/ NORDIC WEST OFFICE

FINLAND AND THE HYDROGEN ECONOMY

CONTENTS

FOREWORD

Hydrogen is the essence of life. It is the first element in the periodic table, most abundant substance in the universe, and a primary ingredient of water. It holds the promise to help save our planet and give us what we dream of: a car that emits only water; fuels that recycle carbon dioxide; a way to store the energy produced by wind and sunshine.

In short, it can help us move away from fossil fuels, and it can lead us to a completely new hydrogen economy.

Does this sound unrealistic?

For a long time, hydrogen as a clean energy source has been considered a utopia: too difficult to handle, too expensive to use, too far from having actual working technologies, infrastructure, or markets in place.

Yet today, hydrogen is considered an important part of the global energy transition. The EU published its ambitious hydrogen strategy in the summer of 2020. Countries around the world are preparing their own hydrogen strategies and securing their spots in the coming hydrogen ecosystems. Companies are using and developing new technologies to perfect the use of hydrogen in various processes.

Hydrogen economy is no longer considered a pipe dream.

The rapid cost decline of renewable energy, technological developments, and the urgency to drastically reduce greenhouse emissions are opening up new possibilities.

Because of these developments, hydrogen has become the new political dream – a solution to solve all of our problems.

In reality, hydrogen is not a solution that will solve all of our problems. Today, hydrogen represents only a modest fraction of the global and EU energy mix, and growing its share requires extensive investments.

Having said that, hydrogen does offer various opportunities for decarbonising industries, mitigating climate change, and diversifying energy systems and supply chains.

It can help foster new technological and industrial development, create whole new industries and exports, and produce new high-skilled jobs.

Hydrogen is suited for many uses. It is already an essential ingredient in numerous industrial processes, and in the future, fossil-free hydrogen can function as a carrier and storage of renewable energy; a new tool for decarbonising industrial processes; a direct fuel for cars, trucks, ships, trains, and airplanes; and as an ingredient for synthetic fuels that can be used with our current infrastructure.

The challenge of hydrogen is that currently most hydrogen is produced from fossil fuels and producing fossil-free hydrogen requires significant amounts of renewable electricity as well as investments in completely new infrastructure.

Because of this, it is extremely important to consider carefully what the most efficient uses of hydrogen are, and what types of investments should be prioritized.

It is time for Finland, too, to start a serious conversation about what hydrogen could mean for Finland's climate targets, energy system, and industries.

Decarbonisation is the key to mitigating climate change, and the window to act is closing fast. Hydrogen can help, but the time to plan, invest and act is now.

This report is a look at the opportunities and constraints of the new hydrogen ecosystem as seen by the five companies that have come together in this project to discuss Finland's future in the hydrogen ecosystem: Fortum, Gasum, Toyota Auto Finland Oy, UPM Energy, and Wärtsilä.

This report explains the basics of hydrogen, shares a vision of what hydrogen could mean for Finland, proposes next steps, and shows what other countries are already doing.

All of these companies have their own specific points of views, but they all also share common views on how the hydrogen society can become reality in Finland. This report brings together those insights.

The report has been produced by Nordic West Office, a pan-Nordic think tank based in Helsinki, Finland.

The working group for the report included Christian Hoffmann, Director, UPM Energy; Pekka Karvinen, Public Relations Manager, Toyota Auto Finland; Aditya Poudyal, Business Development in Hydrogen, Fortum; Matti Rautkivi, Director of Strategy and Business Development, Wärtsilä; and Mikko Syrjänen, Director, Business Development, Gasum.

The report was published in November, 2020.

EXECUTIVE SUMMARY

HYDROGEN PRIORITIES FOR FINLAND

The companies participating in this report think hydrogen offers several opportunities for Finland.

However, it is necessary to find the right focus as in many applications direct use of electricity or use of hydrogen-derived synthetic fuels make more sense than using pure hydrogen.

This report suggests the following priorities for fossil-free hydrogen:

1. **Hydrogen can help Finland decarbonise its industrial processes. Finland should focus on industrial processes that are currently using fossil fuel-based hydrogen, for example in fertilizer production or oil refineries, and industrial processes that are currently using fossil fuels in the process itself, but where the fossil fuels could be replaced by hydrogen, for example in steel production.**

2. **Hydrogen and hydrogen-derived fuels can help Finland store and transport fossil-free energy, and they can offer a viable alternative in mobility where electric batteries are not suitable because of the amount of energy or range required, and where biofuels need to be complemented. This could mean cars and light commercial vehicles, trucks, heavy equipment, ships, trains, or aviation.**

3. **Finland can become a global producer and exporter of hydrogen or hydrogen-derived synthetic fuels, creating a whole new industry and adding high-skilled jobs to its economy.**

HYDROGEN VISION FOR FINLAND

There is an urgent need for a national vision outlining the role of hydrogen in tackling climate change in Finland as well as in the Finnish energy strategy.

This vision must be connected to choices in the primary energy sources for hydrogen production, and it has to be followed by regulation that supports the desired role of hydrogen holistically. Different incentives and regulations must be aligned.

The Finnish government should bring together all the relevant players in the value chain to create this vision for hydrogen's role in Finland and follow this work with the policy choices needed to make this vision reality. This government-led work should consider questions such as:

- **Which uses of hydrogen make the most sense for Finland** taking into account that in many cases using electricity directly is more efficient; that the government is already supporting the electrification of many industrial processes; and that reducing emissions with the help of hydrogen would require us to have excess green electricity available. A system-level view is needed.

- **Which challenges do we want to solve with hydrogen in Finland – and which not?** If we really want hydrogen to play a role, first we need to decarbonise the current power production, and then we need to build new capacity to produce the electricity needed for hydrogen production.

- **What are the best first-use cases for Finland?** For now, the amounts of renewable energy available are limited, as are the amounts of fossil-free hydrogen that can be produced. Finland needs to determine priorities for applications.

- **How does Finland position itself in the global hydrogen economy?**

NEXT STEPS FOR FINLAND

Once Finland's goals for hydrogen are mapped out and the relevant regulation is drafted and enacted, companies can start investing in new opportunities in hydrogen. However, neither Finland nor Finnish companies can wait. The work on all fronts must start now.

The Finnish government should consider creating incentives to get the hydrogen marketplace started, including:

- **Blending requirement for synthetic fuels.** Currently, petrol and diesel distributors are required to blend in up to 20% of biofuel. A similar requirement for synthetic fuels would create demand that would encourage companies to invest in synthetic fuel production.

- **Supporting the building of industrial-scale production plants** for clean hydrogen as well as for synthetic fuel production.

- **Supporting large-scale multi-company projects** aimed at decarbonising industrial operations, creating new products, and expanding Finnish industries' understanding of hydrogen-related technologies, such as electrolysers and carbon capture technologies.

Hydrogen can offer Finland new opportunities for reaching its climate goals, creating new industries and exports, and diversifying its energy supply chains. But it can do this only if Finland makes educated, considered choices about hydrogen's role in its energy system as a whole.

This report is an effort to contribute to the discussion of hydrogen's role in Finland, as well as a call for the Finnish government, scientists, companies, and citizens to join in planning and executing a hydrogen strategy for Finland in the wider context of Finland's future energy strategy that will lead Finland towards a sustainable, successful, profitable, zero-emissions future.

CHAPTER 1:

WHY HYDROGEN NOW?

Hydrogen is everywhere, literally. Yet for most people, the word hydrogen brings only vague memories from the high school chemistry classes.

The reason why hydrogen as a concept and an element can be hard for non-experts to understand is simple: hydrogen rarely appears on Earth on its own. Instead, it forms compounds with other elements. We do not see, touch, or smell hydrogen in our daily lives. Yet it is there, present, every single day for all of us.

The most familiar hydrogen substance to us all is water – a compound of hydrogen and oxygen (H_2O). Products like hydrogen peroxide – a bleaching agent – or a hydrogen car carry hydrogen in their names, making the connection clearer.

But the most discussed hydrogen compounds of the moment are the ones that many do not connect with hydrogen at all: fossil fuels. Oil, coal, and natural gas are all mostly hydrocarbons, compounds of hydrogen and carbon.

Whether we know it or not, hydrogen has been present and used in human history for ***hundreds of years***. Hydrogen provided lift to balloons and airships in the 18th and 19th centuries, and propelled humanity to the moon in the 1960s. Hydrogen in ammonia fertiliser has helped feed a growing global population. And hydrogen has been an integral part of the energy industry since the mid-20th century, when its use became commonplace in oil refining.

When separated from other elements and in standard temperature, hydrogen is a colorless, odorless, tasteless, and non-toxic gas. It can be pressurized to fit in smaller spaces or cooled down to make it liquid.

Technologies already available today enable hydrogen to produce, store, move and use energy in different ways. Hydrogen ***can be produced*** carbon-free with the help of renewable, biobased, or nuclear energy, and it can be transported as a gas by pipelines or in liquid form by ships, much like liquefied natural gas (LNG). It can be transformed into electricity and methane to power homes and feed industry, and into fuels for cars, trucks, ships and planes.

