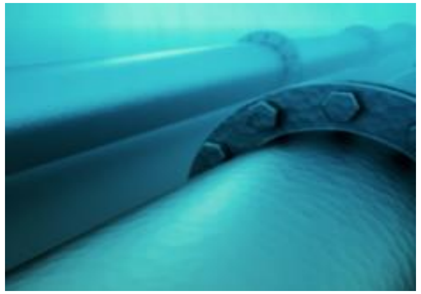
GECF

GECF TECHNOLOGY ROADMAP
HYDROGEN AND THE ROLE OF NATURAL GAS

December 2020







Disclaimer

This report is not intended as a substitute for your own judgment or professional advice for your business, investment, finance, or other activity. The analysis and views presented in this report are those of the GECF Secretariat and do not necessarily reflect the views of GECF Member and Observer Countries.

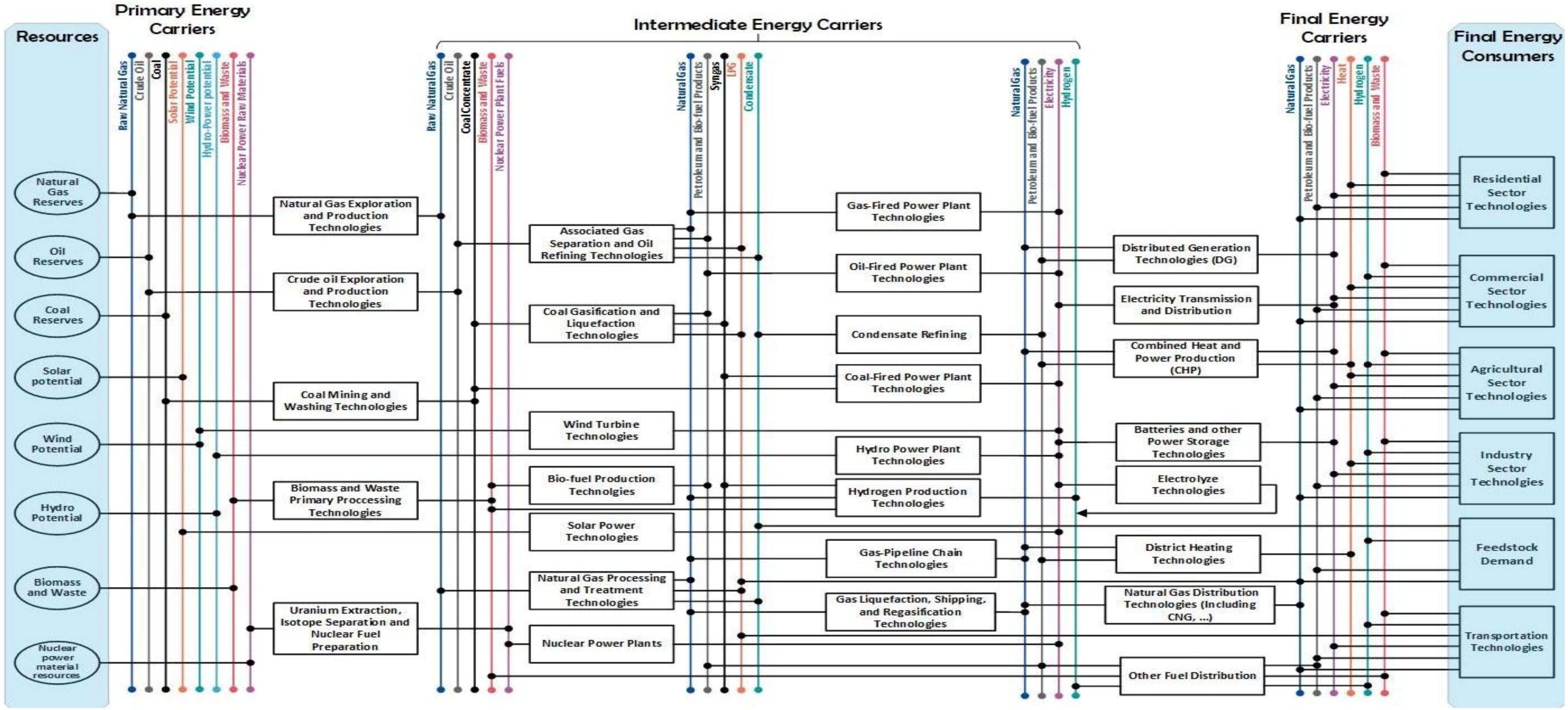
Table of content

GECF

Introduction and basics

GECF Reference Technology Map and the Hydrogen production spectrum

GECF Reference Technology Map



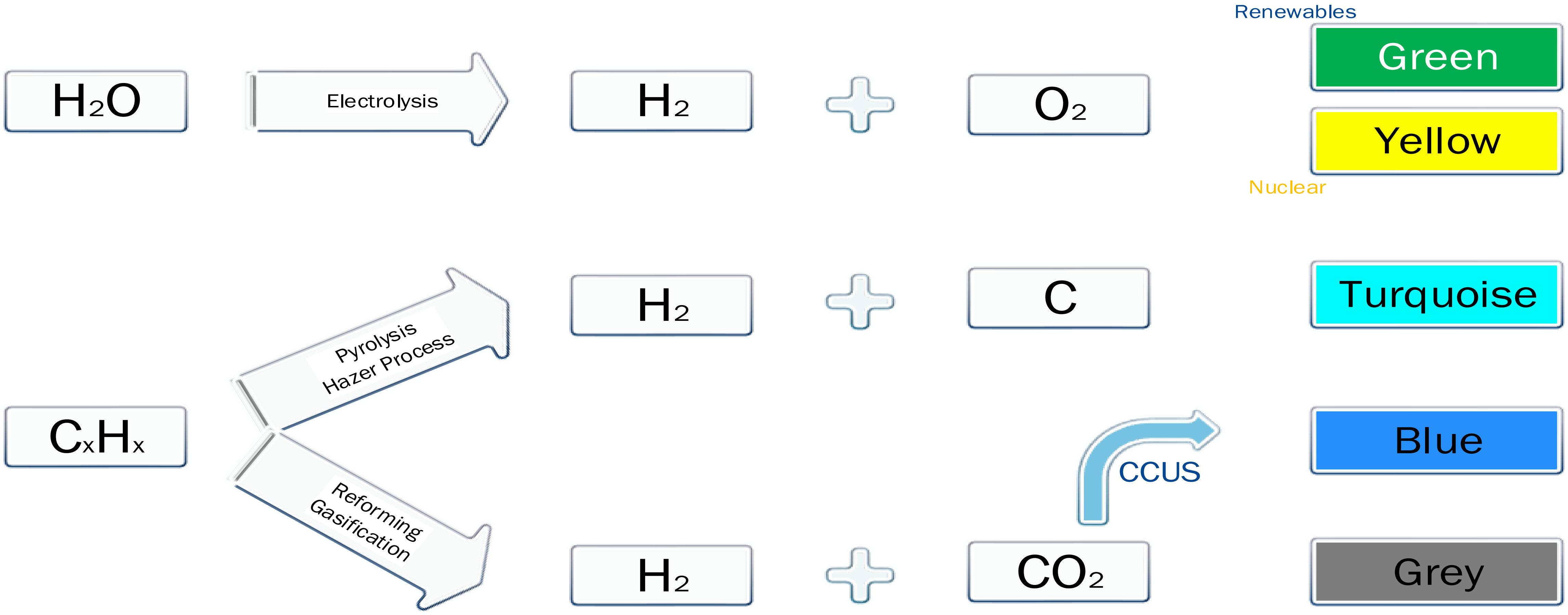
GECF Reference Technology Map

- To a meaningful visualisation of all processes and interactions being undertaken within the energy system, a network diagram depicting the energy-demanding sectors and all available resources is designed. Primary energy carriers go through the process and transformation technologies to be used in final sectors.

