# NEW ZEALAND

A key player for the hydrogen transition.


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## Content

## FOREWORD

When someone talks about New Zealand, some of the things that comes to our minds are the landscapes, such as the location used for filming the lord of the rings, for example. Having a scenery very diverse, from subtropical forests, beaches and offshore islands in the north to glaciers, lakes, snow-covered mountains, and flat plains in the south.


*Kiwi from National Geographic 1*

You may think of wild sports, such as surf or snowboard. Maybe it comes to your mind rugby, represented by the "All Blacks". Also, one can imagine a unique wildlife, where you can find bird and plant species that exist nowhere else in the world. Forests are full of an abundance of interesting plant life, from the towering ancient kauri trees to fronds of nikau palms. You can spot a kiwi, the small, flightless bird that represents New Zealand's national symbol.

Now the time that this research began, I found a lot of resources that show that this is not only a country that has an amazing wildlife, landscape and culture but also a country that has in the South side a wind resource of approximately 70 km/h (data obtained by The Weather Company), which in a Beaufort scale represents a value of 8, denominated hard wind.

According to "ArcGIS" (The World Hydro Map), New Zealand has a lot of hydro potential, being part of the country's energy system for over 100 years and continues to provide half of the country's electricity needs.

The North and Central part of New Zealand have a solar irradiation of 4.0 to 4.2 kWh/m$^2$, daily total, according to The World Bank Group Solar Resource Map. When we multiply the average by 365 days (ideal case), we obtain a yearly total of 1497 kWh/m$^2$. On the solar irradiation scale this number represents a good to very good solar resource.

Finally, another resource that was of interest for this study was the agricultural hectares map which is a very important resource because of two main reasons. Firstly, it's one of the pillars of the economy and secondly because of the busy land.

# HYDROGEN

## Basic Information

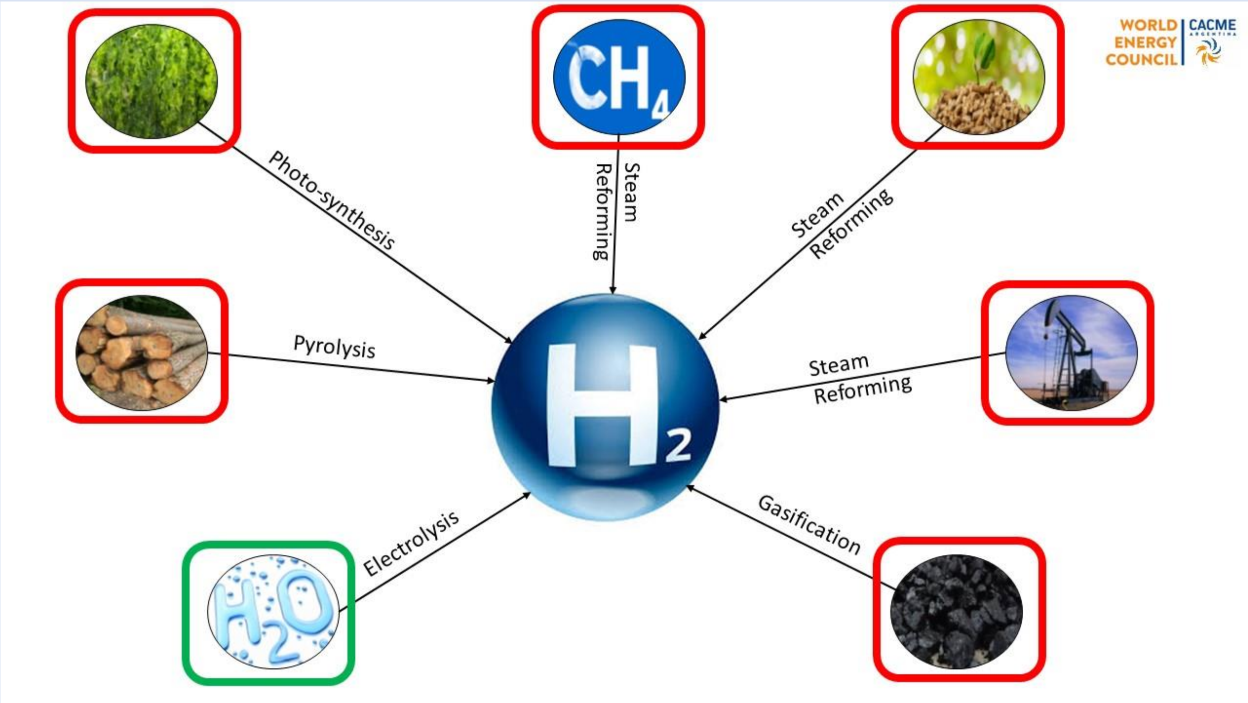
The first thing we need to do, in order to understand the arguments discussed in this debrief, is to introduce this amazing element and some of its characteristics that make so special. Hydrogen (H) is the first element on the periodic table with an atomic number of 1 (Has only one proton and one electron), its name comes from the Greek word Hydrogenium, which means generator of water. This is very important because since the beginning of its discovery it was known that according to the chemical equation, two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water. The most interesting part is that this process is reversible, one can turn the process the other way down and by breaking two molecules of water we can obtain two molecules of $H_2$ (Hydrogen) and one molecule of $O_2$ (Oxygen).

This is the most abundant and simple element. It has been present in the universe since the moment when the elemental particles began to link themselves after the Big Bang, more than 13 M (million) years ago. Even though the stars are consuming it since their formation, it constitutes 75 % of the detectable matter of the universe. This gas is light, flammable and essential for life: without it we would have nor heat nor the Sun, nor water or the organic compounds that constitute the living beings' components. Thanks to the weak bonds it forms with the molecules of water, it remains in a liquid state, without these "hydrogen bonds", water would boil at less than -70 degrees Celsius. Hydrogen was first isolated by the British scientist Henry Cavendish on the mid XVII century and very soon it begun to be used; its low density makes it float in the air, which made it ideal for inflating balloons. The first one on using it for this purpose was a French scientist named Jacques Charles in 1783, but the practical applications which were more important was for the dirigibles and zeppelins, until the Hindenburg incident  where it led to the destruction of the zeppelin by catching on fire because of a short circuit of the materials of the zeppelin LZ129, leading to on 1937, putting an end to the aircrafts supported by hydrogen. Also, it is the most common fuel on NASA rocket ships, well it has a huge potency to generate the thrust the rocket needs. On the past 20 years, there has been a los of research regarding the use of hydrogen as a substitute to fossil fuels on cars, since on the combustion it does not produce carbon dioxide, only harmless water steam.

## Production

An important detail of hydrogen is that is not found freely as $H_2$ (Hydrogen), it is bonded to other elements in nature. So, this means its not a primary energy source. Hydrogen is an energy vector or energy carrier, which means that it needs to be obtained from a natural energy resource and then it can be transformed into the form of desired energy source (electric or heat for example). This process requires the input of energy for its production.

The most common ways of producing hydrogen gas are summarized on image 2. The ones that have the red square are the ones that release $CO_2$ (Carbon Dioxide) on the production process, while the one with the green square, if produced with a renewable energy source it does not release any type of emission on the production process.




*H2 Production Processes 2*

Classifying them by process:

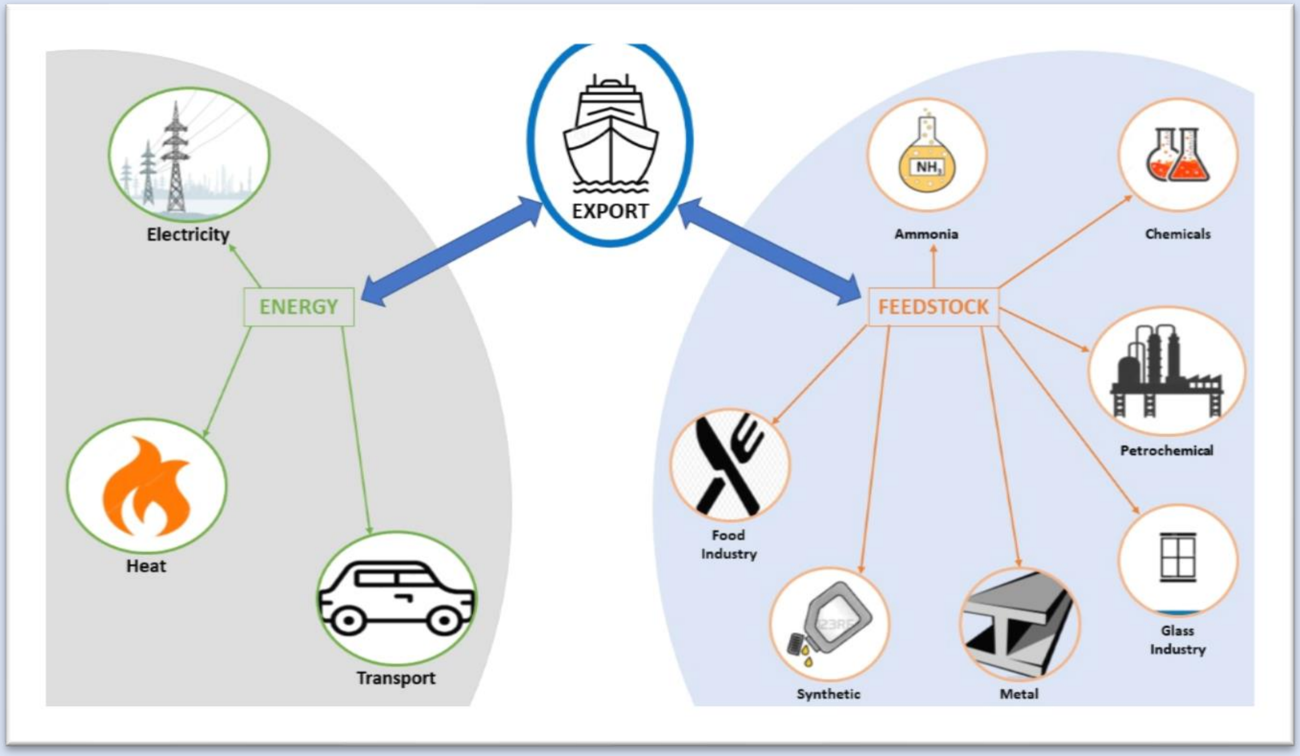
- <u>Steam Reforming:</u> this process is also called steam methane reforming, the reformer reacts with steam at high temperature and pressure with methane in the presence of a nickel catalyst, producing hydrogen gas and carbon dioxide and carbon monoxide. The feedstock can be ***natural gas***, ***oil*** and ***biomass***. The emissions of this process can be captured by CCS (carbon capture storage) technology. This is a process that cannot be applied for small quantities because the technology does not scale down. Another method can be, with a similar procedure, autothermal reforming, where steam or oxygen react with the gas and it is oxidized producing hydrogen and CO (Carbon Monoxide) and CO2 (Carbon Dioxide).
- <u>Gasification:</u> converts organic or fossil fuels into CO, CO2 and H2. This is achieved by reacting the material at high temperatures (more than 700 degrees Celsius), without combustion, with controlled amounts of oxygen and steam. The process uses as feedstock ***coal*** but can also use any ***organic*** or ***fossil fuel***. The emissions of this process can be captured by CCS (carbon capture storage) technology.
- <u>Electrolysis:</u> this technique its very common in chemistry and manufacturing, using a DC (Direct Current), to drive a chemical reaction. In this case the feedstock is ***water*** that produces Hydrogen and Oxygen with a high purity. What is so important of this process is that allows to produce what is called "Green Hydrogen". If the current provided to feed the electrolyzer comes from a renewable energy source, it is a carbon free process. It can also be considered green in the cases of where the energy mix has an 80% share of renewable energy and the electrolyzer uses energy from the grid, it is also considered renewable hydrogen.
- <u>Pyrolysis:</u> is the thermal decomposition of materials at an elevated temperature in an inert atmosphere. It involves a change of the chemical composition and is an irreversible process. It is

most used for the treatment of ***charring wood***, producing char and a mix of CO, CO2 and H2 in the mix. This process also can have its emissions captured and stored for a later usage as well.

- Photosynthesis: this is a low efficiency process, where the feedstock comes from ***algae***, which by the process of interaction with the radiation from the sun and enzymes produce hydrogen gas.

## Hydrogen Applications

We have already explained the properties of this gas and how to produce it. Now that we have the gas what can we do with it? Well hydrogen can be used for two main application, one being the energy market and the other as feedstock. In the following *Image 3,* we proceed to show hydrogen´s application.




*Hydrogen applications 3*

As we can observe we have the export market in the middle of the two main applications. That is what needs to happen in order to enable the hydrogen economy. It is a key factor to know how to export this product, which will be detailed further on.

In the *energy market*, hydrogen can be applied on its three pillars, being electricity, heat and transport.

- Electricity: Hydrogen can be used for the generation of electricity by stationary fuel cells or by its combustion in a combined cycle. Fuel cells today present a higher efficiency, being of 71% and combined cycles having an average efficiency of 50%. Fuel cells can be used for the decentralization of power supply and as a back up generation. As a backup generation hydrogen has long autonomous operation, low maintenance costs due to the lack of moving parts and if produced with renewable energy it enables the export market of renewable energy. Another use in the energy market, which some thermal plants apply today, is its application for cooling the thermal reactors, hydrogen is pumped as a gas and at a certain pressure where it works as a cooling agent, withdrawing heat from the reactor.

- Heat: This gas can be burnt to generate heat but burning things isn´t the only way of producing heat. When hydrogen is used in a CHP (combined heat and power) or in a fuel cell, the process is exothermic, it releases heat. This is a very important factor, because now hydrogen can be used at the same time for two purposes, increasing its efficiency and lowering the costs. It can also be blended in the gas grid, lowering the CO2 emissions from the gas network. We can blend up to 20% hydrogen with the gas pipelines without having to adjust existing infrastructure.
- Transport: For this application vehicles use fuel cells to convert the hydrogen with oxygen from the air into water steam, that is the only emission produced, and electricity, which is used to power the vehicle. Hydrogens energy to weight ratio is ten times greater than lithium-ion batteries. This means having greater range with lighter weight and smaller volume, allowing FCEV (Fuel Cell Electric Vehicles) to be ideal for decarbonizing the heavy-duty transport.

When thinking of hydrogen as *feedstock* there are also many diverse applications:

- Ammonia: Hydrogen gas is the main feedstock to produce ammonia through the Haber-Bosch process. It consists of the reaction of between nitrogen and hydrogen gas to produce ammonia, which is used as feedstock for the chemical industry, as a fertilizer, for the petrochemical industry, as a cooling agent and even there are fuel cells developed to split the NH3 (Ammonia), into N2 (Nitrogen), that is released into the environment which, by being a inert gas, it is not toxic and does not affect the global warming nor the balance of the atmosphere; and also it produces Hydrogen that reacts with oxygen from the air generating water steam and also electricity that can be used to power a car or even used as a backup. The water steam can also be captured by condensation and be used as pure water or electrolyzed to produce more hydrogen and begin the cycle of hydrogen in a fuel cell.
- Chemicals: Hydrogen gas is used as feedstock for the chemical industry to produce hydrogen peroxide, hydrogenation process, for machines that use hydrogen gas and multiple other uses.
- Petrochemical: Hydrogen is used as feedstock for hydrogenation process of oil, benzene and many other processes in the petrochemical chain.
- Glass Industry: Uses hydrogen gas as a protective gas in the production.
- Metal Industry: Used in the production of carbon steels, special metals and semiconductors used in the electronics industry. Hydrogen is used as a reducing agent and as a carrier gas.
- Synthetic industry: Hydrogen is used in the production of syn gas, synthetic fuels by hydrogenation.
- Food Industry: Used for hydrogenation of oils, butter, chocolates and margarine. This allows a more stable product that can tolerate higher temperatures.

As we can see using green hydrogen, we can decarbonize a great amount of industries at once, not only the energy market, but at least 8 markets at once. For this to happen in an efficient way we need to analyze ways to export hydrogen and it being economically viable. This is the challenge that hydrogen is facing today, that needs to be solved as soon as possible in order to enable the hydrogen economy, hydrogen must be transported in a safe and cost-effective manner. The carriers of hydrogen studied up to date are:

- LH2: Liquefied hydrogen has requirements for the distribution. They depend on cryogenic equipment, this technology has a high CAPEX because of the conditions that Liquefied Hydrogen needs to be transported in this state and ensuring a safe distribution.
- CH2: Compressed hydrogen needs the use of high-pressure tankers or pipeline. There are safety issues that need to be considered, but it is cheaper when compared with liquefied hydrogen. This is because the liquefaction process and the cryogenic storage has a higher CAPEX versus the compressed gas, but when discussing safety issues, liquefied hydrogen is safer. If we have a leak of hydrogen gas, as it is so light, it can be dissipated quickly with CO2 (carbon dioxide) or even air flux. In the case that a molecule of hydrogen reacts with oxygen in an explosive reaction, this is why it is more dangerous than using liquefied hydrogen, which by its state and due to cold temperatures it can cause cold burns, but as a liquid it is biologically inert, displacing oxygen gas. Even though it won't react with oxygen gas it is still a flammable liquid that can ignite easily.
- NH3: This carrier consists of a technology that is cheap and can be easily stored. With more than 100 years of experience working with ammonia, this technology is well established and regulated. Ammonia can be stored in its liquid state at -33.4 degrees Celsius at 1 bar pressure, lowering the CAPEX and OPEX of the process management.
- LOHC: Liquid Organic Hydrogen Carrier is an easy and safe way of transporting hydrogen. This transport consists of a two-step process based in hydrogenation of an organic molecule into LOHC and then once delivered dehydrogenating the molecule back into its original state, extracting the pure hydrogen. Even though it consists of a two-step process, that will increase the costs, LOHC is liquid at ambient condition and have similar properties as the crude oil. This means a much cheaper transport and that can use existing infrastructure from the oil industry, being a cheaper and safer way of transporting hydrogen.

A comparison of the technologies will be presented in the following chart.