While challenges remain, hydrogen can offer opportunities to governments that import or export energy, as well as renewable electricity suppliers, industrial gas producers, electricity and gas utilities, automakers, oil and gas companies, major engineering firms, and cities, to mention but a few.

Investments in hydrogen can help foster new technological and industrial development and create skilled jobs.

How can hydrogen do all this for us?

CHAPTER 2:

DIFFERENT USES OF HYDROGEN

Hydrogen is already used in various industrial processes every day. Today, ***about half of the hydrogen*** produced around the world is used to produce ammonia fertilizer (a compound of hydrogen and nitrogen.) About a quarter is used in the world's oil refineries to process crude oil into refined fuels. About a tenth is used to produce methanol, which is used to produce other chemicals and products such as plastics or synthetic fuels.

Other industrial applications of hydrogen include metalworking (primarily in metal alloying); the electronics industry (used as a protective and carrier gas, for cleaning and in etching); and applications in electricity generation, for example for cooling generators.

Yet the reason why hydrogen is at the forefront of our current efforts is related to completely new ways of using hydrogen – ways that can help us mitigate our climate crisis.

The promise of hydrogen is helping us tackle areas where carbon emissions are high, but electricity is difficult to use directly. These ***hard-to-abate emissions*** sources include aviation, shipping, iron and steel production, chemicals manufacture, high-temperature industrial heat, long-distance and long-haul road transport and, especially in dense urban environments or off-grid, heat for buildings.

Hydrogen can also be used to store the energy produced by wind and solar power.

About half of the hydrogen produced around the world today is used to produce ammonia fertilizer. About a quarter is used in the world's oil refineries. The promise is in completely new applications.

1. HYDROGEN AS CARRIER OF ENERGY

Hydrogen can be used as a carrier of energy produced by renewable power sources such as wind and sun.

The problem with these power sources is intermittency – wind dies down, and sun doesn't shine. Yet we need our electricity every day. At other times, these sources can produce more electricity than we need at that given moment. Thus, we need a way to store the excess energy for later use, and electricity is hard to store as such.

Hydrogen can help solve this issue.

One way to produce hydrogen is by separating water into its two primary elements—hydrogen (H_2) and oxygen (O_2). This can be done with the help of an electrolyser, which will pass an electrical current through water and extract the hydrogen.

One way to store renewable energy would be to attach an electrolyser to a renewable energy source and use excess energy to produce hydrogen. This hydrogen could then be stored or transported elsewhere for later use, or it could be processed further into a fuel, for example for cars or for heating.

When pure hydrogen is fed into a fuel cell – for example in a car or a power plant –, it reacts with oxygen and produces electricity and water.

Because of this, it is possible to create a full circle of renewable energy: renewable energy is used to extract hydrogen from water, the hydrogen is transported elsewhere, and a hydrogen fuel cell will reverse the reaction and produce once again electricity and water. Some ***energy is lost*** in the process, but the technologies are becoming more efficient by the day.

This is the idea behind the so-called Power-to-X-technologies. The somewhat difficult term refers to ways to take renewable energy – power – and convert it to some other form – X –that can be stored, transported, and used later. In hydrogen economy, the X is hydrogen.

Hydrogen is now one of the ***leading options*** for storing energy from renewables and could help in storing electricity over days, weeks or even months. Hydrogen and hydrogen-based fuels could potentially transport energy from renewables over long distances – from regions with abundant solar and wind resources to energy-hungry cities thousands of kilometres away.

2. HYDROGEN AS A DIRECT FUEL FOR MOBILITY

Cars can run on various sources of energy: fossil fuels – gasoline, diesel, and natural gas –, on biofuels or biogas, on electricity, on synthetic fuels, or on pure hydrogen. The gas-based fuels can be used either in gas or liquid form.

The best method depends on complex calculations involving access to raw materials and electricity, infrastructure needed, emissions created, and cost-effectiveness of the enterprise.

Hydrogen gas has long been heralded as a potential transport fuel. It is seen as offering a carbon-free alternative to oil and natural gas and complementing other alternatives like electricity and advanced biofuels.

Hydrogen electric vehicles feed pure hydrogen into a fuel cell to produce electricity that runs the vehicle and emit only water.

Hydrogen has some advantages over electric batteries as a power source for cars and especially for heavy transport such as trucks.

Unlike electric vehicles, a hydrogen car could be refuelled quickly just like our current cars. For heavy transport, the electric battery required would need to be extremely heavy whereas hydrogen fuel cell is relatively small and light. Hydrogen fuel tanks, on the other hand, need special technology and take up space.

Hydrogen could also offer innovative solutions for ***trains*** running in remote areas or for ***aviation***.

In the end, the ***competitiveness*** of hydrogen-powered transport depends on fuel cell costs and on the building and utilisation of refuelling stations. For cars the priority is to bring down the cost of fuel cells and on-board hydrogen storage. This could make them competitive with battery electric vehicles at driving ranges of 400–500 kilometres and make them potentially attractive for consumers that prioritise range.

For trucks the priority is to reduce the delivered price of hydrogen. In early stages of deployment, building hydrogen stations that serve captive fleets could help to secure high refuelling station utilisation and thus could be a way to get infrastructure construction off the ground.

In terms of current uses of hydrogen in mobility, hydrogen cars and refuelling stations are already available for consumers in limited numbers in several countries, for example in the United States and Japan.

Fuel cell electric forklifts are already ***commercially viable*** as replacements for existing battery electric forklifts. An estimated 25 000 forklifts have fuel cells globally.

Several European countries are experimenting with hydrogen-powered buses, taxis, or ferries.

3. HYDROGEN FOR SYNTHETIC FUELS OR CHEMICALS

Hydrogen can be used in its pure form. It can also be ***combined with*** other inputs to produce what are referred to as hydrogen-based fuels and chemicals.

Hydrogen-based fuels and chemicals can be used in applications such as engines, gas turbines, and chemical processes. They include such products as synthetic methane, synthetic liquid fuels, and methanol, all of which require carbon alongside hydrogen. They also include ammonia, which can be used as a chemical feedstock or potentially as a fuel, and which is made by combining hydrogen with nitrogen.

One vision for creating a carbon-neutral energy source is this: take fossil-free energy, connect it to an electrolyser, add water, and produce hydrogen. Then take that hydrogen and combine it with carbon dioxide and create a new synthetic fuel – a synthetic hydrocarbon, similar to fossil fuels.

Using this synthetic fuel would release carbon into the atmosphere just like fossil fuels, but it would be recycled carbon.

The advantage of such synthetic fuels is that they could have very high density of energy (depending on the amount of carbon in them) and could thus be used for heavy transport such as trucks, ships, and airplanes.

They could also be used mostly with our current infrastructure, including current cars, pipelines, gas stations, boilers, and storage facilities. Because of this, they are more likely to be adopted as an alternative fuel in the near-term than pure hydrogen.

At the moment the challenges for using such fuels are related to their price and developing technologies for carbon capture further.

4. HYDROGEN IN DECARBONISATION OF MANUFACTURING PROCESSES

Process industry needs innovation to decarbonise. Hydrogen can be a catalyst for such innovation in many ways.

An immediate application in industry is to reduce and replace the use of carbon-intensive hydrogen in refineries, the production of ammonia, and for new forms of methanol production.

Another way to decarbonise would be to capture the CO_2 emissions of a production facility and combine the CO_2 captured with hydrogen, creating a synthetic fuel. The factory could curb its emissions and create a whole new product in the process.

Hydrogen could also help factories cut the use of fossil fuels in the production process itself, as is turning out to be the case for steel industry.

The steel industry is one of the highest CO_2-emitting industries, accounting for 7% of CO_2 emissions globally.

In Sweden steelmaking accounts for 10%, and in Finland for 7% of carbon dioxide emissions. Should the steel industry succeed in decarbonising its operations, the impact on our carbon emissions would be significant.

Sweden's most famous hydrogen project at the moment is Hybrit, a joint effort by the steel manufacturer SSAB, energy company Vattenfall, and the iron ore producer LKAB to create a fossil-free method for producing steel by replacing coking coal in the steel-making process with fossil-free energy and hydrogen.

The pilot plant in Luleå has ***started operations*** this fall. Between 2030–2040, the plan is to convert all the blast furnaces in Luleå and Raahe to use hydrogen instead of coking coal.

The joint venture is also ***building an electrolyser*** to produce the hydrogen needed on-site at the pilot plant in Luleå.

In the case of Hybrit, the investment needed comes from both private and public funds. SSAB, LKAB and Vattenfall have decided on ***investments*** totalling around 165 million euros in the Hybrit project, and the Swedish Energy Agency has granted government support totalling about 60 million euros.

This part is often the challenge: who is going to pay for all the investments needed for such innovation.

Another challenge relates to global trade. Will carbon-neutral steel be competitive in the global market, if other companies are still able to sell and import high-emissions steel without carbon taxes or other methods to incentivise the use of an emissions-free product?