- Economic and technical parameters of each technology will determine the total level of competitiveness. Therefore it is not possible to assess the competitiveness of a definite supply chain without considering the other existing options as well as potential opportunities.

- In the map, we see that hydrogen is playing a unique role compared with other technologies as it can be produced by electricity or hydrocarbon at the same time that it can be used to produce electricity or bio hydrocarbons. This fact gives an inimitable role to hydrogen to be able to play as both final energy or intermediate fuel and storable form of energy.

Hydrogen production spectrum



Hydrogen production spectrum

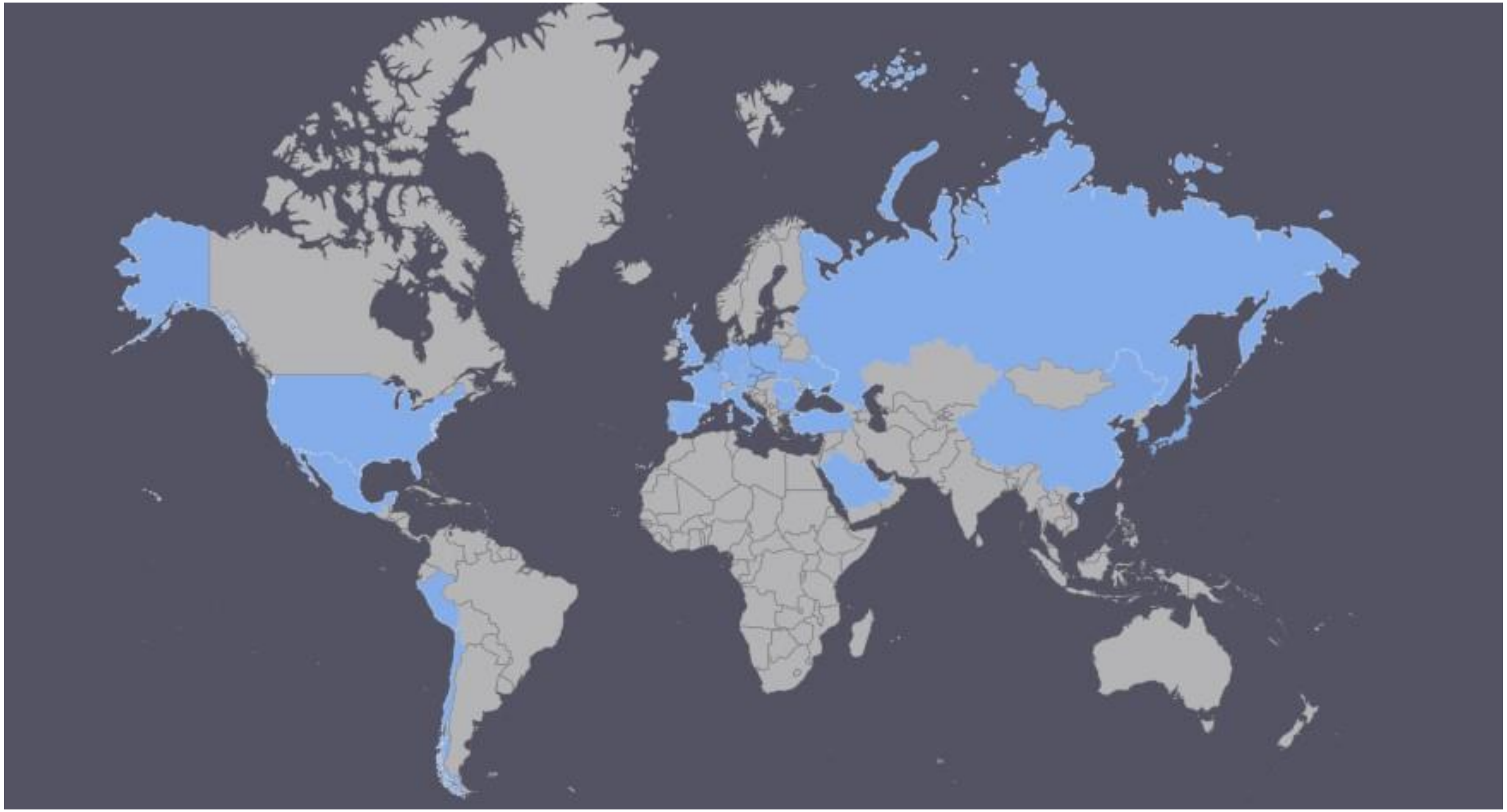
- Blue hydrogen refers to hydrogen produced from natural gas by chemically fragmenting into the hydrogen and carbon dioxide while carbon capturing measures are employed. The captured carbon, mostly in the form of CO2, will be injected safely in depleted gas fields or used to enhance oil and gas fields’ recovery or as feedstock for the chemical process in the industry. The latter processes are commonly translated into CCUS.