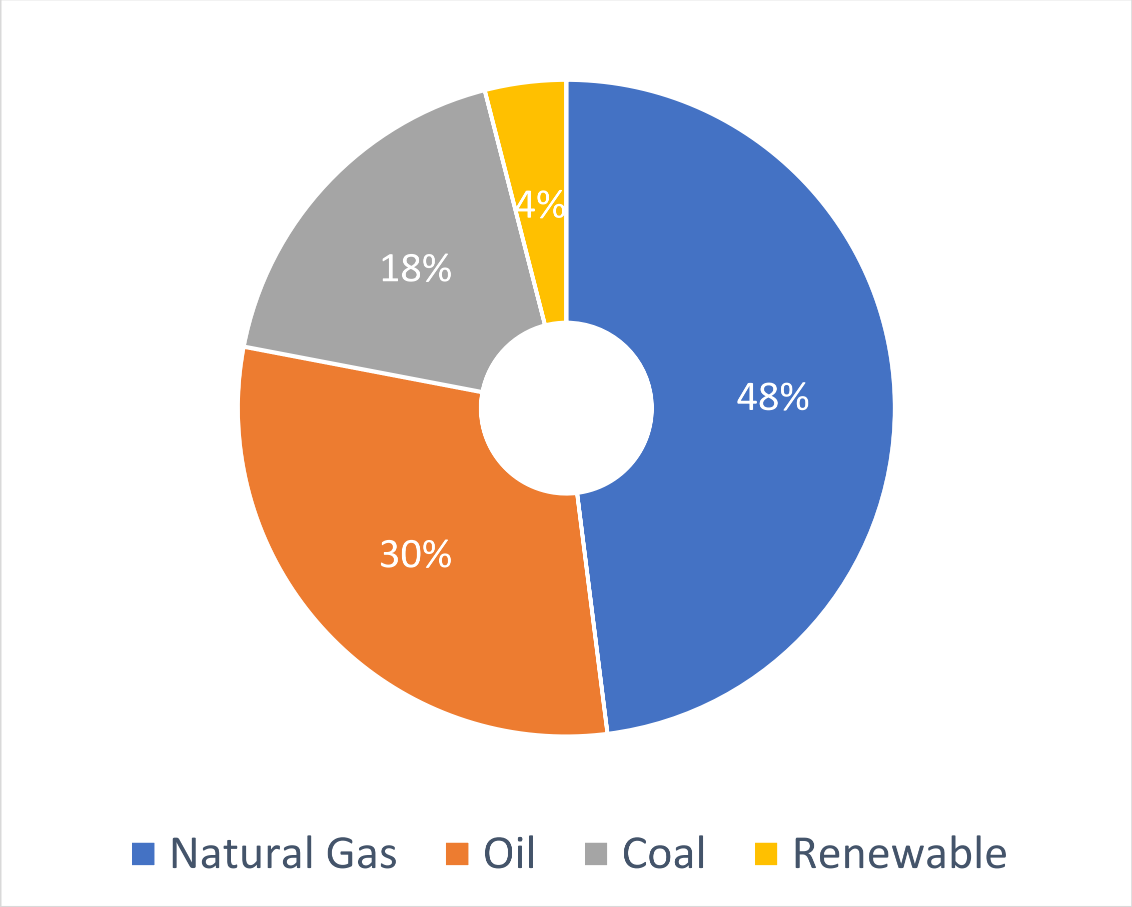
| | **LOHC** | **LH2** | **CH2** | **NH3** |
|---|---|---|---|---|
| **1 Ton of H2** | 18 m3 | 14 m3 | 12 m3 | 10 m3 |
| **Transport Maturity** | Development | Early Stage | Development | Mature |
| **H2 Extraction** | Good Efficiency | Excellent Efficiency | Excellent Efficiency | Excellent Efficiency |
| **Toxicity** | Non | Low | Low | High |
| **Safety** | High | Medium | Low | High |

## GLOBAL HYDROGEN SITUATION

Hydrogen is a subject that has been studied for more than twenty years. Today it has caught attention of many people, mainly driven by the energy transition and the need of decarbonization. In this part of the debrief we will analyze what is the situation of hydrogen up to date (2020).

### Production

Recent studies, done by DNV-GL, show a global production of 70 million tons per year of hydrogen gas. When analyzing the production chart, done by the author of the debrief, we can see that 96% of the global production of hydrogen comes from fossil fuels and only 4% from renewables. This can be because of technology costs, because of the use of existing infrastructure and because it is the technology that has been used by the major oil companies to produce a cheap hydrogen for their petrochemical processes.

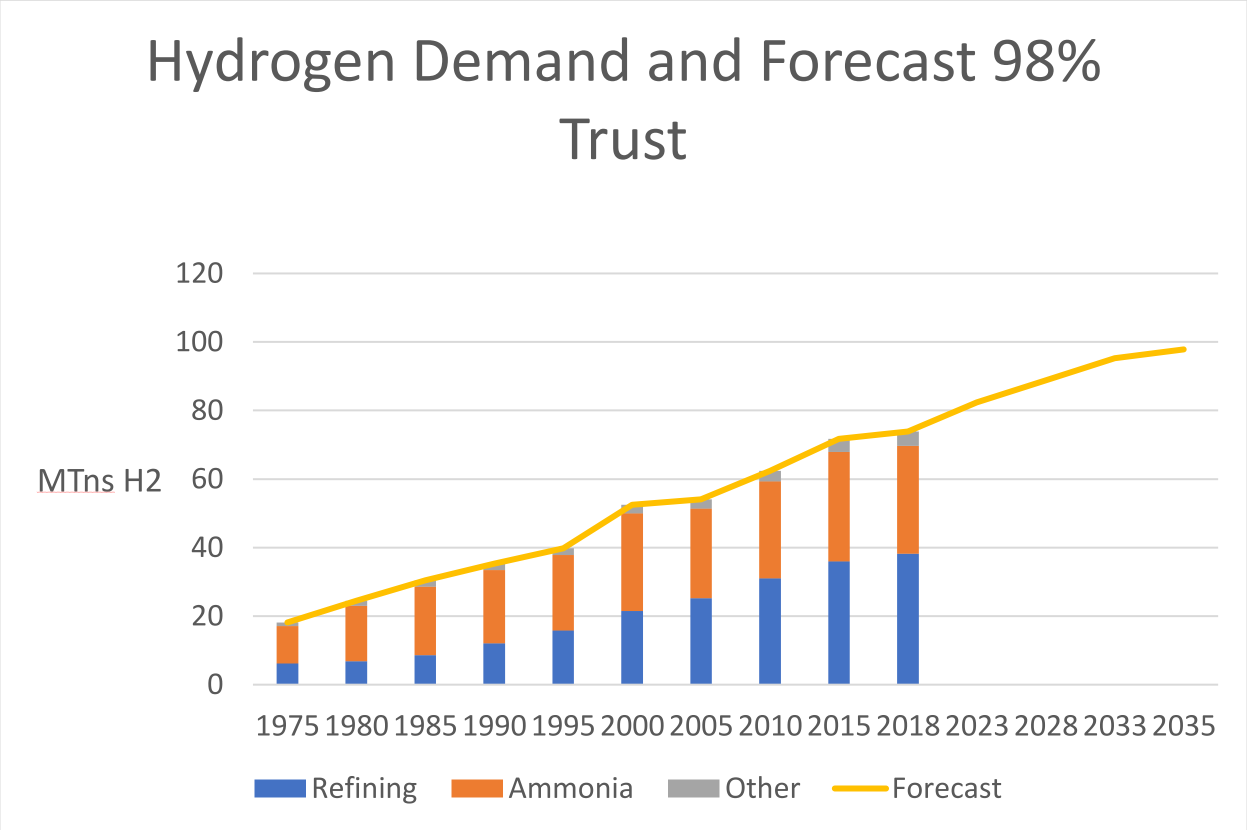



*Hydrogen Global Production by Feedstock 4*

If the costs of renewable energy decrease, the share of green hydrogen, produced by renewables energy, will increase and with policies that promote the use of hydrogen, the amount produced will also increase. We can see that the use of coal is less than oil and gas for hydrogen production, mainly because of decarbonization policies and the efficiency of the steam reforming technology, which is higher than the gasification of coal. Oil and gas lead the share of feedstock for hydrogen production. In the transition to a cleaner and more sustainable production process CCS, carbon capture and storage, can be applied in order to reduce the amount of emissions in the production process. The top producers of hydrogen are the United States, South Korea, Japan, Kuwait and Germany.

## Demand

In this section we will use the demand provided by the International Energy Agency, with a forecast done with a 98% trust analysis.