5. HYDROGEN IN DECARBONISATION OF GAS HEATING

Heating and cooling of homes, businesses and public buildings constitutes ***around half*** of the EU's final energy consumption and is the biggest energy end-use sector, ahead of transport and electricity. The ***majority*** of heating appliances currently used in Europe are gas-fuelled, with a market share of just over 45%.

In Finland, the role of natural gas in heating is non-existent. However, the European efforts to decarbonise gas-based heating can offer Finnish industries new opportunities for exports in the energy or technology sectors.

The promise of hydrogen in decarbonising gas-based heating in Europe lies in the possibility of blending fossil-free hydrogen into existing natural gas networks in order to replace some of the natural gas currently used in heating while longer-term prospects could include the direct use of hydrogen in hydrogen boilers or fuel cells.

The difficulty in this approach is refitting or rebuilding the current gas pipelines to be able to handle hydrogen, which has somewhat different chemical properties than natural gas and can cause corrosion in current metal pipes. At the customers' end, the boilers need to be adapted or switched to be able to handle hydrogen in addition to or in place of natural gas.

CHAPTER 3:

CHALLENGES TO SOLVE

1. PRODUCING HYDROGEN

The world currently produces and consumes around 70 million tonnes of pure hydrogen per year, and the demand is set to rise. The question becomes: how is all this hydrogen going to be produced?

Hydrogen can be extracted from fossil fuels, and natural gas is currently the primary source for it, accounting for around ***three quarters*** of the annual global hydrogen production. Gas is followed by coal – due to China's coal-based hydrogen production –, and a small fraction is produced from the use of oil, or from water with electrolysis and a low-carbon energy source.

Hydrogen produced from natural gas is not carbon free, as it derives from a fossil fuel and as the separation of hydrogen from natural gas releases carbon dioxide.

The problem then becomes obvious – producing hydrogen from fossil fuels does not help in curbing carbon emissions (unless the carbon released in the process is captured and stored, as the Norwegians are planning to do.) In fact, production of hydrogen today for already existing needs is responsible for annual CO_2 emissions equivalent to those of Indonesia and the United Kingdom combined.

The goal, then, should be to increase the production of carbon-free hydrogen to replace the current fossil-based hydrogen as well as to meet the growing demand.

The way to do this is to increase the production of hydrogen produced from water with fossil-free energy sources as well as develop carbon capture and storage technologies for the current production of hydrogen.

However, increasing the production of carbon-free hydrogen demands serious investments in new technologies as well as new production facilities.

While electrolysers are already in operation, their production capacity is currently relatively low. They can range in size from small, appliance-size equipment to large-scale, central production facilities but at present, electrolysers are no larger than 10–100 megawatts.

Within the EU, the currently operating ***300 electrolysers*** produce less than 4% of total hydrogen production, and the total European production capacity for electrolysers is below 1 GW per year.

Much bigger electrolysers or facilities are needed.

A hydrogen factory with a capacity of a gigawatt would operate a hundred to a thousand of the current-size electrolysers. The partners in the Dutch ***Gigawatt Electrolyser*** project will jointly investigate what it takes to build such an electrolysis plant in the Netherlands around 2025–2030. They estimate that one gigawatt water electrolysis facility would produce annually about 90,000 tonnes of hydrogen.

To put this into perspective, the present hydrogen consumption in the Dutch chemical industry amounts to approximately 1.5 million tonnes per year. To produce all this hydrogen via electrolysis, Holland alone would need 16 of such one-gigawatt electrolyser facilities – which do not exist yet anywhere in the world.

With the current state of technology and current market prices, the investment for a one-gigawatt electrolysis plant would amount to about one billion euros. The partners in the Gigawatt Electrolyser project aim for a design that would reduce this amount three- or fourfold, bringing the cost back to around 350 million euros for a one-gigawatt electrolysis plant.

The new EU Hydrogen Strategy is calling for upscaling to larger size, more efficient and cost-effective electrolysers in the range of gigawatts that, together with mass manufacturing capabilities and new materials, supply hydrogen to large consumers.

In the future, it might also be possible to produce so-called biohydrogen with the help of algae using the energy from the sun.

Hydrogen colour theory

- **Grey hydrogen** is obtained from fossil fuels.
- **Blue hydrogen** is grey hydrogen, but the CO_2 produced from it is captured and stored.
- **Green hydrogen** is produced by electrolysis from water using renewable energy.
- **Clean hydrogen** refers to hydrogen produced from water using either renewable or nuclear energy, making it carbon-free.

2. PRODUCING ELECTRICITY

The world is moving towards an electrified society. Anything that can be run on electricity, will be.

The aim is to produce all that electricity emissions-free, or at least to be able to capture the carbon dioxide released from the use of low-carbon energy sources, such as natural gas, until new solutions can be found and implemented. The main energy sources of the future will be wind, solar, hydro, geothermal, and in all likelihood, nuclear power.

Hydrogen will play a role in this energy transformation as it can function as a carrier and storage for renewable energy. At the same time, it adds to the need for electricity as the hydrogen currently produced from fossil fuels needs to be replaced by hydrogen produced with clean energy, and as the demand for hydrogen is growing.

According to the International Energy Agency, producing all of today's global dedicated ***hydrogen output*** with electricity and water would result in an electricity demand of 3 600 terawatt hours (TWh), more than the total annual electricity generation of the European Union.

The European Commission also notes that renewable electricity production needs to massively increase as about a quarter of renewable electricity might be used for renewable hydrogen production by 2050.

Depending on what kinds of hydrogen strategies countries and regions will follow, we might be looking at about doubling the total electricity production in Europe from the current level. And all this energy production needs to be fossil-free.

This is the reason some countries such as Germany and the Netherlands are already drawing up plans for importing hydrogen from outside the EU – they do not seem to believe that it will be possible to produce enough renewable energy within the EU to produce all the hydrogen Europe will need.

3. BUILDING NEW INFRASTRUCTURE

As a light gas of small molecules, hydrogen requires special equipment and procedures to handle it. Hydrogen is so small it can diffuse into some materials, including some types of iron and steel pipes, and increase their chance of failure. It also escapes more easily through sealings and connectors than larger molecules, such as natural gas.

Hydrogen may be transported via pipelines or trucks or ships for example docking at adapted LNG terminals. Transport can happen as pure gaseous or liquid hydrogen, or as hydrogen-based fuels or chemicals such as methane or ammonia. Hydrogen can also be stored in for example salt caverns.

However, as hydrogen is a light gas with low energy density, it is more challenging to store and transport than fossil fuels or hydrogen-derived fuels such as methane or ammonia. Turning the gas into liquid requires extremely low temperatures – close to absolute zero. Packing the gas into smaller spaces by pressurizing it requires using more electricity and creating new high-pressure containers for trucks, trains or ships.

Hydrogen can be blended with natural gas and injected into the current gas grid, but as it tends to embrittle current metal pipes, the percentage of hydrogen in the current pipes can't be very high. In reality, either conversion of the current pipes or completely new pipes will be needed.

This is why infrastructure such as pipeline and delivery networks are of particular importance. While hydrogen can be produced locally close to where it is consumed, its storage and distribution benefit from economies of scale and technological developments.

In the case of hydrogen use for road transport, the need for a network of refuelling stations is obvious. The current slow pace of infrastructure development and spread of hydrogen refuelling stations is a brake on adoption.

However, if hydrogen is converted into hydrogen-based fuels and feedstocks, such as synthetic liquid fuels and ammonia, it is possible to make use of existing infrastructures. This can reduce the costs of reaching the final user.

From the perspective of final users, new technology can also be required for example in the form of hydrogen fuel cells that burn hydrogen and produce electricity, hydrogen boilers for heating, or new types of engines or gas turbines.

Currently, the development of hydrogen infrastructure is slow and holding back widespread adoption. Tackling this is likely to require planning, coordination and investment that brings together national and local governments, industry and investors.

4. SAFETY OF HYDROGEN

Hydrogen is a non-toxic gas, but it is highly flammable. It has a flame that is not visible to the naked eye and it is colourless and odourless, making it harder for people to detect fires and leaks. It can also be self-igniting.

However, hydrogen has already been used for decades industrially, including in large dedicated distribution pipelines. ***Protocols*** for safe handling at these sites are already in place, and they also exist for hydrogen refuelling infrastructure in site-specific forms.

The challenge is that safety protocols can remain complex and unfamiliar compared to those for other energy forms. Widespread use in the energy system would bring new challenges. They would need further development and any public concerns would need to be alleviated.

Hydrogen is a non-toxic gas, but it is highly flammable. It has a flame that is not visible to the naked eye and it is colourless and odourless. Safety protocols exist but need development.

CHAPTER 4:

THE PRICE OF HYDROGEN

When it comes to the current price of hydrogen, the European Commission ***notes*** that today, neither renewable hydrogen nor low-carbon hydrogen, meaning fossil-based hydrogen with carbon capture, are cost-competitive against hydrogen produced from natural gas.