- Green hydrogen is also another term to call hydrogen produced from renewable resources like wind and solar. Wind and solar are among the most deployed renewable technologies, and their produced electricity can be used through the electrolysis process to split water molecules into hydrogen and oxygen. Electrolysis process needs pure water and electricity, and it will not contribute to any carbon provided we don’t consider the whole supply chain including the carbon footprint associated to the manufacturing of the solar cells and wind technology parts.

- Turquois hydrogen is the hydrogen produced from natural gas but implementing pyrolysis. In this technology, natural gas is passed through molten metal, and the results are carbon black or solid carbon and hydrogen.

Recent developments and policies adopted by countries

Countries with adopted strategies or announced projects



Strategies, policies and other efforts

- In recent years several countries adopted policies to promote hydrogen or established their hydrogen strategies. Some other countries have led some research projects to investigate how they can benefit from hydrogen in their energy systems.

- Some countries such as Japan and South Korea defined their strategies mostly relying on the import of hydrogen while some other countries such as Norway, China and Brunei are looking into the hydrogen as a potential commodity for export.

- One subject that has been acknowledged in most of the strategies and adopted policies is variety of application considered for hydrogen including transportation, industry fuel and feedstock, electricity and other sources like residential and commercial buildings.

- Storing hydrogen as an energy storage technology is also considered in several strategies due to the flexibility of the hydrogen to transform into electricity and produce from excess electricity mostly sourced by renewables

Austria

GECF

- The Government of Austria is ambitiously aiming to introduce and fit in hydrogen in the national climate and energy strategy. The government has already introduced a hydrogen strategy, and the current environment minister has announced that the new hydrogen strategy would be possibly announced by the end of the year 2020

- A bunch of companies in Austria have already carried out projects and commenced initiatives in order to promote hydrogen energy as a reliable source in line with the climate goals. These companies including Voestalpine, Austrian Power Grid, and VERBUND are considered as partners of the H2FUTURE project the is funded by EU mostly focused on green hydrogen

- In a very recent development, In December 2020, three months of test operation for the first hydrogen fuel-cell train called Coradia iLint by Alstom completed. The Austrian Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology had just given the official approval. Therefore with this development, Austria becomes the second country in Europe which has been officially accepted this train as an alternative solution over the diesel trains to deal with climate concerns.

Bulgaria

- Energy policy in Bulgaria supports hydrogen as a field that needs to be further enhanced in the country. For example, under the Energy and Climate Integrated Plan of the Republic of Bulgaria, hydrogen is being aimed to develop through to the planning horizon till 2030. In this plan, the potential role of the hydrogen in the transport sector and the power sector is well recognised.

- The interest to develop hydrogen in Bulgaria is also witnessed in many other national policy documents such as in Energy Strategy of Bulgaria and also in the Innovation Strategy for Intelligent Specialisation

- There are some hydrogen production plants in the country (associated with the other industries) for example a facility owned by Lukoil located in Bourgas that produces hydrogen in an oil refinery. So this in-place facilities has the potential to convert to the low-carbon or clean hydrogen by implementing CCUS measures.

- In September 2019, regional development ministry in Bulgaria announced a legislation that had been prepared in order to facilitate the construction of the hydrogen filling stations in the country. According to the act, the number of hydrogen filling stations in Bulgaria could reach more than 10 by 2025 and50 by 2030.

Chile

- In December 2020, the German Ministry of Economy made an 8.2 million euros contribution to the hydrogen plant planned by Siemens in Chile. The plan is targeting to build and operate a wind power plant which is going to produce power for hydrogen production through electrolysis in southern Chile, Haru Oni. The hydrogen is assumed to be consumed for generating synthetic methanol or gasoline. In the primary stage, the plant is going to produce annually 130,000 litres by 2022, but it is expected to rise to 550 million litres by 2026

- In November 2020, Ministry of Energy revealed a natural strategy that aims to establish the country as a global leader in not only production of green hydrogen but also export hydrogen to the consuming centres in Asia and Europe. The country is targeting to expand the capacity of green hydrogen based power to 5GW by 2025. Another goal is to achieve the global lowest cost production of green hydrogen by 2030 with targeting the Levelised cost of less than USD 1.5 per Kg of the hydrogen. And also according to the Energy Minister announcement in November Chile is aiming to invest more than USD 200 billion to become one of the top exporters of hydrogen worldwide

China

- China is the largest hydrogen producer and consumer worldwide mostly through grey hydrogen production. Only around 1% of the total hydrogen production in China can be categorised under the clean hydrogen production.

- There have been extensive efforts put into promoting the hydrogen vehicles since the 13th five-year plane was announced in 2016. Currently, the highest share of hydrogen application is related to the fuel cell vehicles in transportation and in manufacturing synthetic chemicals.