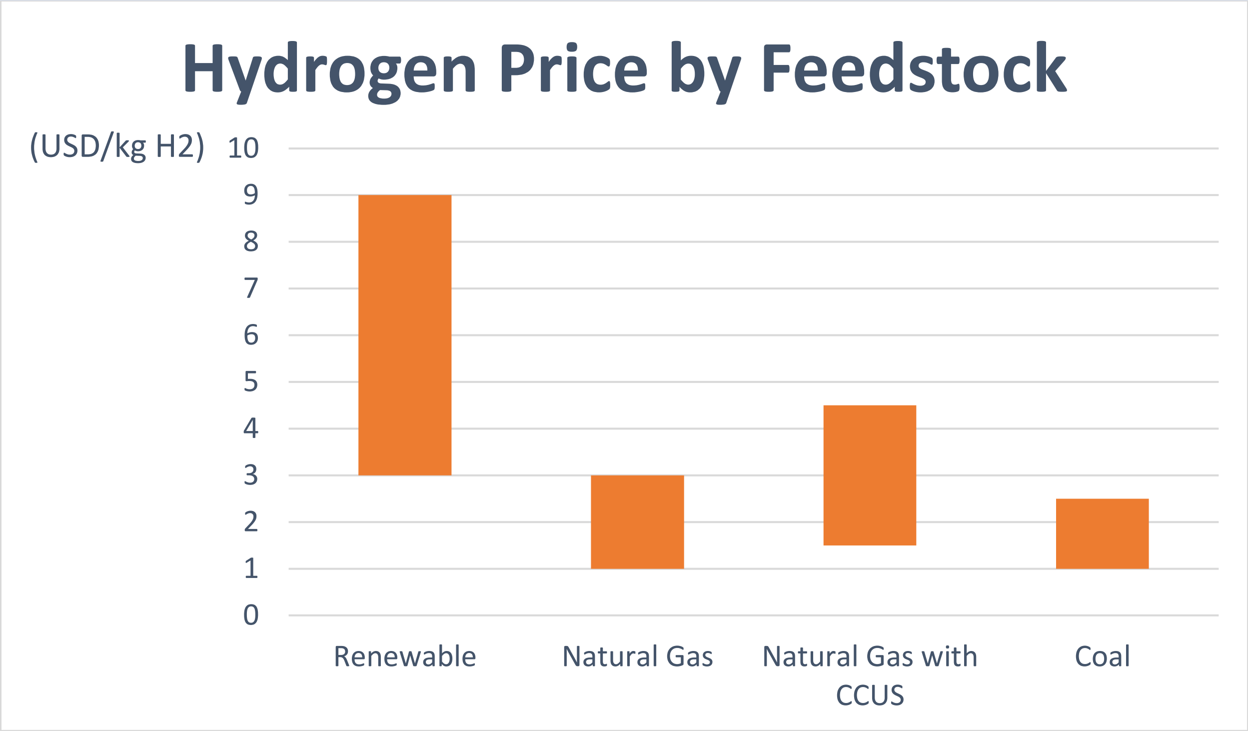



*Hydrogen Demand 5*

As shoed in the chart we can see that approximately 90% of the demand of hydrogen up to 2018 was for refining and ammonia production. The 10% that is under the label of "other" is used for the food industry, fuel cells and the other applications discussed on the past sections of the debrief. With this information a forecast was done, and we can expect an increase on the demand of hydrogen. Analyzing the curve, the slope decreases on 2028, this can be due to all the investments done on hydrogen and companies waiting to see the market's reaction. The increase of hydrogen demand can be firstly because of the increase of the ammonia demand for fertilizer and because of the incentives by policymakers and governments promoting the use of green hydrogen as an energy carrier to decarbonize the energy mix and industrial sector. Another variable to see in the chart is that the hydrogen demand shows an uptrend since 1980's with a 3% yearly increase up to date, with the forecast we can expect this increase to be of 7% yearly in the next decade.

## Prices

In this part we will discuss the prices of hydrogen, which have a widespread depending on the production technology, efficiency and feedstock. The data used for the chart presented was provided by the International Energy Agency.




*Hydrogen Price by Feedstock 6*

The bigger spread on the price is with renewables, this is because it depends a lot on the resource used (mini hydro, geothermal, solar or wind), the energy mix of the country and its price, if the electrolyzer is connected to the grid or directly to the power source. But the main reason of the spread in the costs is because of the renewable's prices, if costs keep on decreasing, green hydrogens cost will decrease as well. The costs of natural gas and coal are similar, but these tend to increase by a factor of 0.5 approx. when implementing carbon capture, which increases the CAPEX of the technology. This chart relates with the chart number 4 of the global share of hydrogen production. Understanding the costs will help explain why most of hydrogens production comes from fossil feedstock.

Below we present a chart, made by the International Energy Agency, where we can see the price composition by technology, stipulating CAPEX, OPEX, efficiency and other parameters. They are all presented with todays costs, a forecast with a BAU, business as usual, market for 2030 and a Long-Term strategy for 2050.

With those prices and variables detailed below we obtain a medium price for hydrogen of:

| Technology | Medium price |
|---|---|
| Renewable | 6 USD/KgH2 |
| Natural gas | 2 USD/KgH2 |
| Nat with CCUS | 3 USD/KgH2 |
| Coal | 1.5 USD/KgH2 |

| Technology | Parameter | Units | Today | 2030 | Long term |
|---|---|---|---|---|---|
| Water electrolysis | CAPEX | **$USD/kW_e$** | 900 | 700 | 450 |
| | Efficiency (LHV) | **%** | 64 | 69 | 74 |
| | Annual OPEX | **% of CAPEX** | 1.5 | 1.5 | 1.5 |
| | Stack lifetime (operating hours) | **hours** | 95 000 | 95 000 | 100 000 |
| Natural gas reforming | CAPEX | **$USD/kW_{H_2}$** | 910 | 910 | 910 |
| | Efficiency (LHV) | **%** | 76 | 76 | 76 |
| | Annual OPEX | **% of CAPEX** | 4.7 | 4.7 | 4.7 |
| | Emission factor | **$kgCO_2/kgH_2$** | 8.9 | 8.9 | 8.9 |
| Natural gas reforming with carbon capture | CAPEX | **$USD/kW_{H_2}$** | 1 680 | 1 360 | 1 280 |
| | Efficiency (LHV) | **%** | 69 | 69 | 69 |
| | Annual OPEX | **% of CAPEX** | 3 | 3 | 3 |
| | $CO_2$ capture rate | **%** | 90 | 90 | 90 |
| | Emission factor | **$kgCO_2/kgH_2$** | 1.0 | 1.0 | 1.0 |
| Coal gasification | CAPEX | **$USD/kW_{h_2}$** | 2 670 | 2 670 | 2 670 |
| | Efficiency (LHV) | **%** | 60 | 60 | 60 |
| | Annual OPEX | **% of CAPEX** | 5 | 5 | 5 |
| | Emission factor | **$kgCO_2/kgH_2$** | 20.2 | 20.2 | 20.2 |
| Coal gasification with carbon capture | CAPEX | **$USD/kW_{H_2}$** | 2 780 | 2 780 | 2 780 |
| | Efficiency (LHV) | **%** | 58 | 58 | 58 |
| | Annual OPEX | **% of CAPEX** | 5 | 5 | 5 |
| | $CO_2$ capture rate | **%** | 90 | 90 | 90 |
| | Emission factor | **$kgCO_2/kgH_2$** | 2.1 | 2.1 | 2.1 |

*Hydrogen Price by IEA 7*

In the table above we can see that for all the other methods of production that aren´t based on renewable energy we also stipulate the emission factor associated with that technology.

Below we present another table of the International Energy Agency, which was used for this debrief where we see the variables considered when calculating the ammonia costs.

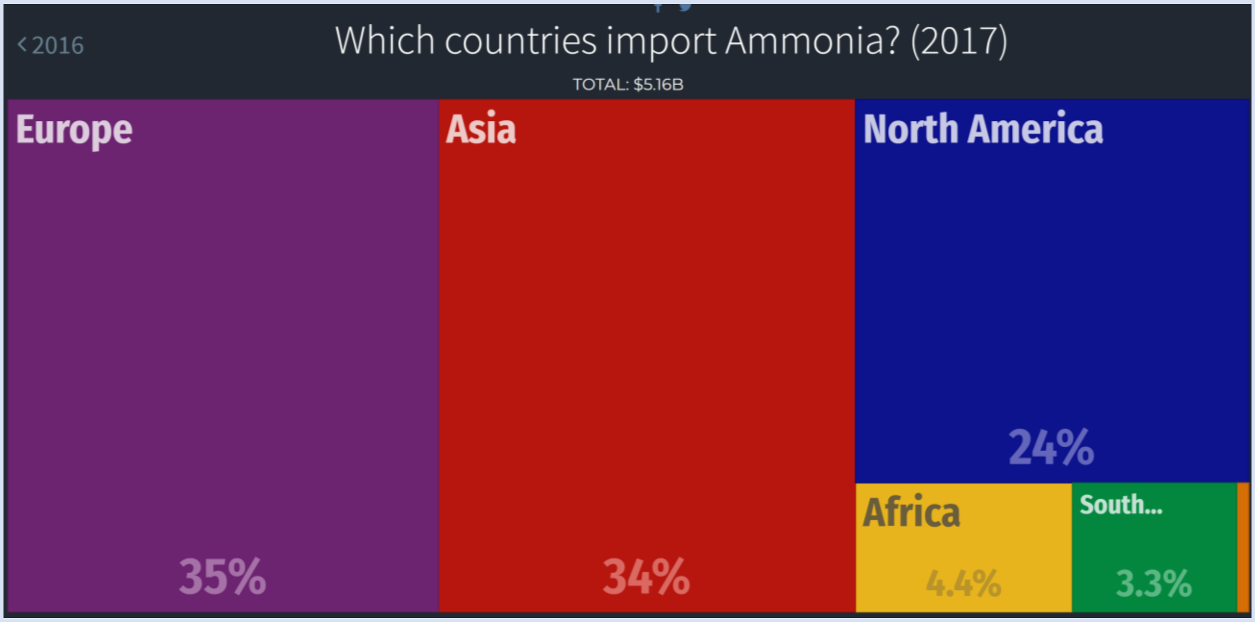
| Feedstock | Parameter | Units | Today | 2030 | Long term |
|---|---|---|---|---|---|
| Natural gas | CAPEX | $USD/tNH_3$ | 905 | 905 | 905 |
| | Annual OPEX | % of CAPEX | 2.5 | 2.5 | 2.5 |
| | Gas consumption | $GJ/t_{NH_3}$ | 42.0 | 38.3 | 32.2 |
| | Electricity consumption | $GJ/t_{NH_3}$ | 0.3 | 0.3 | 0.3 |
| | Emission factor | $kgCO_2/kgNH_3$ | 2.35 | 2.14 | 1.8 |
| Natural gas w/CCUS | CAPEX | $USD/tNH_3$ | 1 315 | 1 260 | 1 165 |
| | Annual OPEX | % of CAPEX | 2.5 | 2.5 | 2.5 |
| | Gas consumption | $GJ/t_{NH_3}$ | 42.0 | 38.3 | 32.2 |
| | Electricity consumption | $GJ/t_{NH_3}$ | 1.3 | 1.3 | 1.3 |
| | Emission factor | $kgCO_2/kgNH_3$ | 0.12 | 0.11 | 0.09 |
| Coal | CAPEX | $USD/tNH_3$ | 2 175 | 2 175 | 2 175 |
| | Annual OPEX | % of CAPEX | 5 | 5 | 5 |
| | Coal consumption | $GJ/t_{NH_3}$ | 38.4 | 38.4 | 38.3 |
| | Electricity consumption | $GJ/t_{NH_3}$ | 3.7 | 3.7 | 3.7 |
| | Emission factor | $kgCO_2/kgNH_3$ | 3.9 | 3.9 | 3.9 |
| Coal w/CCUS | CAPEX | $USD/tNH_3$ | 2 810 | 2 810 | 2 810 |
| | Annual OPEX | % of CAPEX | 5 | 5 | 5 |
| | Coal consumption | $GJ/t_{NH_3}$ | 38.4 | 38.4 | 38.3 |
| | Electricity consumption | $GJ/t_{NH_3}$ | 5.3 | 5.3 | 5.3 |
| | Emission factor | $kgCO_2/kgNH_3$ | 0.2 | 0.2 | 0.2 |
| Biomass | CAPEX | $USD/tNH_3$ | 6 320 | 6 320 | 6 320 |
| | Annual OPEX | % of CAPEX | 5 | 5 | 5 |
| | Biomass consumption | $GJ/t_{NH_3}$ | 45.0 | 45.0 | 45.0 |
| | Electricity consumption | $GJ/t_{NH_3}$ | 5.0 | 5.0 | 5.0 |
| | Emission factor | $kgCO_2/kgNH_3$ | 0.0 | 0.0 | 0.0 |
| Electrolysis | CAPEX | $USD/tNH_3$ | 945 | 855 | 760 |
| | Annual OPEX | % of CAPEX | 1.5 % | 1.5% | 1.5% |
| | Electricity consumption | $GJ/t_{NH_3}$ | 37.8 | 35.3 | 33.2 |
| | Emission factor | $kgCO_2/kgNH_3$ | 0.0 | 0.0 | 0.0 |