It should be noted that this is no different from most technologies for decarbonisation – new technologies involve considerable development costs and do not yet have the benefits of scale. Many are projected to become competitive in the near-future, and any cost-benefits calculations should always consider the emissions produced.

According to the European Commission, estimated costs today for fossil-based hydrogen are around 1.5 €/kg for the EU, highly dependent on natural gas prices, and disregarding the cost of CO_2. Estimated costs today for fossil-based hydrogen with carbon capture and storage are around 2 €/kg. Estimated costs today for renewable hydrogen are 2.5–5.5 €/kg with the price of renewable electricity driving the cost.

Yet the relative costs of producing hydrogen from different sources in different regions, and how they will compete in the future, are unclear.

However, costs for renewable hydrogen can go down quickly.

International Energy Agency ***analysis*** finds that the cost of producing hydrogen from renewable electricity could fall 30% by 2030 as a result of declining costs of renewables and the scaling up of hydrogen production. Fuel cells, refuelling equipment, and electrolysers can all benefit from mass manufacturing.

Based on the assessment of international energy organizations, electrolyser costs have already been reduced by 60% in the last ten years and are expected to halve in 2030 compared to today with economies of scale. In regions where renewable electricity is cheap, electrolysers are expected to be able to compete with fossil-based hydrogen in 2030.

In principle, hydrogen has to be able to compete on price with other ways of decarbonising in order to make hydrogen-based solutions viable for business.

When comparing the costs of hydrogen to fossil-based solutions, the price of continued emissions for climate also needs to be considered. If the overall goal is to cut emissions and hydrogen can help do so, it might be the right choice even if is more expensive than emission-producing alternatives.

On the other hand, were the price of CO_2 to rise in the global cap and trade programs, alternative options like clean hydrogen will become more competitive.

CHAPTER 5:

THE MOST EFFICIENT USE OF HYDROGEN

All energy sources and carriers, including fossil fuels, encounter efficiency losses each time they are produced, converted, or used. In the case of hydrogen, these losses can accumulate across different steps in the value chain.

After converting electricity to hydrogen, shipping it, and storing it, and then converting it back to electricity in a fuel cell, the delivered energy can be ***below 30%*** of what was in the initial electricity input. This makes hydrogen more "expensive" than using direct electricity. It also makes the case for minimising the number of conversions between energy carriers in any value chain.

While hydrogen can be used for multiple purposes, it is important to consider what type of uses create the most efficient energy system as a whole when taking into account emissions as well.

As a rule of thumb, renewable electricity should be used directly whenever possible whether in transport, heating, or industrial processes.

Clean hydrogen should be first used wherever it is needed directly as hydrogen.

The role of hydrogen should be determined based on where using it is the most effective choice from the point of view of:

- Emissions reduction
- Energy efficiency
- Costs
- Energy self-sufficiency and security of supply

Some suggestions for where clean hydrogen produced by electrolysis from water should be used first:

1. **In industrial processes that are currently using fossil fuel-based hydrogen**, for example in fertilizer production or oil refineries.
2. **In industrial processes that are currently using fossil fuels in the process itself**, but where the fossil fuels could be replaced by hydrogen, for example in steel production.
3. **In mobility where electric batteries are not suitable** because of the amount of energy or range required, and biofuels need to be complemented. This could mean cars, trucks, heavy equipment, ships, trains, or aviation. Hydrogen could be used either in pure form or as a hydrogen-derived synthetic fuel.
4. **In heating where hydrogen or hydrogen-derived synthetic fuel** can potentially be blended with natural gas, and thus contribute to decarbonising of heating, or where current gas infrastructure can be repurposed for hydrogen at a reasonable cost and where other solutions such as heat pumps, electric boilers or thermal batteries are not sufficient. In Finland, this could mean district heating but mostly this would apply in countries with gas-based heating.

At the same time, it is possible that hydrogen will take off first in industries and services that are directly serving customers willing to pay a premium for environmentally friendly options. This could include flights, cruises, and cars using pure hydrogen or hydrogen-based synthetic fuels.

CHAPTER 6:

HYDROGEN FOR FINLAND

What does hydrogen mean for Finland?

What does it mean for Finnish industries and companies, for Finland's energy system, and for Finland's efforts to reach the current government's ***goal*** for Finland to be carbon-neutral in 2035 and carbon-negative soon after that?

Considering the extensive discussions on hydrogen's role in the future energy systems and manufacturing processes in the European Union as well as the ambitious hydrogen strategies of many countries, the discussion in Finland has so far been muted.

As of yet, Finland does not have a national hydrogen strategy. However, the current government is considering the role of hydrogen for Finland in its new climate and energy strategy, to be published in the summer of 2021.

As the hydrogen ecosystem is wide and varied, each country, industry, and company will have to think carefully about its own strengths, goals, and needs to figure out where it can be the most competitive. At the same time, all actors need to consider what kinds of joint efforts across industries, sectors, and borders are needed for the hydrogen ecosystem as a whole to get started.

The companies participating in this report see several advantages and opportunities for Finland to cut emissions, create new industries, produce new exports, and create new high-skilled jobs.

1. HYDROGEN FOR DECARBONISING INDUSTRIAL PROCESSES

Finnish economy relies on heavy process industries such as forestry, steel, chemicals, mining and manufacturing heavy equipment.

Many of these industries, including oil and biorefineries, use hydrogen in their industrial processes. Being able to replace the current fossil-fuel based hydrogen with clean hydrogen would help Finland as a country as well as individual companies and industries reduce their reliance on fossil fuels as well as cut carbon emissions.

In addition, clean hydrogen can help these industries recycle their carbon emissions by offering possibilities for using the carbon produced and captured to combine it with hydrogen in order to create synthetic fuels.

2. HYDROGEN AS STORAGE FOR RENEWABLE ENERGY

Currently, ***80% of Finland's electricity production*** is free from carbon emissions.

In addition, Finland has the resources needed to grow its capacity for generating wind as well as solar power. Finland relies currently also on renewable imports from its Nordic neighbors, mainly Norway and Sweden. In addition, Finland can rely on its nuclear power plants to produce fossil-free electricity. Currently, Finland plans to expand both its wind power generation as well as inaugurate its ***Olkiluoto 3*** nuclear power plant by the end of 2021.

However, due to cold winters, large swaths of energy-intensive industry and ambitious climate strategy, Finland's energy system faces serious challenges.

Finland already relies on imports to satisfy its electricity needs, particularly on cold winter days. It is not feasible to rely on imports alone for the increasing electricity needs that decarbonisation requires – Finland needs to produce more fossil-free energy itself.

Hydrogen or hydrogen-derived synthetic fuels can support the building of more wind power as well as provide energy storage for cold days with little wind.

3. FINLAND AS A PRODUCER OF SYNTHETIC FUELS

Hydrogen-based synthetic fuels can use existing infrastructure, which makes them more likely to be adopted as an alternative fuel in the near-term than pure hydrogen.

Finland possesses several strengths that could make Finland competitive as a synthetic fuel producer and exporter. These competitive advantages include 1) access to cheap fossil-free energy, 2) abundance of fresh water, 3) biobased carbon dioxide, and 4) engineering prowess.

1) **Reliable and cost competitive fossil-free electricity**
As mentioned, 80% of Finland's electricity production is already free from carbon emissions, and Finland has the ability to increase the production of fossil-free energy.

2) **Fresh Water**
To produce 1 kg of hydrogen, 9 kg of water is needed. Most existing electrolysers require the water to be fresh or highly purified, making use of saline water difficult and expensive.

While countries and regions with abundance of solar power are at an advantage when it comes to the ability to produce cheap renewable electricity, these regions are often experiencing an excruciating dearth of fresh water.

Finland can compete with its access to both.

3) **Biobased carbon dioxide**

Producing hydrogen-based synthetic fuels requires carbon dioxide. In Finland the carbon dioxide could be captured directly from the forestry production plants where most of the carbon dioxide released is wood-based as opposed to deriving from fossil fuels.

In smaller scale, biobased CO_2 is available also from biogas facilities.

In addition, Finnish forestry industry has already created ideal conditions for synthetic-fuel production by virtue of the current energy arrangements and locations of the production plants. The facilities are typically built close to water and use hydropower or biomass as their energy sources, making the combination of fresh water, renewable energy, and biobased carbon dioxide potentially available at the same location.

4) **Engineering prowess and hydrogen know-how**

Finnish research organizations and companies have been active in developing hydrogen-related technologies for decades, for example the technology for fuel cells. Aalto University, the Lappeenranta University of Technology, and VTT all have extensive expertise in hydrogen-related technologies and pilot projects.

Hydrogen production in Finland is also already abundant. In addition to ***dedicated hydrogen production*** units, hydrogen is produced as a side product in chemical, forest, and steel industries. Finnish industries have already extensive experience in handling hydrogen.