- In 2018, the National Alliance of Hydrogen and Fuel Cell was launched with the aim of developing China's hydrogen sector.

- In November 2020, Air Products announced that it would launch liquid hydrogen production plant with a capacity of 30 tonnes per day by 2022. The project is expected to become the first large commercial size liquid hydrogen production plant in China and the largest facility of this kind throughout Asia.

- In October 2020 Hyundai Motor Company signed an MoU to supply more than 300 hydrogen truck and heavy vehicles to China. Heavyweight transportation is considered as subsector in transportation that is not well suited to benefits from battery electric vehicles for the decarbonisation. But hydrogen vehicles are regarded as the best solution for decarbonising this sector.

European Union

- In July 2020, the EU published its hydrogen strategy. The Strategy was published exactly on the same day when another official document called Energy Sector Integration Strategy was published. These two strategies emphasised the need for a meaningful change and transition in the energy sector for the decarbonisation.
- In the Hydrogen Strategy, green hydrogen is introduced as the main priority for EU in hydrogen development but acknowledged that other low-carbon solutions for hydrogen production are also needed in short- and medium-term.
- The Strategy defines an ambitious target of 40GW of green hydrogen capacity within Europe though to 2030.
- In shorter-term in a more ambitious target, the Strategy sets a vision for 6GW of hydrogen from electrolysis by 2024.
- The Strategy acknowledged the role of hydrogen in the decarbonisation of the transport sector in which other practices for decarbonisation such as electrification is challenged.

France

- In November 2019 the French president signed a law on energy and climate that defines an objective over usage of low carbon hydrogen rate at 10% by 2023 and between 20% and 40% by 2030 according to the document. Adoption of this law was considered as part of France commitment to the Paris Agreement.

- In November 2020 France signed an agreement with European Investment Bank (EIB) aiming to promote hydrogen sector. According to this agreement, the promoters of hydrogen sector will benefit financial as well as technical support of EU climate bank. This agreement comes under a programme in EIB that is called InnovFin Advisory programme and is supported by European Commission

- In September 2020 government of France announced a national strategy for clean hydrogen to the leading associations and players in the hydrogen economy. The government is targeting 6.5 GW of hydrogen production capacity by 2030 .

Germany

- In June 2020 government of Germany announced the national Hydrogen Strategy. Within the strategy, hydrogen is recognized as key role player in progressing with the energy transition. The primary step to achieve the goals is mentioned to enhance hydrogen technology and establish a firm and sustainable market for the generation and consumption of hydrogen in Germany.
- As a cornerstone of the Strategy the government of Germany anticipates around 90 to 110 TWh of hydrogen will be required by the year 2030. Therefore as an effort to meet part of this demand, government aims to develop capacity of generation up to 5 GW.
- In December 2020, during the Russian-German Raw Materials Forum, Deputy Prime Minister of Russia indicated that Russia and Germany are exploring several forms of cooperation in the field of hydrogen energy. He stated that two countries are considering partnership in advancing technologies and implementing joint projects to generate and ship hydrogen to Germany.
- In November 2020, Australia and Germany decided to lead a feasibility study project by academt centres and industry leader for the creation of reneable hydrogen supply chain betwewn Austrlia and Germany

Japan

- In terms of developing hydrogen studies, projects and establishing roadmaps and strategies related to the hydrogen economy, Japan is one of the well-advanced countries worldwide with having several years of experience in research and development in hydrogen-related technologies.
- The third version of the Strategic Roadmap for Hydrogen and Fuel Cells was released in March 2019. Within the Roadmap, three different time frames have been introduced. For example, the year 2022 is introduced as a timeframe for technologically demonstration of storing hydrogen and transporting hydrogen from outside the country. Full-scale hydrogen production is mentioned to achieve by 2030 and the materialising the full-fledged use of clean hydrogen by 2050.
- A piece of news published in Nikkei newspaper in December 2020 revealed that Japan's government aims to make hydrogen a major source of power by 2030 with having produced equals to more than 30 nuclear reactors. According to the news, the government will invest 2 trillion yen (USD 19 billion) to support making hydrogen as a viable and significant source of electricity generation.
- In October 2020, Japan's Industry Minister in a virtual hydrogen conference emphasised its country's efforts on creating a commercial hydrogen supply chain by 2030 in supporting the reduction of carbon emissions. He indicates that Japan is speeding up the advancement of the technologies to enhance transportation of hydrogen using ships by 2030.

Russia

- Russia is also an established producer of hydrogen worldwide and similar to most of the other current producers, the generated hydrogen is being consumed internally in oil refineries and some industries as feedstock. To date, the initial draft of the road map for the hydrogen development as a source of energy for the years between 2020–2024 has been developed.
- In November and December 2020 some statements by officials from both Russia and Germany unveiled the promising cooperation of the two countries in the field of hydrogen production and trade. For instance, Director-General for European and International Climate Policy of the German Federal Ministry for the Environment said that Nord Stream 2 might become a major route to supply hydrogen to Europe. He also emphasised that based on the increasing interest in hydrogen in Europe he foresees promising prospects for the future cooperation between Germany and Russia. Gazprom also announced that it had proposed a large hydrogen generation plant in Germany close to the point that Nord Stream pipeline lands.
- On December 1st 2020 Russian Deputy Prime Minister at the Russian-German Raw Materials Forum announced that Germany and Russia are considering technology partnership and leading discussions on developing a joint roadmap for the development of hydrogen.