*Ammonia Costs by IEA 8*

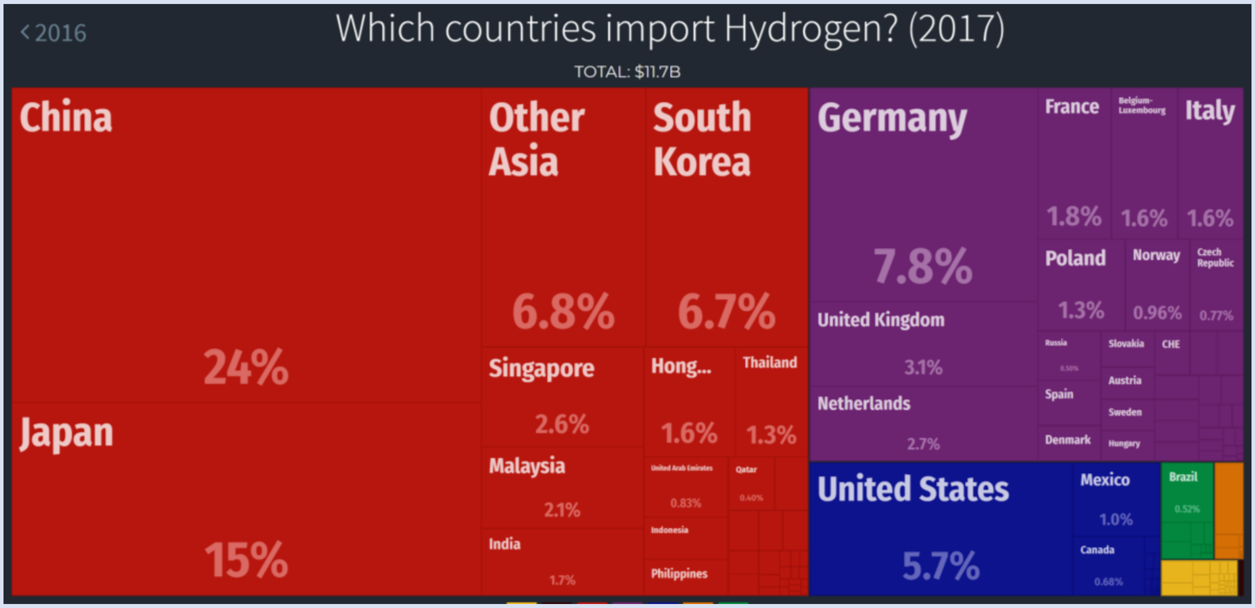
For ammonia it's the same case as with hydrogen, we have the emissions factor by technology and the price today (2020), the expected for 2030 and the forecast for long term being 2050.

## Hydrogen and Ammonia Imports

We can´t talk about the global situation without considering what is going on with the imports of hydrogen and ammonia globally. The information used for this section was provided by OEC World. Both ammonia and hydrogen imports represent an 18 Billion USD/year industry. When looking at the charts below on Image 9 and 10, we can see that more than half of the ammonia imports are for Europe and Asia, being a 35% of the share for Europe and 34% for Asia. On the other hand, when looking at the chart number 10, we can see that for hydrogen is a totally different scenario. Where almost half of the imports are for Asia, being of 46% and then Europe for a 29% of the imports share.




*Ammonia Imports By continent 2017 by OEC 9*




*Hydrogen Import by Country 2017 by OEC 10*

Once we analyze these charts we can get to the following conclusions: Almost half of the global imports of hydrogen are for Asia and in the case of Ammonia, Asia and Europe lead the imports market. When studying the numbers provided by OEC, we could design the table of the top 4 leaders and importers of ammonia and hydrogen. When looking at the table presented below, we can see the potential market and countries for developing a hydrogen and ammonia business models. These four countries are responsible for 47.7% of the hydrogen imports, which represent 5.588 BUSD per year and 25.4% of the ammonia market imports which represent a total of 1.25 BUSD per year.

| Country | Hydrogen Import in USD | Hydrogen Import in % of global market | Ammonia Import in USD | Ammonia import in % of global market |
|---|---|---|---|---|
| South Korea | 783 MUSD | 6.7% | 380 MUSD | 7.4% |
| India | 205 MUSD | 2% | 600 MUSD | 12% |
| China | 2.8 BUSD | 24% | 206 MUSD | 4% |
| Japan | 1.8 BUSD | 15% | 64.7 MUSD | 2% |

In conclusion, we can say that if we where thinking of developing a business model for hydrogen and ammonia, ASIA would be the most promising buyer and where we should aim. Also we can see that the demand of hydrogen and ammonia is in an uptrend, which is very good, meaning that this is the ideal time to get in this market and invest in green hydrogen considering that all recent studies, done by the major agencies forecast this uptrend. We should also consider that with hydrogen multiple businesses will emerge, diversifying the offer and demand.

## NEW ZEALAND´S SITUATION

In this section we will analyze what is the current situation in New Zealand regarding the energy market, hydrogen, emissions and the ammonia industry. First, we will begin studying what is the energy mix that this country has and what is the impact of this matrix.

### Energy Mix

Today New Zealand has a 40% share of renewables in the energy mix, being the third highest rate of renewable energy as a portion of primary supply in the OECD. This means that 60% of the energy mix comes from fossil sources.