In addition to possessing hydrogen-specific knowledge, Finnish industries' general expertise in engineering, electrochemistry, and oil and biorefining is well suited to new hydrogen-related industries, for example for building components for electrolysers, developing new types of engines, or producing hydrogen-based fuels and chemicals.

If the Finnish government and Finnish companies decided to take on the development of technologies needed for synthetic fuel production as well as the creation of large pilot projects, Finland could compete at the global level for a position as a leading exporter of synthetic fuels as well as the technologies required in the production of such fuels.

CHAPTER 7:

NEXT STEPS FOR FINLAND

1. CREATING A NATIONAL VISION OF HYDROGEN FOR FINLAND

The Finnish government should take steps to include a carefully considered vision of hydrogen role for Finland in the new climate and energy strategy, examining questions specific to hydrogen and Power-to-X technologies.

This strategy work should bring together the government, companies, and scientists to define Finland's goals for hydrogen both within Finland and outside of Finland.

The work should determine hydrogen's role in Finland's energy strategy and in helping Finland reach its climate targets, and it should decide what the priorities for hydrogen in Finland are.

The strategy should also define how Finland sees its role and goals within the global hydrogen ecosystem.

This government-led work should consider questions such as:

- Which uses of hydrogen make the most sense for Finland? This discussion should take into account that in many cases using electricity directly is more efficient; that the government is already supporting the electrification of many industrial processes; and that reducing emissions with the help of hydrogen would require us to have excess green electricity available. A system-level view is needed.

- Which challenges do we want to solve with hydrogen in Finland – and which not? If we really want hydrogen to play a role, first we need to decarbonise the current power production, and then we need to build new capacity to produce the electricity needed for hydrogen production.

- What are the best first-use cases for Finland? For now, the amounts of renewable energy available are limited, as are the amounts of fossil-free hydrogen that can be produced. Finland needs to determine priorities for applications.

- What could hydrogen mean for Finland in terms of job creation? Hydrogen-based solutions can create new high-skilled jobs for example in engineering.

- How does Finland position itself in the global hydrogen economy? Is Finland going to be an exporter of fossil-free hydrogen or hydrogen-based fuels? Or is Finland planning the opposite – to import hydrogen for its own use? Is Finland aiming to lead in hydrogen-related technologies or are we planning to buy such technologies from abroad? What are Finland's strategic goals in relation to the European Union's hydrogen plans and needs?

Once the vision is outlined, the government should define policy areas that need to be adjusted and ensure that all the policy areas are aligned.

2. CREATING THE REGULATION GOVERNING THE HYDROGEN ECONOMY

Currently hydrogen is hardly mentioned in the Finnish energy regulation.

The Finnish government needs to act urgently and create the broader policy and regulatory environment for integrating hydrogen into Finland's energy system. This regulatory framework should include answers to questions such as:

- What is the definition of renewable energy in the context of CO_2-free hydrogen production – does this definition, for example, include hydrogen produced with nuclear or hydropower?
- How is hydrogen embedded in the different legislative documents?
- What will the energy taxes for the production of hydrogen or hydrogen-derived fuels be like?
- What is the permitting process like for hydrogen-related projects?
- Are the existing hydrogen-related regulations, for example on safety protocols, up-to-date and does anything need to be revised?

Without such a framework, companies cannot make sound, long-term investment decisions.

3. CREATING INCENTIVES FOR THE HYDROGEN MARKETPLACE

One challenge for hydrogen is getting the hydrogen marketplace open. Right now, the field is suffering from the chicken-and-egg problem, in which everyone is waiting for someone else to take the first step.

Potential producers of clean hydrogen are not investing in new production capacity as they don't have buyers at the ready.

Potential buyers are not able to move forward, as there isn't enough of a supply of clean hydrogen nor the distribution infrastructure for delivering it.

Potential distributors are not building the infrastructure, as they don't have enough suppliers nor buyers on hand.

The price of green hydrogen remains high, and business prospects uncertain.

Such incentives could include:

- **Blending requirement for synthetic fuels.** Currently, petrol and diesel distributors are required to blend in up to 20% of biofuel. A similar requirement for synthetic fuels would create demand that would encourage companies to invest in synthetic fuel production.
- **Supporting the building of industrial-scale production plants** for clean hydrogen as well as for synthetic fuel production.
- **Supporting the building of hydrogen refuelling stations** in combination with a well-planned pilot project for hydrogen use for example for heavy transport such as trucks or heavy equipment.
- **Supporting large-scale multi-company projects** aimed at decarbonising industrial operations, creating new products, and expanding Finnish industries' understanding of hydrogen-related technologies, such as electrolysers and carbon capture technologies.

4. ADVANCING A JOINT HYDROGEN STRATEGY FOR THE NORDICS

The Nordic region shares a joint interest in securing its role in Europe's hydrogen ecosystem with its combined strength in renewable energy as well as in engineering.

The competition over the EU's investments is bound to be fierce, and currently some initiatives are proposing externalizing some of the EU's investments into renewable energy and hydrogen production outside the EU. The Nordic region could and should offer a credible alternative or addition to such plans as the European Union's energy self-sufficiency should also be a concern.

The Nordic countries should highlight their ability to contribute to the EU's future energy needs as well as to the coming hydrogen trade and secure the region's connections to potential Central European users of renewable energy, hydrogen, and hydrogen-derived fuels and chemicals.

These connections mean literal delivery routes as well as the channels for discussions and planning.

The Nordic region is among the most stable, innovative, sustainable, and technology-savvy in the world. It should be seen as the leading partner for other nations and regions – especially within the EU – in all areas of renewable electricity as well as hydrogen production.

Finland should advance such thinking and cooperation within the Nordic countries as the region is stronger when advancing shared goals together.

CHAPTER 8:
CLOSING REMARKS

Finally, the most important task for Finland as a nation is to understand the role hydrogen in the coming energy transformation.

Hydrogen is not a magical solution that will solve all of our problems or even all of our decarbonisation efforts.

However, it is an opportunity to decarbonise parts of our industrial processes and energy needs, and a valiant opportunity at that. When used efficiently and purposefully as part of the wider energy system and as companion to other solutions, hydrogen can offer us a realistic tool for getting closer to our climate targets and a zero-emissions society.

In order to get there, we need to establish a joint effort of industries, scientists, the government, and the citizens.

The government's role is to lead this joint effort of mapping out a whole new energy system and making considered choices that create a well-functioning, efficient, emissions-free, and profitable energy system for the future. This work must include clear and substantial consideration of hydrogen.

Once the policy framework providing long-term stability and direction is set, the markets and the companies will lead the way and make the investments needed.

Many other countries are already clearly ahead of Finland in this work, especially in relation to hydrogen.

The time for Finland to create its own vision for hydrogen is now.

Once the policy framework is set, the markets and the companies will lead the way and make the investments needed. The time for Finland to create its own vision for hydrogen is now.

APPENDIX 1:
GLOBAL MARKETPLACE

Currently, the world's ***biggest exporters*** of hydrogen are China, the U.S., Germany, South Korea, and Norway. However, all this hydrogen is produced mostly from fossil fuels.

The future global hydrogen marketplace will be directly linked to the new geography of global electricity production.

As producing green hydrogen requires considerable amounts of renewable energy, potential new hydrogen producers could be regions with abundant sunshine – Southern Europe, Africa, or the Middle East – or countries with abundant offshore wind energy, for example countries like Holland, Denmark, and Norway.

On the other hand, producing low-carbon hydrogen from natural gas with carbon capture and storage or fossil-free hydrogen with the help of renewable and nuclear energy would expand the scope of competitive production.

The new international trade in hydrogen has the potential to create completely new trade relations as well as improve the security of supply, as energy sources and transport routes will become more diverse.

One illustration of the potential trade relations is the European ***2X40 GW Green Hydrogen Initiative*** by the European industry association Hydrogen Europe.

The initiative promotes a massive increase of electrolyser production within the EU.

However, the initiative envisions that only half of the proposed 80 gigawatts of new hydrogen capacity would be produced in Europe. The other 40 gigawatts would be produced in North Africa and Ukraine since those regions have access to cheap solar and wind power.

The hydrogen produced in these regions would then be imported to Europe via pipelines. According to the initiative, building of a large new hydrogen pipeline from Egypt, via Greece to Italy, 2,500 km, with 66 GW capacity, consisting of 2 pipelines of 48 inch each, would require an investment of about €16.5 billion.

THE EU HYDROGEN STRATEGY

The European Commission published this past summer its ambitious ***hydrogen strategy*** aiming to ramp up the production of hydrogen up to 10 million tonnes of hydrogen by 2030. The EU is prioritizing renewable hydrogen, produced using mainly wind and solar energy.

According to the European Commission's estimates, cumulative investments in renewable hydrogen in Europe could be up to €180–470 billion by 2050, and in the range of €3–18 billion for low-carbon fossil-based hydrogen.

The emergence of a hydrogen value chain serving a multitude of industrial sectors and other end uses could employ up to 1 million people, directly or indirectly.