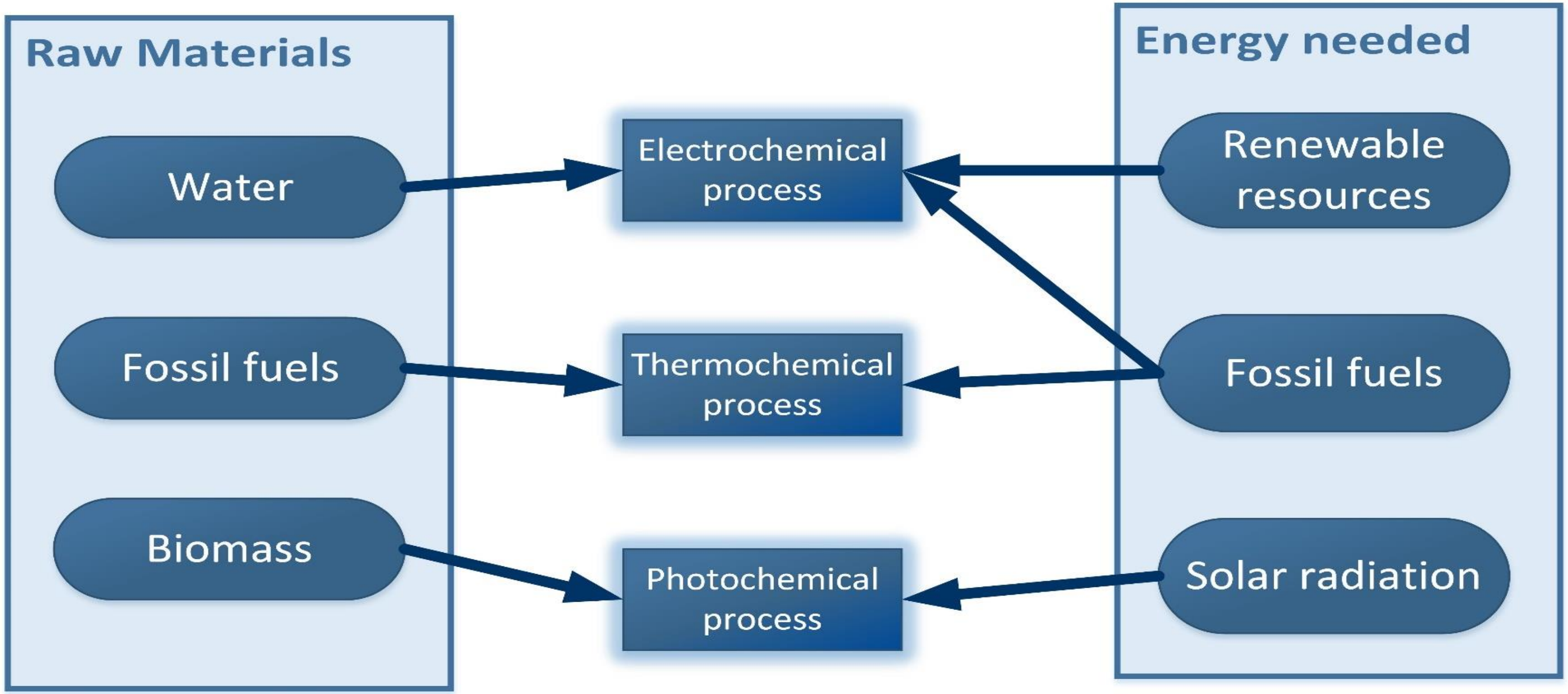
UK

- In November 2020, the regulator of UK energy networks gave the green light to gas network SGN to start launching a pure hydrogen gas network for a trail. It is expected that more than 300 homes connect to the network that is wholly separated than the main gas network. Unblended hydrogen will be supplied through the network and the residence of the homes will be given the option to connect into the trial network for free energy charge and maintenance. The construction of the network is planned to start in 2021, and the facilities will begin to work in 2022, and the trail will end in 2027.
- In November 2020, UK government defined a target for developing 5 GW hydrogen generation by 2030. In the announcement, the hydrogen is mentioned to be “low-carbon hydrogen” therefore it might be from both blue or green hydrogen. The government aims to capitalise up to 500 million Pounds in hydrogen that almost half of it is planned to be invested in hydrogen production facilities, and the rest will be spent on the trail project in connecting homes to the hydrogen networks using hydrogen in residential proposes.
- In November UK Prime Minister revealed a 12 billion Pound 10-point plan that highlights the promising role that CCS and hydrogen can play in green industrial revolution. The plan puts forward a further funding to construct two carbon capture clusters by mid-2020s and another two clusters to be developed by 2030