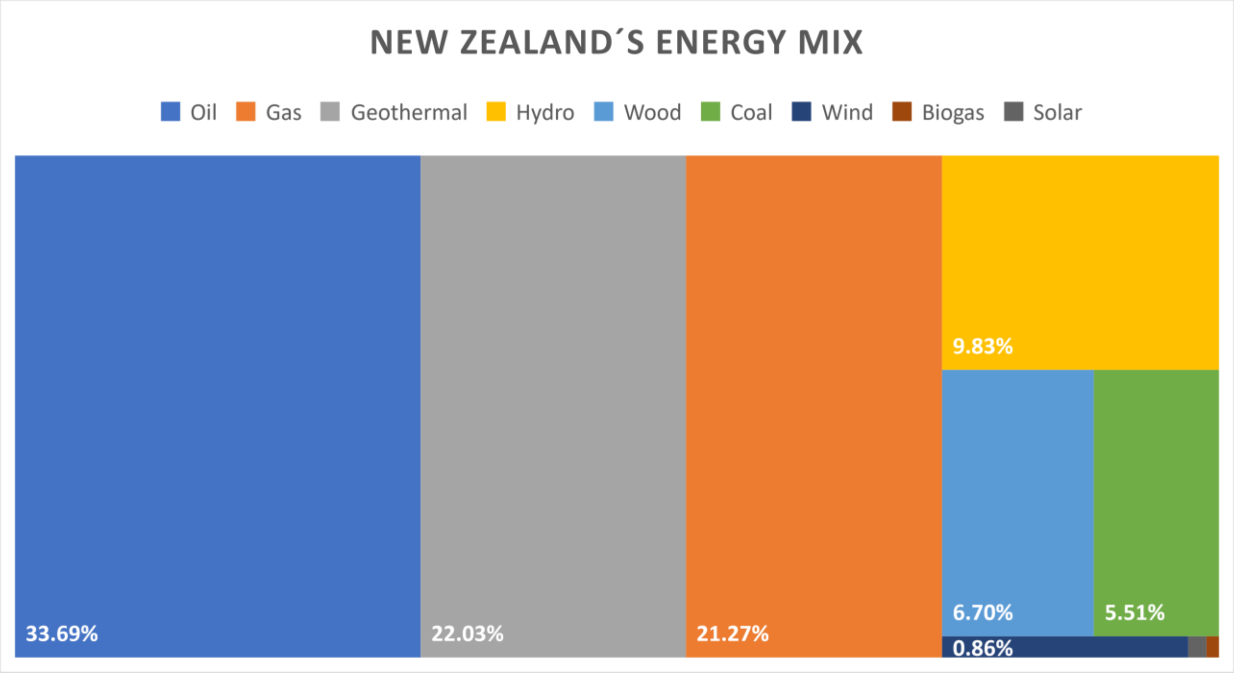
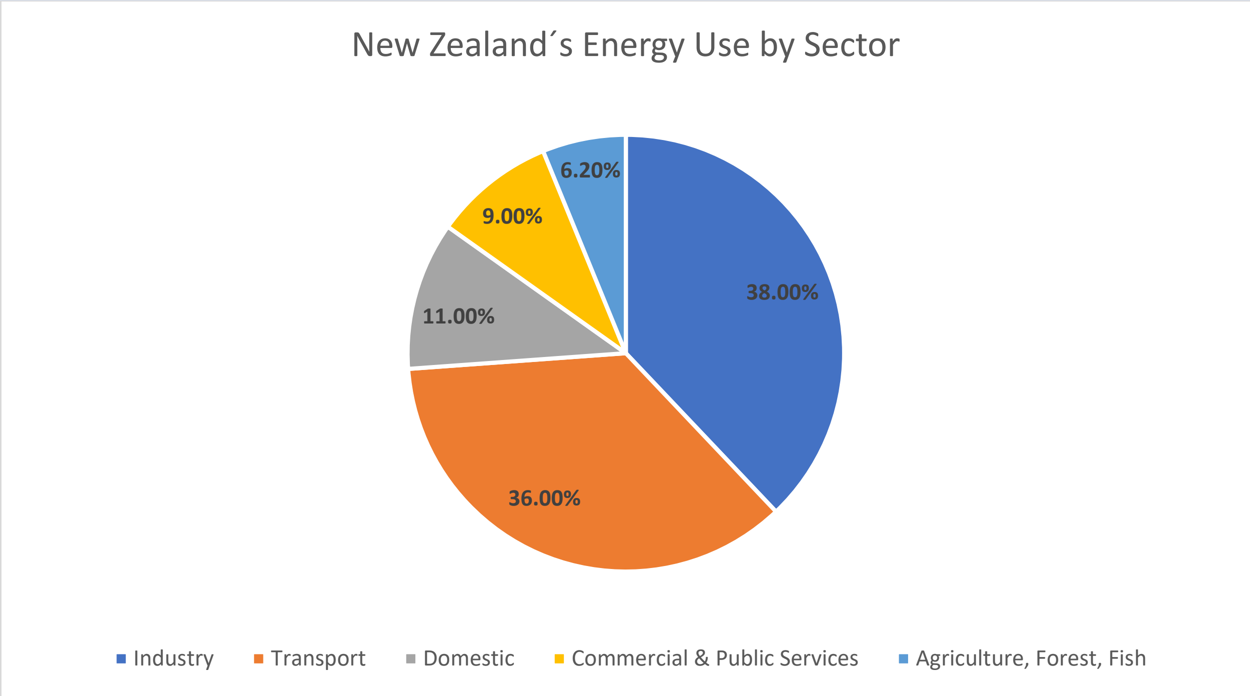



*Chart made with Data by NZ Government 11*

We can see that the biggest share of renewable sources comes from geothermal, which is a resource that has a great quality and potential in New Zealand. Nevertheless, they still have more than half of the mix that relies in fossils, mostly oil and gas. What does a 60% of fossils in the energy mix mean? Well they are responsible for 40% of New Zealand´s total $CO_2$ emissions, which are 31.475 kTn/Yr. This is almost half of the country´s emissions, but we need to take into account that the total emissions from New Zealand are approximately 0.15% of the global emissions, even though its contribution to the worlds emission is very small, the gross emissions of the country have increased by 19% since the 1990s. The consumption of oil is of 49 M barrels per year and 4.7 B cubic meters of natural gas per year.

### Energy Use Per Sector

Another variable that will be discussed is what is the end use of this energy. This data was provided by Energy-Mix Nz and was used to make the following chart.



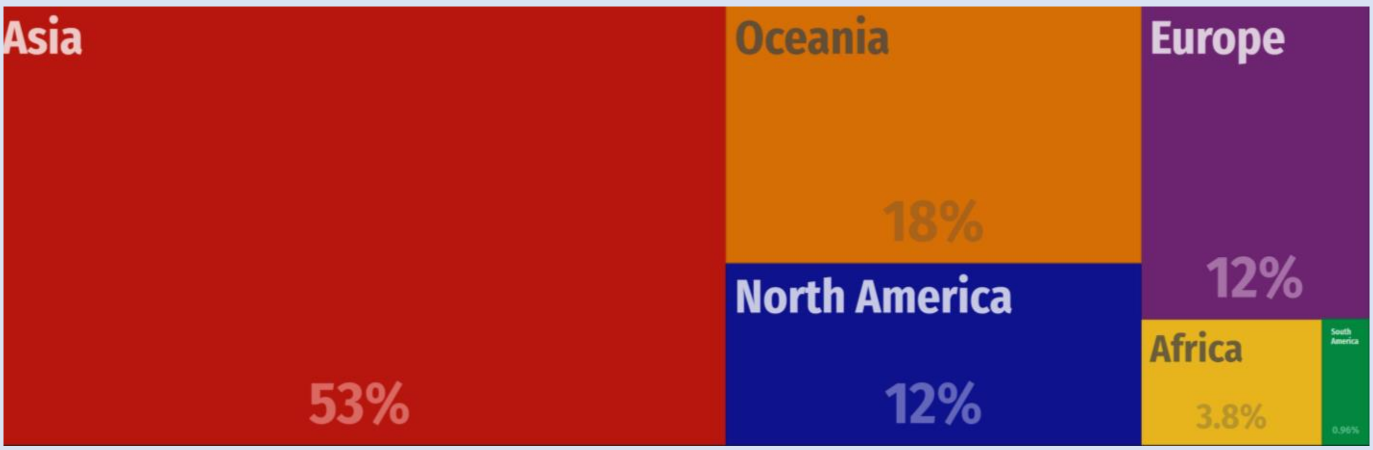

*New Zealand Energy Use by Sector 12*

this chart and a little research we could find that the Agricultural sector is not a big consumer of energy, but when looking at its emissions, it is responsible for 49% of the total New Zealand emissions, so we can estimate that half of the country's emissions are due to this sector. More than half of the country's energy is destined to Industry and transport. Inside the energy sector, transport is responsible for 43.5% of CO2 emissions. So, when thinking in sustainable projects, one of the main issues to solve is the emissions produced by the agricultural sector, because the fact that they don't consume a lot of energy doesn't mean that they are emissions free. Secondly, when thinking of green energy projects to decarbonize the energy mix, we should aim to the industry and transport sector, being transport a priority because of the high emissions. Hydrogen can be a clean energy carrier and a solution to all these problems. It will act as a clean energy carrier and a decarbonizer at the same time.

## New Zealand Exports

Something that is very important to analyze is what is New Zealand exporting to support their economy. They are the 57$^{th}$ largest export economy in the world and the 41$^{st}$ more complex economy according to the Economic Complexity Index. The last studies done by the OEC, registered that New Zealand exported a total of 37.3 B USD and imported a total of 36.3 B USD, resulting in a positive trade balance of 988 M USD. The country's GDP Is 205 B USD which is around 41.1 K USD per capita. Almost half of the export are based on animal products, this is due to the great agricultural resource and that it represents around 54% of the country's economy.


*New Zealand Export by product by OEC 13*




*New Zealand Export by Country by OEC 14*

More than half of the exports are for Asia, where China, South Korea and Japan are the top buyers. This makes sense considering the quality of the products, the cost of the distribution and the short distance.

