When the demand for maritim hydrogen is in place, our belief is that the rest of the value chain, going all the way back to increased production of hydrogen will follow. A lot of the technology is already in use in other industries/applications and can be refitted for maritime use.

The first vessels that are already in or near operation, are smaller vessels for passenger transportation, with a gradual increase in size towards car ferries and large express boats. In the Belgian city of Antwerp, Hydroville is the first certified passenger shuttle that uses hydrogen to power a diesel engine, transporting up to 16 people on the waterways. It contains both hydrogen and diesel as a back-up fuel and can achieve a speed of 27kn. To begin with, the vessel was fuelled from a truck carrying gaseous hydrogen, but key stakeholders are currently building the first maritime bunkering station for hydrogen, giving a clear-cut example of how a vessel also contribute towards developing the entire value chain.

Taking it a step further is the California project Water-Go-Round, which when launched in mid-2019 will be the first commercial fuel cell passenger ferry in the world. Taking up to 84 passengers and the ability to operate for two full days before refuelling, it allows for an emission-free ride around San Francisco Bay.

Similar projects for express boats are also underway in Norway, where the government recently put forward an ambition to reduce emissions for sectors that are non-subject to climate quotas with 45% compared to 2005-levels and cut emissions from inland shipping and fishing in half by 2030.

Several world-leading companies from the Norwegian maritime cluster are currently working towards a hydrogen express boat with over 200 passengers travelling the 95 nautical miles between Trondheim and Kristiansund. Not only are technical aspects close to implementation but within the areas of safety and regulations, there is development taking place. In May 2018, the Norwegian joint venture Hyon received the worlds first approval-in-principle from DNV GL of module-based fuel cell solutions for use in the maritime environment.

For another type of vessel, the car ferry, using public tenders have been an important factor. Already a success formula from the introduction of battery electric ferries, the Norwegian public road administration recently handed out the first contract to the ferry company Norled for a hydrogen-powered car ferry in December of 2018. By then, a consortium of partners in Scotland had already financed a sea ferry a few months earlier, making it a race to become the world's first operating hydrogen-ferry.

For the car ferry in Norway, a solution using liquid hydrogen has been chosen, with the hope of creating a bridge to larger vessels. Supply vessels, cruise ships, and for that matter large bulk ships, travel far greater distances than an express boat or car ferry and need much more fuel.

A supply vessel to the oil and gas industry would need about six tonnes of hydrogen for a standard three-day operation. In gaseous form the hydrogen at 350 bar pressure would need storage of about 250 m^3, compared to only 85 m^3 in liquid form. This becomes even more evident for cruise ships that might need up to 30 tonnes of hydrogen a day if used for propulsion.

With a move towards hydrogen vessels, what is happening in the rest of the supply chain? It seems clear that hydrogen must be transported from the production site to end customers. The Japanese company Kawasaki has for many years now developed a hydrogen carrier, capable of transporting large amounts of liquid hydrogen across continents from 2020 and enabling a global market. More recently, the Norwegian companies Equinor, Wilhelmsen, Moss Maritime and DNV-GL have developed a design for a bunkering vessel for ship-to-ship refueling. For land-based distribution of hydrogen, several container-solutions or cryogenic tanks already exists.

It also seems that the largest producers of hydrogen have an optimistic market outlook. During December 2018 and January 2019, major gas producers made public plans to increase the global production capacity of liquid hydrogen from 300 to 400 tonnes per day. However, a key question remains: the use of emission-free hydrogen. The amount of hydrogen from renewable electricity must increase and the current production facilities must implement carbon capture and storage.

The challenge ahead is, therefore, to increase the tempo even faster and take advantage of economies of scale, both to reduce the price of infrastructure and the production cost of hydrogen itself. The climate puzzle is far from done, but with hydrogen we are holding a key piece that can Make Green Happen!

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