Technology status and new updates

Current technologies for hydrogen production

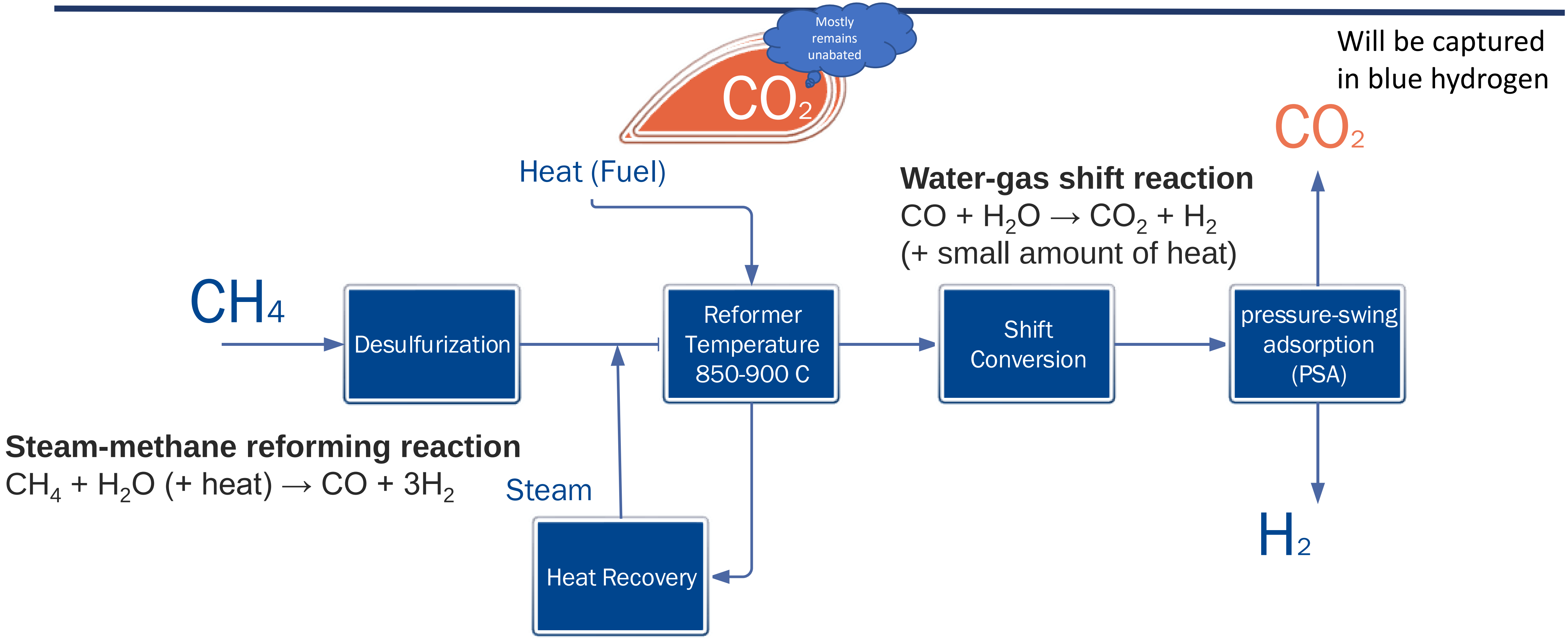
Hydrogen source map



Hydrogen source map

- Hydrogen is produced through transforming materials that some of them are considered as energy carrier unlike electricity generation that mostly transforms an energy carrier to electricity. For example, in steam turbines, natural gas is combusted, and its energy content turns into the heat and heat turns water to supper hot steam. The steam drives the turbines and electricity is generated.
- Water is not considered a fuel or energy carrier, but it can be split into hydrogen and oxygen through electrolysis. Electrolysis requires electric energy, which can be provided by any type of power production, including those which consume fossil fuels or those which produce electrical energy from renewable resources such as wind and solar.
- The most frequently implemented method is the catalytic conversion or steam reforming of hydrocarbons followed by gasification of coal, tar sands, etc. Around 94% of current hydrogen production is from gasification or reforming.
- In steam reforming, natural gas plays in two different roles. Part of the volume of natural gas is reformed into the syngas. The syngas turns in to the CO_2 and hydrogen in the water gas shift reactor. The second part is the volume of natural gas to be combusted and provide energy.