The EU's main strategic hydrogen goals involve:

1. **Building large-scale electrolysers**
   From 2020 up to 2024, the EU strategic objective is to install at least 6 GW of renewable hydrogen electrolysers in the EU and to have up to 1 million tonnes of renewable hydrogen produced.

   From 2025 to 2030, the EU envisions hydrogen as an intrinsic part of the energy system with at least 40 GW of electrolysers installed and up to 10 million tonnes of renewable hydrogen produced in the EU.

2. **Creating hydrogen valleys**
   The Commission envisions the emergence of local hydrogen clusters – so-called "Hydrogen Valleys" – that will rely on local production of hydrogen with renewable energy production close-by and the hydrogen transported only over short distances.

   This could mean for example large-scale electrolysers connected to clean electricity production and supplying renewable hydrogen for example to industrial areas, airports, ports, and for heating residential and commercial buildings.

3. **Hydrogen as fuel**
   In transport, the Commission anticipates early adoption of hydrogen especially in public transport such as in local city buses, taxis, or specific parts of the rail network, where electrification is not feasible. Hydrogen fuel cells should be further encouraged in heavy-duty road vehicles, alongside electrification, including coaches, special purpose vehicles, and long-haul road freight.

   For inland waterways and short-sea shipping, hydrogen can become an alternative low emission fuel. For longer-distance and deep-sea shipping, scaling up fuel cell power and using renewable hydrogen for the production of synthetic fuels, methanol or ammonia – with higher energy density – are required.

   Hydrogen should also be longer-term option to decarbonise the aviation and maritime sector through the production of liquid synthetic kerosene or other synthetic fuels. In the longer-term, hydrogen-powered fuel cells, requiring adapted aircraft design, or hydrogen-based jet engines may also constitute an option for aviation.

   Estimated investments of €65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refuelling stations.

   The Commission will consider various options for incentives at EU level, including the possibility of minimum shares or quotas of renewable hydrogen or its derivatives in specific end-use sectors (for instance certain industries as the chemical sector, or transport applications.)

4. **Replacing fossil fuels in industrial production**
   Hydrogen can form the basis for investing in and constructing zero-carbon steel making processes in the EU, envisioned under the Commission's new industrial strategy.

APPENDIX 2:
COUNTRY STRATEGIES

GERMANY

Germany is one of the leading promoters of hydrogen in Europe. A big importer energy and with a limited ability to produce renewable energy itself, Germany has made hydrogen a key part of its energy transition (Energiewende) strategy as it seeks to end its reliance on coal.

Germany is also aiming to be the world leader in hydrogen-related technologies.

Germany's national ***hydrogen strategy*** was published in June 2020, and the government set aside a massive ***€9 billion*** earmarked for hydrogen-related initiatives. In addition to the €7 billion earmarked for green hydrogen in Germany, the government stimulus includes a further €2 billion to build up partnerships with other countries.

Germany's strategy comes in two parts.

First, it seeks to establish a strong and sustainable production and market for the use of hydrogen at home, while at the same time creating networks for importing hydrogen.

In order to cover part of the increasing demand for hydrogen, Germany plans to establish up to 5 GW of hydrogen generation capacity including the offshore and onshore energy generation facilities needed for this. An additional 5 GW of capacity are to be added by 2035 and no later than 2040.

Germany has a well-developed gas infrastructure consisting of a tightly knit natural gas network and the gas storage units connected to it. In the future, part of this infrastructure is to be used for hydrogen as well. Further networks are to be created exclusively for the transport of hydrogen.

However, as Germany's domestic generation of green hydrogen will not be sufficient to cover all new demand, the country is making a significant effort to create international markets and delivery systems for green hydrogen.

Its hydrogen strategy calls for intensifying cooperation with other EU member states, particularly those capable of producing large quantities of wind or hydropower – the countries bordering the North and Baltic Sea – but also those with the conditions for producing significant amounts of solar power – the countries of southern Europe.

This renewable energy would then be transformed into either gaseous or liquefied hydrogen or synthetic fuels and transported to Germany via pipelines or tankers.

One important initiative is Germany's ***hydrogen alliance with Morocco***, with plans to produce hydrogen in the country using solar energy. The plan fits under the motto some have described as "shipping the sunshine."

The government is also funding a range of projects to develop hydrogen and related technologies, such as the flagship ***Carbon2Chem*** and ***Kopernikus*** projects.

Carbon2Chem project aims to capture gases produced by steel mills and use these gases to produce various chemical products. Nitrogen and hydrogen contained in these gases can be used to create ammonia. In turn, ammonia can be used to make mineral fertilizer.

The ***Kopernikus project P2X*** addresses topics related to hydrogen generation, transport, and usage.

Other possible initiatives are a 2% quota for renewable kerosene made of hydrogen for aviation fuels.

Meanwhile, German states are supporting their own projects. The northern city state of Hamburg announced ***plans*** in September 2019 to build a hydrogen electrolysis plant with a capacity of 100 megawatts in the Port of Hamburg running on surplus electricity from wind turbines.

Th hydrogen produced could be used to serve the large factories processing steel, aluminum, and copper located near-by. It could also be used in heavy-duty freight transport, shipping, or local public transport, or to supply the metropolitan area with district heating.

German gas pipeline operators revealed earlier this year the ***blueprint*** for the world's largest hydrogen grid, which could eventually cover around 5,900 kilometres with links to the neighbouring Netherlands. The first section should reach 1 200 kilometres by 2030. Only 100 kilometres of the first stage would need to be built, with the rest being converted former gas pipelines, according to the grid operations' association FNB Gas. The grid has been dubbed “H2 Startnetz” and it is expected to cost €660 million.

THE NETHERLANDS

The Netherlands published its ***hydrogen strategy*** in 2020 but the country is already home to dozens of ***hydrogen-related pilot projects***. The projects include:

- Building electrolysers of various sizes connected to wind or solar power and often installed at the location where the hydrogen would be used for industrial processes, as fuel, to store renewable energy, or to produce synthetic fuels.
- Producing hydrogen from biogas.
- Creating technologies for repurposing natural gas power grids for transporting hydrogen.
- Deploying hydrogen-powered garbage trucks, ships, buses, and trains.
- Installing filling stations for cars, trucks, buses, and ships.
- Building central heating burner systems using hydrogen to replace the current boilers using natural gas.
- Using hydrogen to heat residential areas.
- Exploring the possibilities for producing hydrogen onsite at an airport to be used as fuel and as emergency power source.

The Netherlands considers hydrogen a way to stay central in international energy transports. As the demand for hydrogen is expected to grow, there will be the need for significant amounts of hydrogen to be both produced in and imported to Europe.

The Port of Rotterdam has already emerged as a ***hub for hydrogen-related projects***.

The Dutch government has asked the Rotterdam Port Authority to map out the various options to import hydrogen from abroad. Similar to how the port presently imports large volumes of oil and coal for the Netherlands, Germany and Belgium, in the near future, Rotterdam wants to serve as a major hub for renewable energy flows.

The port is expecting to have electrolysers run by Shell and BP to be built in the special industrial area by the port, powered by offshore wind. The Port Authority and the Dutch natural gas operator Gasunie are planning to jointly construct and operate a hydrogen pipeline from the port to transport the hydrogen to end users.

The short-term focus for the Netherlands is creating the first generation of production plants and gaining experience with the production and uses of green hydrogen within the Netherlands. The Netherlands has given itself a target of electrolysis capacity of 500 MW of installed capacity by 2025 and 3–4 GW of installed capacity by 2030.

The partners in the Dutch ***Gigawatt Electrolyser*** project will jointly investigate what it takes to build a large-scale electrolysis plant in the Netherlands around 2030, producing an estimated 90,000 tonnes of hydrogen annually.

Public financial support will be aimed at applied research and innovative pilot projects, which are eligible for a subsidy for 25% of the eligible costs, with some companies being eligible for 45% or up to 15 million euros. Government will also support temporary operating costs for new projects with about 35 million euros per year.

Other core efforts include linking hydrogen to offshore wind energy, creating an obligation for green hydrogen blending in the natural gas grid, and advancing the legal framework surrounding hydrogen especially in relation to the existing gas grid.

In the transport sector, national targets include 50 hydrogen refuelling stations, 15,000 fuel cell vehicles, and 3,000 heavy-duty vehicles by 2025 and 300,000 fuel cell vehicles by 2030.

The Netherlands supports a European blending obligation for aviation fuels. If impossible, the Netherlands will pursue a domestic Sustainable Aviation agreement to reach 14% blending of sustainable fuels by 2030 and 100% by 2050.

NORWAY

Norway published its ***hydrogen strategy*** in 2020. With its abundant sources of renewable energy in hydro and wind power, as well as natural gas, Norway is well placed to benefit from the coming transformation.

Norway considers it important for the government to increase the number of pilot and demonstration projects in Norway by supporting technology development and commercialization.

The ***green transition package*** presented by the government on the same day as the hydrogen strategy contains "an enforced and significant commitment to hydrogen."