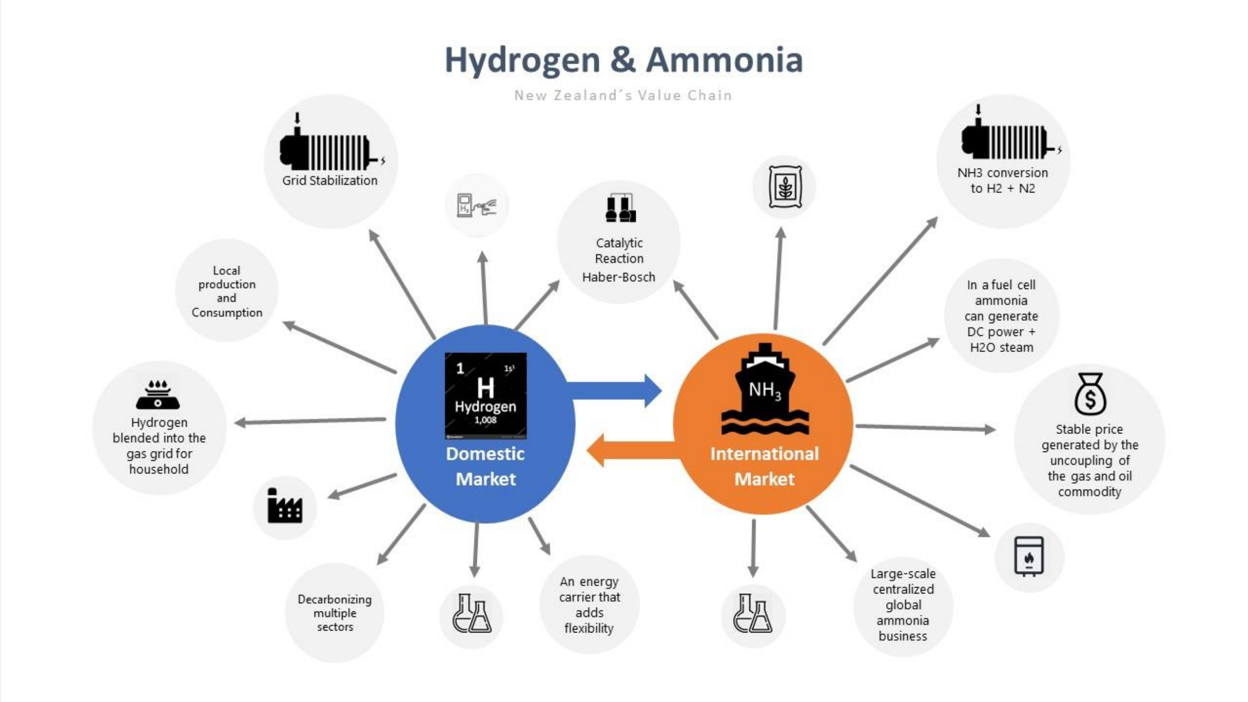
Summarizing, New Zealand is a country with a lot of potential, with a lot of resources and a positive trading balance. They have a 60:40 (fossil and renewable percentage) energy mix, which is a very good share, but it can be improved. The problems that need to be solved as soon as possible are the agricultural emissions, the transport emissions and the industrial energy use. When thinking of possible alliances for an export business model we should think in aiming at Asia, principally South Korea, India, China and Japan that are the ones that already have trading routes defined with New Zealand.

## BUSINESS MODEL

With all the information above, research and studies we designed a business model for developing an economically viable hydrogen and ammonia value chain, in order to enable the hydrogen economy and positioning New Zealand as a top energy transition leader. When we developed this concept, we thought on the following variables:

- Promoting the investment in renewable energy sources.
- Paris agreement and the commitment of New Zealand to reach net zero emissions.
- Choosing a model that can be accepted locally.
- Implementation of a way of exporting clean energy and satisfying international demands.
- Use as a foundation existing infrastructure and know how.

### Hydrogen and Ammonia Value Chain




*H2 & NH3 Value Chain 15*

The model is based on developing hydrogen and ammonia economy. We considered splitting the market in domestic and international. The domestic market will be supplied by pure green hydrogen and the international by green ammonia. The first thing we need to understand is that green hydrogen can be transformed into ammonia by a synthetic reaction and ammonia can be split into hydrogen by a catalytic reaction, meaning that is a reversible process named Haber-Bosch process.

What led us to leave hydrogen for the domestic market was basically the costs and the challenges that exporting hydrogen represents, that's why we suggest ammonia to be the carrier for hydrogen in ships. A recent study, done by the International Energy Agency with Australia as an example, presented that the cost of hydrogen for a domestic market is cheaper, 6.4 USD per Kg of H2 and for the export market it is cheaper to provide ammonia at 5.4 USD per Kg of H2 versus pure hydrogen and LOHC. These costs consider the reconversion factor, distribution, transmission, export and import terminals, conversion and production costs. On the other hand, another factor that led for choosing ammonia as a export carrier was, that the country already exports ammonia, they already have a defined trading route, the know-how, the safety of transporting it and also that there is existing infrastructure which reduces substantially the costs.

## Domestic Market

When talking about hydrogen we will assume that it was produced by a renewable source of energy and electrolysis, ensuring a high purity and zero emissions product. What is so noble about hydrogen is the diverse applications and that by decarbonizing just one thing we will be collaborating to decarbonizing multiple sectors at once.

The *first* application is as a *fuel* either on a fuel cell or a combustion engine. Hydrogen can be used as a way of providing a 100% renewable carbon free fuel. Unless a battery car is charged directly by a renewable energy source, or by a hundred percent renewable energy grid, it will always have emissions associated with the electricity used by the vehicle. So, hydrogen can be a way of providing the transport sector with a clean fuel. Hydrogen can begin with heavy duty transport, where hydrogen has a lot of advantages versus lithium ion batteries and later, when the costs drop, we can begin with applications on light vehicles.

Hydrogen can be used for *grid stabilization*, when we reach moments of peak demand, fuel cells with a fast response will be able to provide with the electricity needed for the grid. The same can happen when we have a surplus of energy and low demand, that excess energy can be destined to an electrolyzer and produce hydrogen for a backup in the case of future needs. A good thing of hydrogen is that it does not discharge with time so we can count on a determined backup of hydrogen as potential power with the security that it wont decrease with time.

*Local production and consumption* will generate more jobs positions, more investments in renewable energy, help the country reach its objectives of sustainable development, a market that will have access to an affordable, secure and sustainable fuel and feedstock for processes. For the production of hydrogen we consider using offshore wind and solar farms, because of the little free space and trying to leave as much onshore space free for the agricultural sector which Is very important for the country´s development, and both on and offshore electrolyzers that can both use sweet water or water from the sea with a desalination membrane. The hydrogen produced can be transported inside the country with a pipeline, studies show that up to 1500km pipeline construction are economically viable for hydrogen transport. Considering that the New Zealand is approximately 1600km long, connecting the country in key spots for the hydrogen pump in the pipelines, this investment and project is viable. We should also consider that because of the size of the country it won’t be needing many refueling stations, is just a case to study the “hotspots” where they should be installed.

*Hydrogen for blending in the gas* grid is another possibility that can be up to 20% blend without having to change neither infrastructure nor appliances. This can begin as a trial run of hydrogen blending and injection to the grid, that it helps decarbonizing the gas grid as well, because we will have less end use emissions and transition into a 100% hydrogen grid with the cash flow from the business models and reinvestment in the readjustment and building of new pipelines, that in the case of already building the hydrogen pipeline for its transport, the same infrastructure can be used for supplying the houses with this gas. One thing to have in mind is that the appliances need to be changed or readjusted for the use of 100% hydrogen gas, due to its density and pressure.

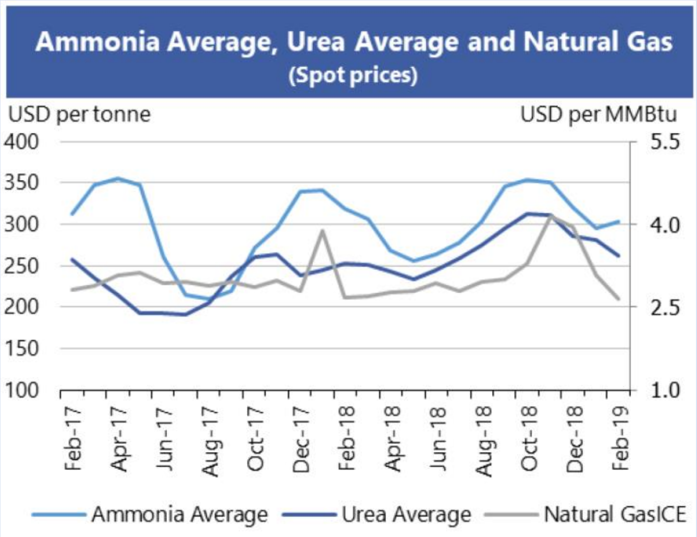
*Industry* is also a user of hydrogen, as we detailed in the above sections, but we can now provide them with a high purity green hydrogen, this way they will have less emissions associated with their processes and collaborate with the mitigation of emissions. This green hydrogen can be a marketing tool that adds value to their products that use clean hydrogen. The same concept applies for the food and *chemical industry*. Another application is as a cooling agent for both large scale refrigeration and data centers, where it shows a lot of benefits such as being used for *cooling* and electric generation.

Some may ask why now, what changed in all of these years where we used hydrogen but no one spoke about a hydrogen economy, well firstly the energy transition into a more sustainable energy system and secondly we no longer see hydrogen as a gas that can generate electricity when used in a fuel cell. The new concept in this change of paradigm is seeing hydrogen as a *clean energy carrier*, that has the flexibility of being a decarbonizer of multiple sectors and enabler of clean energy trade, which up to date it is not possible with no other method nor technology. We can see a future where companies and investors will be able to trade renewable energy in the form of hydrogen.

## International Market

For the export of hydrogen, we chose ammonia as a carrier and as a secondary business. We saw a lot of secondary business models that arise with hydrogen, well the same thing happens with ammonia.

The first application of ammonia that comes to mind is the *fertilizer* industry, this is the most used product in the agricultural sector and providing green ammonia, may be more expensive than regular ammonia, but the fact that it is made by green hydrogen can ensure a stable price during the year. One problem that regular ammonia presents is that as it is produced by natural gas, its price depends on the price of the commodity as seen on the following chart provided by FAO (Food and Agriculture Organization).




*Ammonia, Urea and Gas price by FAO 16*

As we can see ammonias price is not stable and has a lot of volatility joint to the natural gas price. Nevertheless, the increase or decrease in the commodity price is not proportional to the increase or decrease on the price of ammonia. So, in this case we can provide a product that not only is “cleaner” but also that can allow a projection of costs during the year due to its stable price.