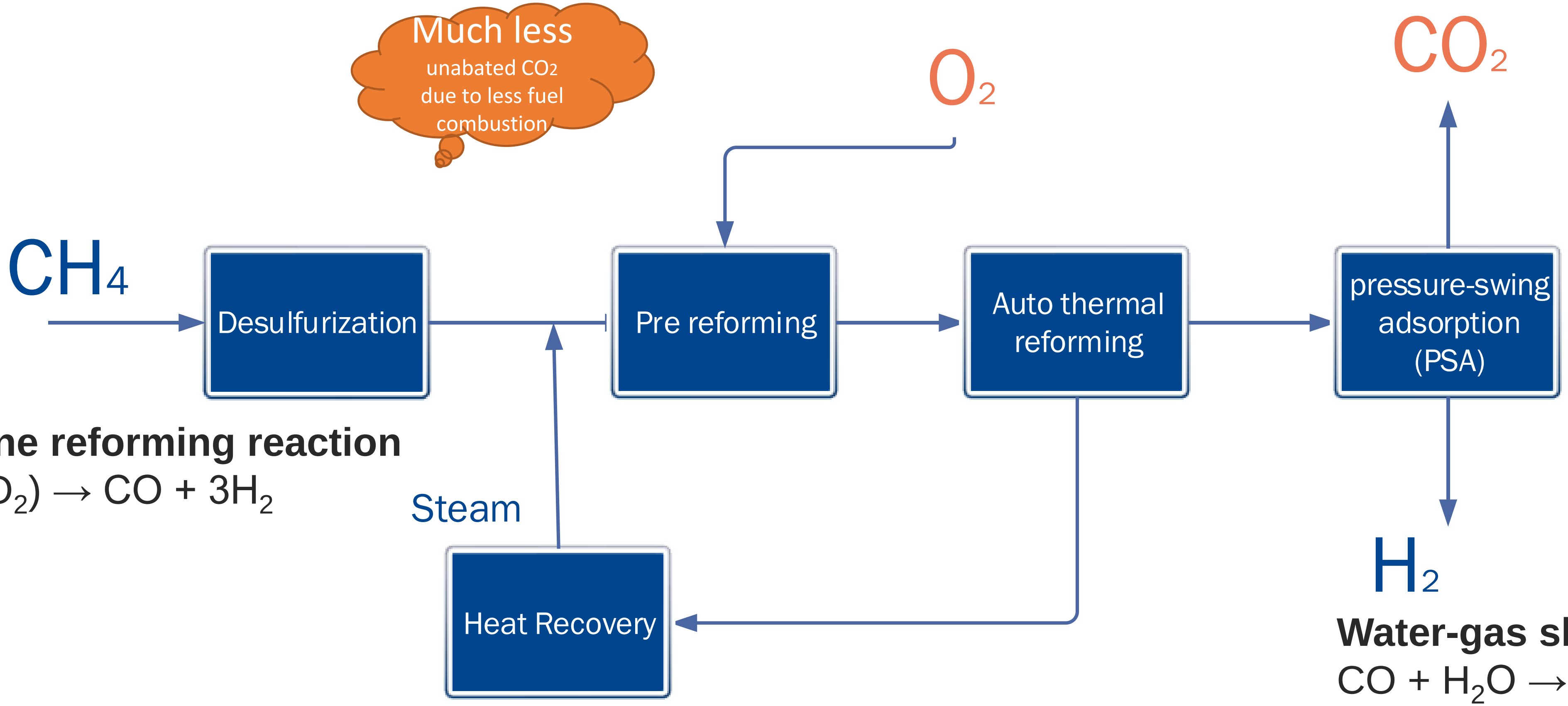
Steam Methane Reforming



Steam Methane Reforming

- Steam methane reforming (SMR) can be mentioned as the most established technology for producing hydrogen from natural gas feedstock that has been widely utilised.
- High-grade temperature steam (750°C–1,100°C) is used in the presence of a nickel catalyst. Steam under high pressure (3-35 bar) reacts with methane
- Hydrogen is produced in two-stage of the reaction chain, and at the end, half of the produced hydrogen is sourced from splitting the water (and not only natural gas reforming)
- CO2 is emitted from both burning gas for heat and separated from H2.
- When we talked about blue hydrogen from the SMR technology, we are normally talking about CO_2 capturing happening at the end of the process when the H_2 is being separated. But the carbon emitted for providing the heat that is mostly through the combustion of natural gas remains unabated. The total CO_2 capture rate is about 90%

Autothermal reforming



Steam-methane reforming reaction

$CH_4 + H_2O\ (+O_2) \rightarrow CO + 3H_2$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2$

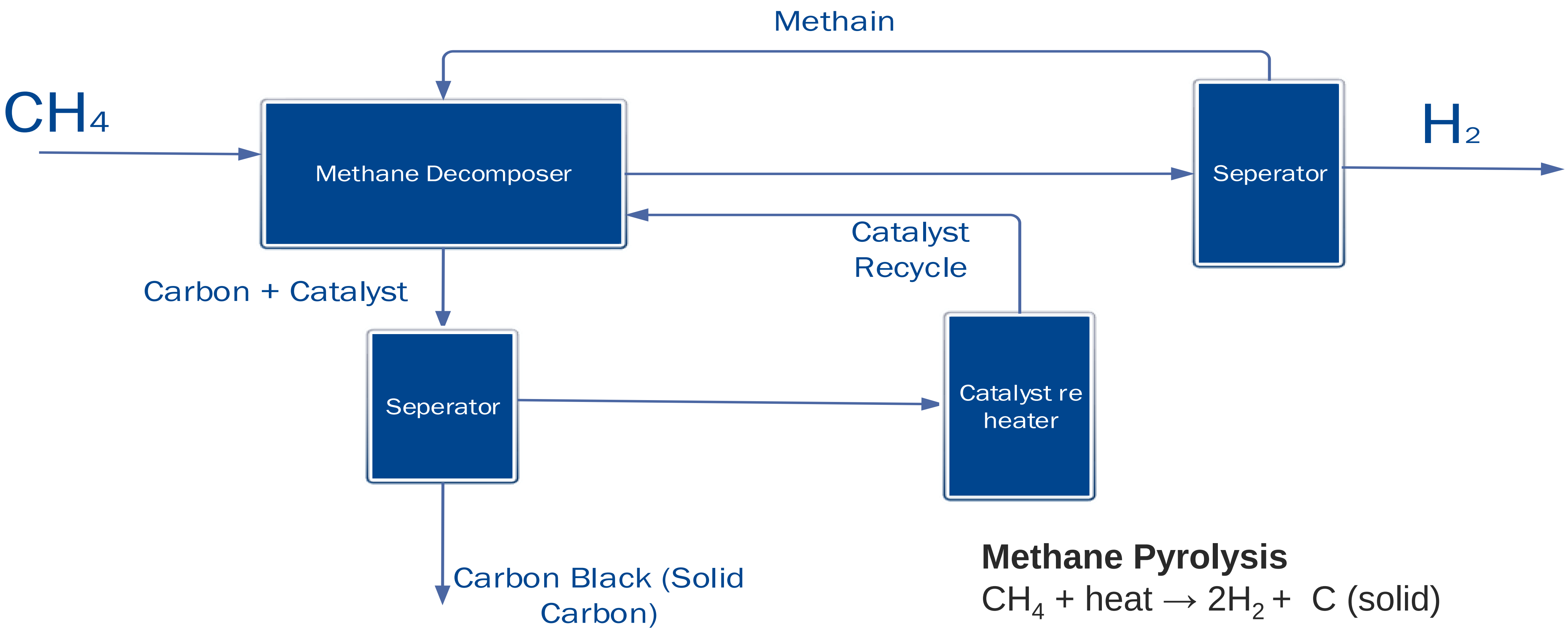
Autothermal reforming

GECF

- ATR Requires pure oxygen rather than pre-heated steam and higher temperature than SMR (1000 -1200 C)
- In ATR technology, there is no external fuel heating. Self-heating process will generate heat for the whole process (auto-thermal). In this technology, part of the feed gas that is natural gas is combusted.
- The ratio of H_2 /CO in syngas produced in autothermal reforming is less than that in SMR. So There are various hybrid SMR+ATR to optimise the technology for hydrogen production
- There are several on-stream ATR units in the industry mostly in ammonia plants, but as the secondary reforming process after primary SMR. In the methanol industry, there are some stand-alone ATR technologies
- Capital cost for ATR is higher than SMR due to the pure oxygen needed
- In terms of carbon capturing, capex in SMR is higher due to the dual-source of CO_2 in the process (produced syngas and heat). In this case, ATR is more attractive for “blue” hydrogen production, especially if a higher rate of CO_2 capturing is needed