The Norwegian government is supporting new projects through programmes like ***EnergiX***, which provides funding for research and innovation to achieve sustainable energy system, and ***Pilot-E***, which allows for consortia of companies to apply for funding for specific projects. End-customers planning to utilise the new solution may also qualify for investment aid.

In 2018, EnergiX program allocated 50 million euros for projects. The Norwegian government ***announced*** in 2020 that it will allocate about 340 million euros for such projects over the next three years.

For blue hydrogen produced from natural gas with carbon capture and storage, Norway is focusing on carbon capture and storage (CCS) technologies. The country has created a state-owned company ***Gassnova*** to specifically focus on CCS. The Norwegian government is supporting these developments also through the ***Climit*** programme, the ***Technology Centre at Mongstad*** – which offers companies and scientists the facilities to test carbon capture technologies – and the ***Norwegian full-scale CCS project*** which includes storage of CO_2 on the Norwegian continental shelf.

In July 2020, Norway's state-owned energy company Equinor announced ***plans*** for a large-scale hydrogen plant in the UK producing hydrogen from natural gas with carbon capture and storage. The facility would be the biggest in the world of its kind, and it would use capture and storage technology to extract and bury the resulting carbon under the North Sea. The project would help the industrial cluster in the Humber region of the UK to decarbonise its operations.

Norway is also working on becoming a "hydrogen powerhouse within green shipping." There are already maritime projects underway, including:

- A ***hydrogen-electric ferry*** in Rogaland starting in 2021, run by the Norwegian shipping company Norled.
- The Hayvard Group's project for emissions-free shipping in the fjords, and for a ***Coastal Steamer*** running on hydrogen fuel cells, to be operational in 2022.
- The Trøndelag county council has a hydrogen development project for high-speed passenger ferries to replace obsolete ferries in the years to come.

Norway is working on transitioning from hydrogen produced from fossil fuels to green hydrogen in refining petroleum products and manufacturing chemicals.

CHINA

China is one of the most important global actors in hydrogen, and the nation that Germany names as its "main competitor" in the hydrogen arena. The country is already the world's largest producer of hydrogen derived from coal, and hydrogen is part of its "Made in China 2025" and "China Standards 2035" industrial strategies.

China's ***thirteenth five-year plan*** for 2016–2020 identifies hydrogen technology as a next-generation emerging technology to support. Since the issuance of the 13th Five Year Plan, the Chinese government has issued other policies and reports concerning hydrogen.

Much of it has focused on hydrogen fuel cell technology, but other technologies are being explored so that China can make use of its vast domestic hydrogen production – the largest in the world (***accounting for approx. 30% of the world's volumes***).

China's ***hydrogen fuel cell vehicle roadmap*** published in 2016 sets out to deploy one million cars using hydrogen fuel cells by 2030. Broadly, the objectives are to improve functional requirements like cold starts, bringing costs down to be cost-competitive first with electric vehicles (and then traditional), and to improve qualities like maximum speed and lifespan.

The Ministry of Finance also issued a document in April 2020 which outlined a target to develop the supply chains necessary to produce hydrogen fuel-cell cars over the next four years.

The government had originally intended to end subsidies for new energy vehicles (including hydrogen-powered ones) in 2020, but it announced in 2020 that it ***would extend them through 2022*** (with a reduction in subsidization).

In June 2020, the Ministry of Housing and Urban-Rural Development issued a policy calling for the ***development of standards*** concerning the storage of liquefied hydrogen at filling stations.

A draft law was issued in April 2020 by the National Energy Administration that included hydrogen as an energy source for the first time.

THE UNITED STATES

The United States is already heavily engaged in the hydrogen economy with hundreds of millions of dollars of public and private investment per year.

According to an American ***industry report***, the U.S. boasts more than half the world's fuel cell vehicles; about 25 000 fuel cell material handling vehicles in operation, such as ***forklifts*** used in Walmart distribution centres and BMW plants or container handlers at Port of Los Angeles; more than 8,000 small-scale fuel cell systems in 40 states, and more than 550 MW of large-scale fuel cell power plants installed or planned.

Nearly all of the hydrogen currently consumed in the United States is ***created from natural gas*** and ***used by industry*** for refining petroleum, treating metals, producing fertilizer, and processing foods. The major ***hydrogen-producing states*** are California, Louisiana, and Texas.

The National Aeronautics and Space Administration (NASA) began using liquid hydrogen in the 1950s as a rocket fuel, and NASA was one of the first to use hydrogen fuel cells to power the electrical systems on spacecraft.

As of the end of October 2019, there were about 80 fuel cell power plants operating in the U.S. with a total of about 190 megawatts (MW) of (net summer) electric generation capacity. The largest is the Red Lion Energy Center in Delaware with 27 MW capacity, which uses hydrogen produced from landfill gas to operate the fuel cells.

Several car manufacturers have begun making light-duty hydrogen fuel cell electric vehicles available in select regions such as Southern and Northern California, where there is access to hydrogen refuelling stations.

The American industry has created its own suggestion for a ***hydrogen roadmap*** for the U.S. The coalition estimates that hydrogen could deliver approximately €140 billion in revenue and 0.7 million jobs by 2030, and approximately $750 billion in revenue and 3.4 million jobs by 2050.

JAPAN

Japan has been building a full-blown hydrogen society for years.

The focus has been especially on hydrogen cars with Japanese car makers such a Toyota leading the way. Currently Japan is aiming to increase the number of hydrogen vehicles in Japan to 40,000 units by 2020, 200,000 units by 2025 and 800,000 units by 2030. It will also aim to increase the number of hydrogen stations, hydrogen buses, and the number of forklifts. It will promote fuel cell trucks and small ships.

Another vital interest for Japan is using hydrogen to ensure the nation's energy needs. Currently Japan is dependent on overseas fossil fuels for most of its primary energy supply. Japan's energy self-sufficiency rate has stagnated after the shutdown of nuclear reactors post-2011 Great East Japan Earthquake. Renewable energy power generation accounts for only about 15% of Japan's total power generation.

Hydrogen is significant to Japan in many ways, as discussed in Japan's ***hydrogen strategy***.

- The adoption of hydrogen allows for the diversification of energy sources around the world, minimizing problems with procurement.
- Hydrogen allows for the reduction of carbon emissions in power generation, transportation, heat use, and industrial processes.
- A hydrogen-based society is a means to an end in realizing Japan's energy policy (Energy security, Economic efficiency, Environment suitability, and Safety).
- The promotion of hydrogen technologies will create a new growth industry, leading to industrial promotion and the enhancement of Japan's competitiveness.
- Japan has the opportunity to become a global leader in hydrogen adoption.

APPENDIX 3:
PARTICIPATING COMPANIES

FORTUM: WELL POSITIONED FOR THE HYDROGEN ECONOMY

Fortum is a European energy company with activities in more than 40 countries. It provides its customers with electricity, gas, heating and cooling as well as smart solutions to improve resource efficiency.

Together with its largest subsidiary Uniper, it is the 3rd largest producer of CO_2-free electricity in Europe. Uniper is a pioneer in clean hydrogen development and in the power-to-gas field in general.

Producer of fossil-free electricity and clean and low-carbon hydrogen
The clearest opportunities for Fortum in building the hydrogen economy are in the decarbonisation of industries by leveraging its CO_2-free electricity portfolio for production of clean and low-carbon hydrogen as well as in storage and transport of hydrogen.

Clean and low-carbon hydrogen open opportunities for:

- Complementing existing flexible electricity and heat supply technologies such as hydropower, batteries, and underground heat and gas storages.
- Producing hydrogen in the Nordics relying on decarbonised and competitive electricity and exporting it to the Continental Europe, circumventing bottlenecks in the electricity grid.
- New business concepts related to flexible electricity consumption.
- Combining hydrogen with carbon dioxide to produce synthetic fuels.

Producer of clean hydrogen in Europe
Uniper has two existing hydrogen production plants, one in Hamburg and the other in Falkenhagen, Germany, where hydrogen produced with wind power is methanised or injected directly into the natural gas network.

In 2020, Uniper signed a ***cooperation agreement*** with Siemens Gas and Power. One focus of the planned cooperation is the production and use of clean hydrogen – in other words, hydrogen from CO_2-free energy sources. The companies intend to implement projects in this field together, addressing the entire value chain.

GASUM: SUPPLIER OF GREEN GAS AND ELECTRICITY AND POSSIBLE DISTRIBUTOR OF HYDROGEN-DERIVED FUELS

As an energy industry multitasker, Gasum has a natural interest in hydrogen. Fully owned by the Finnish state, Gasum is the leading player in the Finnish natural gas market and is the biggest distributor of liquefied natural gas (LNG) in the Nordic countries. Gasum is also the leading supplier of biogas in the Nordic countries, currently owning 15 biogas plants in Finland and Sweden.

Gasum has also expanded to electricity markets and is the leading energy market services provider in Finland. In addition to portfolio management services and physical market services, for example balance management, this covers guarantees of origin, wind power purchasing agreements, and other services related to renewable electricity.