We should not forget that the main reason of choosing ammonia is to *carry hydrogen*, so another business model is to satisfy the hydrogen demand in the way of hydrogen for the international market. We saw the pros and cons of transporting H2 in the form of ammonia and when analyzing the PMI (Plus, minus and interesting) we can see that this way  has a lot of positive aspects, one of them being that we can send one ship just with ammonia, which already has the trading routes designed and the technology for its cheap transportation and we can then provide the ammonia as a feedstock or end product for those potential clients and also part of that ammonia split it into hydrogen and deliver the hydrogen on the demand spots.

Recent studies also show that *ammonia fuel cells* and cars are being developed so that is another potential market, the emissions will be N2 which is harmless and water steam, that can be condensed and then electrolyzed to produce hydrogen or just released into the atmosphere and use the ammonia to generate the electricity needed to power a car or as a power backup.

Ammonia boilers are being studied as well, a way of burning ammonia to generate *heat*. Scientists and engineers developed ways to use it for heat generation through burning furnaces for example. So, these are possible new businesses that will emerge in this period of transition. It is also used as a *cooling* agent in thermal processes, having a low cost and a high efficiency.

So, when we think in all the secondary businesses, we are generating a way of exploiting all the benefits that green hydrogen and ammonia present. This is why we chose this model, it adds flexibility, reliability and also enables a diverse range of businesses, allowing companies to have a product that can be sold in one way to different customers and end users allowing to reduce the market , default and concentration risks.

## *Drivers*

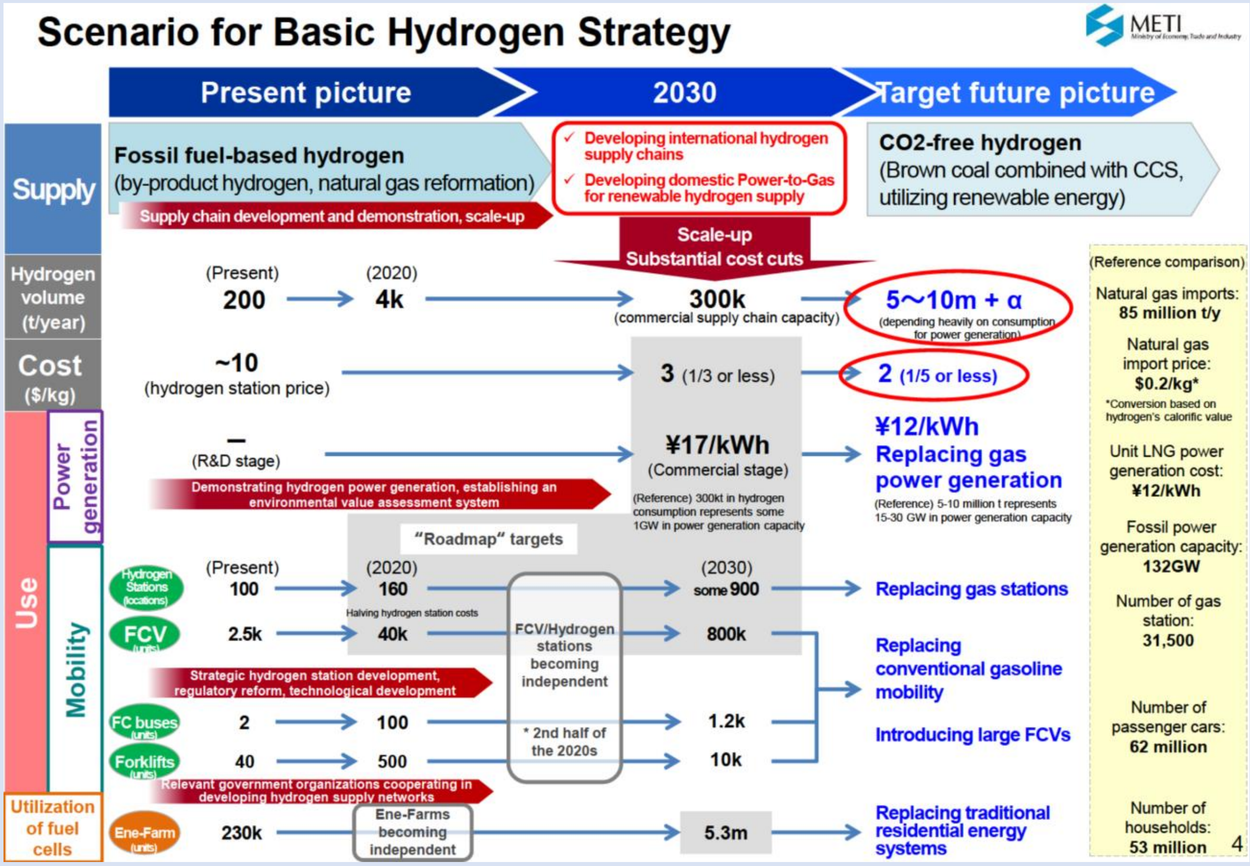
There are three pillars that probably will work as a driver for the application of this hydrogen model in New Zealand. Japans memorandum, New Zealand´s Green Paper and Net Zero. Proceeding to review each one of them:

- Japans Memorandum: this is a partnership with Japan to develop hydrogen technology. It is the first memorandum of its kind in the world. Aims to share know how and technology.
- New Zealand Green Paper: looks to signal the opportunity that hydrogen can bring to New Zealand and frame for a national strategy. This paper sets a roadmap for the country’s future of hydrogen development.
- Net Zero: the governments energy strategies set the policy direction and priorities focusing on transitioning to a net zero carbon emissions by 2050.

These three are related to all of the content written above, japans memorandum is a fundamental pillar for this business strategy aiming to provide them not only with green hydrogen to satisfy their demand but also with green ammonia that will replace regular ammonia as a more sustainable product. The green paper is a guideline for the investors to look at when analyzing this business model and the aim of this project is to collaborate with New Zealand achieving its objective of having 100% renewable energy mix by 2035 and reaching net zero emissions by 2050.

## Simulation

Japans hydrogen strategy was used for this exercise:




*Japans Hydrogen Strategy by METI 17*

We propose a scenario providing only 10% of Japans forecast demand and 10% of its actual ammonia demand, supplied by hydrogen in the form of green ammonia, considering that it will be used for both supplies.

Analyzing the share of renewables that New Zealand has today, the amount of oil used for ammonia production and for the transport sector, the gas used in households and calculating its associated CO2 emissions for each of this variables we came up with a possible scenario. Where the 100% renewable energy was reached, the replace of 30% ICE (internal combustion engines) in transport by BEVS (battery electric vehicles) and FECV (Fuel cells electric vehicles) and did the math to see what would be the cash flow and also the impact in emissions and oil usage.

| Variable | New Zealand 2019 | New Zealand 2035 | Dividends |
|---|---|---|---|
| Renewable Energy Mix | 40% | 100% | |
| Oil used by Transport Sector | 76% of total production | 61% of total production | |
| Gas in networks for heat | 100% Natural Gas | 20% of green Hydrogen and 80% natural gas | |
| Ammonia Export | 0% | 10% of Japans demand 41 kTn/Yr. | 20.1 M USD/Yr. |
| Hydrogen Export | 0% | 10% of Japans demand 916 kTn/Yr. | 7.9 B USD/Yr. |
| Total Emissions of these variables | 10 M Tn | 8 M Tn, presenting a 20% drop in emissions | |

As we can see this is just a scenario and can be applied for "n" number of scenarios, this was just done to see what impact it would have both in emissions and dividends the implementation of a hybrid hydrogen and ammonia model. The objective is to see that hydrogen will enable a cleaner path for New Zealand, being an example to follow in the energy transition and that it should aim to supply the domestic market with pure green hydrogen and exporting this gas in the form of ammonia, where then can be used for many things and also converting it back to hydrogen, but this model supports a free market where it can collaborate with the exports of the country as well, allowing to develop a stronger economy.

# CONCLUSION

The development of a hydrogen economy will provide with a flexible, zero emission, clean energy carrier. It can decarbonize multiple industries and has a high energy density, being ideal for its application in heavy duty transport. Hydrogen can be stored for large periods of time solving the clean energy storage problem. This is the basis for achieving sustainability, having a secure and reliable way of storing energy. Ammonia is a well-known product with an already built infrastructure, which lowers the CAPEX. It will allow to transport hydrogen, but it will also develop new business models as the ammonia detaches from the gas commodity price. Fuel cells that convert ammonia into water steam and electricity will be a technology that will fit very well in this business model.

## A possible roadmap

We should have in mind that plans are worthless, but that planning is everything, so we need to have a strategy and a roadmap if we wish to reach success. One of the first steps will be for the government to dictate a hydrogen decree, where they will give incentives for companies to invest in hydrogen. This decree could also set time frames for using steam reformers in a certain period with carbon capture so they can provide a cheaper and more affordable hydrogen and create a stable demand. Once this period passes by, they must commit to changing their production to green hydrogen. This can be one of the options, another can be that this decree establishes that in the cases of existing infrastructure hydrogen produced by steam reformers with carbon capture can be used for a determined period of time but the new projects need to be with green hydrogen. Once the hydrogen market begins to develop, reaching breakeven points companies can clean the process with the increase of the demand. We must never forget that the main objective is enabling the hydrogen economy to reach sustainability. Now there are some decisions that may not be the ideal, but they work as incentives and promotion for the major companies to investing in this kind of technology. Today we have the know-how, we have the technology and also, we have got a lot of people talking about this amazing vector, now we need to think of ways that can help develop the required demand in a economically viable way. In the meantime, cleaning the process as much as we can and having government and companies involved in a commitment to producing and supplying green affordable hydrogen.