If global demand for hydrogen grows as projected, the trend will have several implications for Gasum's business strategy.

Providing energy for the production of hydrogen
Most of the hydrogen today is produced from natural gas. Should the demand for hydrogen rise, this could lead to a boom in sales of natural gas and LNG – Gasum's core business.

On the other hand, increasing amount of the hydrogen needed will be produced from water with the help of electricity, building up the demand for electricity. Gasum will be there to help provide the energy needed. Gasum can offer power sourcing and portfolio management services and supply green electricity for hydrogen plants. This can be combined with the optimization of the sourcing and use of the potential flexibility related to the hydrogen production in the electricity markets.

In the future, it might also be feasible to produce hydrogen from biogas. As the leading Nordic producer and supplier of biogas, Gasum would be well positioned to benefit from such innovations.

Producer of synthetic fuels
As the world seeks to supplement or replace fossil fuels with hydrogen or hydrogen-based synthetic fuels, Gasum could potentially balance its offering of natural gas by adding importing, selling, and producing hydrogen or hydrogen-based synthetic fuels to its portfolio. This can have synergy with Gasum's current biogas production as CO_2 is a side product at biogas production facilities.

Currently, Gasum sells LNG for maritime transport, industry and heavy-duty road transport in Finland, Sweden, and Norway, and it is continuously expanding its gas filling station network. Should maritime or truck transport switch from LNG to using hydrogen or hydrogen-based synthetic fuels, Gasum could also be there to offer that fuel.

TOYOTA: A PIONEER OF HYDROGEN CARS, TRUCKS, GENERATORS, LUNAR ROVERS, AND NOW WHOLE CITIES

Japan is one of the nations that has been building a full-blown ***hydrogen society*** for years. Japanese car makers such a Toyota have been leading the way.

Manufacturer of hydrogen-powered vehicles
Toyota began developing hydrogen-powered cars more than 20 years ago. It's current flagship product is the second-generation Toyota Mirai – "future" in Japanese. The Mirai is a 4-door sedan using pure hydrogen as fuel, originally introduced in 2014. Today, the company has sold more than 10,000 fuel cell vehicles globally.

Toyota has set itself a ***target*** for global annual hydrogen fuel cell vehicle sales of at least 30,000 after 2020.

And how does a hydrogen car work?

When you pump hydrogen into a Toyota Mirai, the gas ***travels to fuel tanks*** where it is stored. It then moves from the tanks to the car's ***high-powered*** fuel cell stacks and reacts with oxygen from the air, creating electricity and water.

When the driver puts their foot on the accelerator, electricity from the fuel cell stack is sent to the motor. The water is sent out of the tailpipe – the only emissions the car produces.

Currently Toyota Mirai's main markets are the United States, Japan and Europe.

However, Toyota's vision for hydrogen reaches far beyond only passenger cars.

Builder of a full hydrogen society
The company is actively developing for example ***heavy-duty trucks***, ***buses***, ***forklifts***, ***generators***, ***power supply vehicles*** and ***lunar rovers***, which are all using fuel cell technology and running on hydrogen.

Toyota's hydrogen trucks ***are being*** tested for example in California, where they are already used to haul cargo received at the Ports of Los Angeles and Long Beach throughout the Los Angeles Basin. The project ***includes*** the building of hydrogen fueling stations.

In the maritime world, Toyota has helped develop an energy-autonomous ***hydrogen vessel*** – a electrically propelled catamaran that is operated using a mix of renewable energies, a fuel cell, and an on-board system that produces carbon-free hydrogen from seawater.

In January 2020, the company revealed ***plans*** to build a prototype city of the future on a 175-acre site at the base of Mt. Fuji in Japan. Called the Woven City, it will be a fully connected ecosystem powered by hydrogen fuel cells. The groundbreaking for the site is planned for early 2021.

Toyota is also a co-chair of the Hydrogen Council, a global CEO-led coalition of more than 90 companies.

UPM: INNOVATING FOR A FUTURE BEYOND FOSSILS BOTH IN ENERGY PRODUCTION AND EMISSIONS REDUCTION

UPM leads the forest-based bioindustry into a sustainable and innovation-driven future. The company creates renewable and responsible solutions that replace fossil-based materials by making the most of residues and side streams.

In addition, UPM focuses on zero-carbon electricity generation and developing solutions for industrial energy excellence.

UPM's Biofore strategy aims to respond to some of the biggest challenges facing the world today, such as resource scarcity, climate change, loss of biodiversity, and depletion of clean water.

UPM's strategic focus also enables the company to seize emerging opportunities such as those presented by hydrogen.

UPM Energy – Embracing the decarbonization of the society

UPM Energy is the second largest electricity producer in Finland. It generates low-emission electricity in its own and co-owned power plants.

In addition, UPM Energy's operations include physical electricity and financial portfolio management as well as services to industrial electricity consumers and producers. Through its ownership in Teollisuuden Voima (TVO), UPM Energy is major shareholder in the nuclear power assets in Olkiluoto, Finland.

UPM Energy is investigating hydrogen opportunities in form of business and service model development, in an energy system moving towards becoming 100% carbon-free.

Beyond that, UPM Energy assesses the potential hydrogen could play in the Nordic and Central European power markets going forward.

Emission reductions and future opportunities

UPM has committed to the United Nations Global Compact's Business Ambition for 1.5°C, joining leading companies in a promise to pursue science-based measures to limit global temperature rise to 1.5°C.

The company's goal is to reduce its CO_2-emissions from fuels and purchased electricity by 65% from the 2015 levels by 2030. UPM also aims to reduce the emission levels of its supply chain by a third.

While bioenergy based on sustainable forestry is CO_2 neutral as such, release of CO_2 is part of the renewal cycle. The CO_2 released in the combustion, however, could be utilised as a raw material if captured and combined with hydrogen.

UPM is therefore looking into technologies that can synthesise biogenic CO_2 and turn hydrogen into hydrocarbons.

UPM is also evaluating the feasibility of utilizing carbon-free hydrogen at a cost-efficient manner in biofuels refining process. In order to achieve entirely fossil-free production process, the current hydrogen feedstock, based on natural gas, would need to be replaced with green hydrogen.

WÄRTSILÄ: POWER-TO-X, HYDROGEN ENGINES, AND SYNTHETIC FUELS

Wärtsilä is a global leader in smart technologies for the marine and energy markets. The company's core products include gas, multi-fuel, liquid fuel, and biofuel power plants, energy storage systems, as well as technologies for the maritime sector, including cruise ships, ferries, fishing vessels, merchant ships, offshore and special vessels. The company has operations in more than 80 countries around the world.

As hydrogen is becoming a crucial source and carrier of energy in the world energy systems and for the maritime industry in particular, Wärtsilä is expanding its operations in hydrogen-related technologies.

Designer of hydrogen engines

As the leading manufacturer of medium speed engines, Wärtsilä is already ***designing engines*** that will work with various future fuels. Wärtsilä's engines are already capable of combusting 100% synthetic carbon-neutral methane and methanol, and tests with blends of up to 60% hydrogen and 40% natural gas have also already been made. The development continues towards enabling its gas engines to burn 100% hydrogen fuel.

Builder of synthetic fuel plants

Wärtsilä is also exploring opportunities to add synthetic fuel plants to its technology portfolio. It is conducting several studies including one feasibility study for synthetic fuel production at Vantaa Energy's waste-to-energy-plant in Finland. The planned facility would produce carbon-neutral synthetic methane using carbon dioxide emissions, hydrogen, and electricity generated at the waste-to-energy plant.

A second ***pilot plant*** is planned for Joutseno, Eastern Finland in partnerhip with multiple other companies. It would use carbon dioxide from a cement facility and excess hydrogen from a chemical factory as main raw materials for creating synthetic methanol.

Creator of Power-to-X ecosystems

In 2020, the Finnish government ***granted*** Wärtsilä one million euros to support the company's research in the field of Power-to-X technology – that is, to study the ecosystem needed for transforming renewable energy into other forms for storage and transport.

In the X-Ahead project, Wärtsilä will form and lead a network of universities, research industries, and small and medium-sized enterprises on a national as well as a global scale. The project will study carbon capture technology, electrolysis, synthetic fuels, process modelling, and industrial-scale feasibility. Wärtsilä's own starting investment for the projects is 2,5 million euros.

Nordic West Office
Haapaniemenkatu 5
00530 Helsinki
Finland

1152 15th Street, NW
Washington, D.C. 20005
USA

www.nordicwestoffice.com

Risto E. J. Penttilä, CEO
risto.penttila@nordicwestoffice.com
Nordic West Office

Nordic West Office is a global affairs consultancy, a pan-Nordic think tank and a gateway to the U.S. market. We are well connected and have deep experience in the U.S., the Nordics and Europe.

We help Nordic companies navigate globally. We also help international companies succeed in the rapidly strengthening New Nordics region.

/ NORDIC WEST OFFICE