Pyrolysis

GECF



Methane Pyrolysis

$CH_4 + heat \rightarrow 2H_2 + C\ (solid)$

Pyrolysis

- To produce hydrogen through pyrolysis natural gas is flowed through molten metal with the existence of catalyst. The results of the process will be hydrogen and solid carbon. There are various pyrolysis processes such as gas reactor, molten metal and plasma. The pressure of the process is 1 bar and temperature can be in a range between 300 to 2200 C
- Various hydrocarbon feedstock can be sued for the pyrolysis, including biomass. For the heating process, also different methods can be applied, such as microwave and plasma.
- The hydrogen yield is lower than those for reforming. As the hydrogen molecule is only derived from the feedstock hydrocarbon and not water. So still the business models are relying on the commercial value of the solid carbon
- There is no direct CO_2 emission and no water usage.
- The technology is not mature and still is in laboratory scale

Shell Blue hydrogen technology

- Technology is based on “Shell Gas Pox” (SGP)
- The process is by nature non-catalytic
- The technology does not need steam
- The process is operating at higher pressure
- Technology is integrated with carbon capture process

Shell claims:

OPEX reduction: 34%

LCOH reduction: 22%

CAPEX reduction: 17%

CO2 capture: 99%

With only CO_2 costing of USD 25-35 per tone it becomes competitive against grey hydrogen

Source: Shell website and gas-to-power journal

Shell Blue hydrogen technology

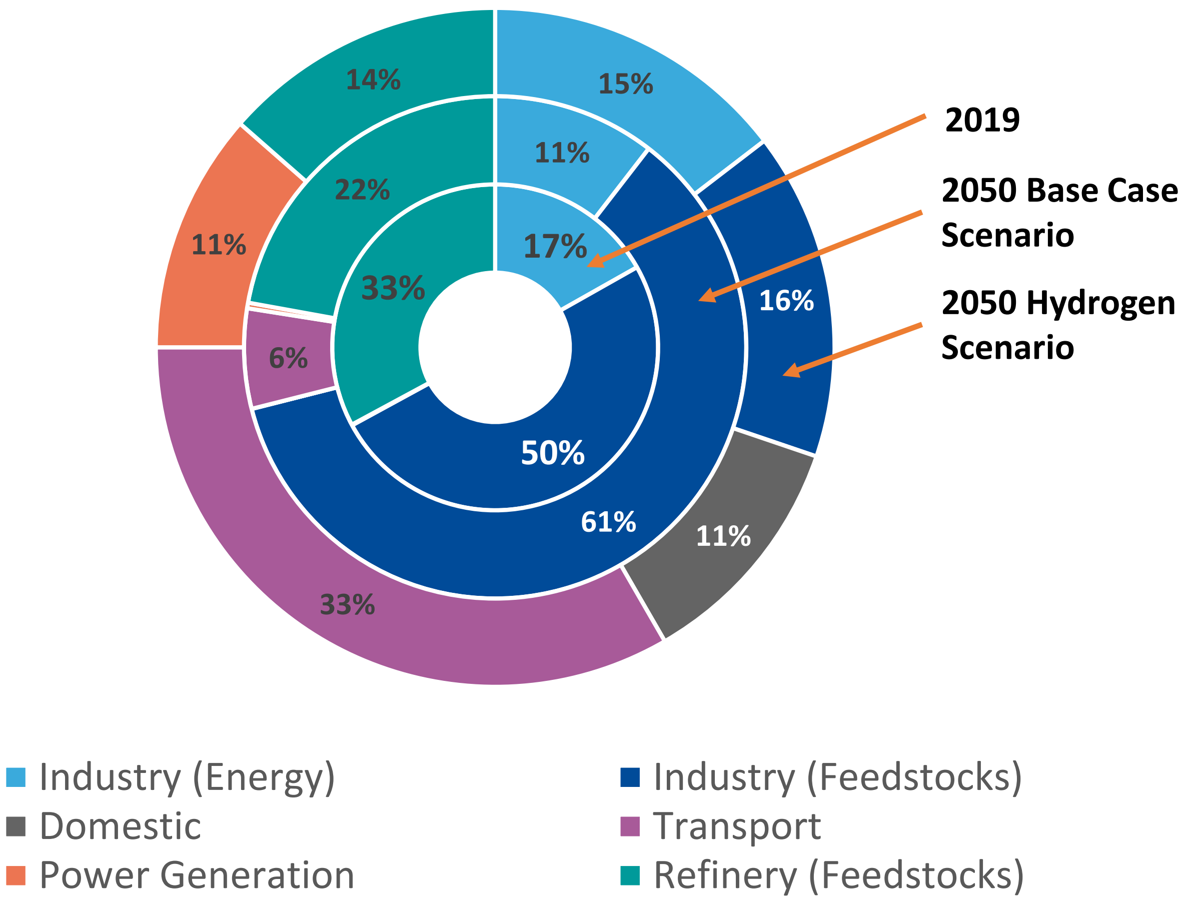
- Shell's blue hydrogen process integrates the company's gas partial oxidation (SGP) technology with ADIP ULTRA solvent solution. The technology of SGP, unlike conventional ATR, does not need steam. And the process produces high-pressure steam that mostly is consumed within the process and the rest can be supplied to other consumers
- The process is mentioned to be more robust against the feed gas contaminants. So, there is no pre-treatment unit for the feed gas. This makes the process much more straightforward and enables the process to accept different qualities of natural gas as feed.
- The levelised cost of hydrogen generation is much reduced in the process. SGP technology, compared with a conventional ATR, reduces the levelised cost of the production by 22%. This reduction is sourced by reduction from both capital expenditure and operational expenditure estimated at 22% and 34% lower respectively compared with the current ATR technology

Source: Shell website and gas-to-power journal

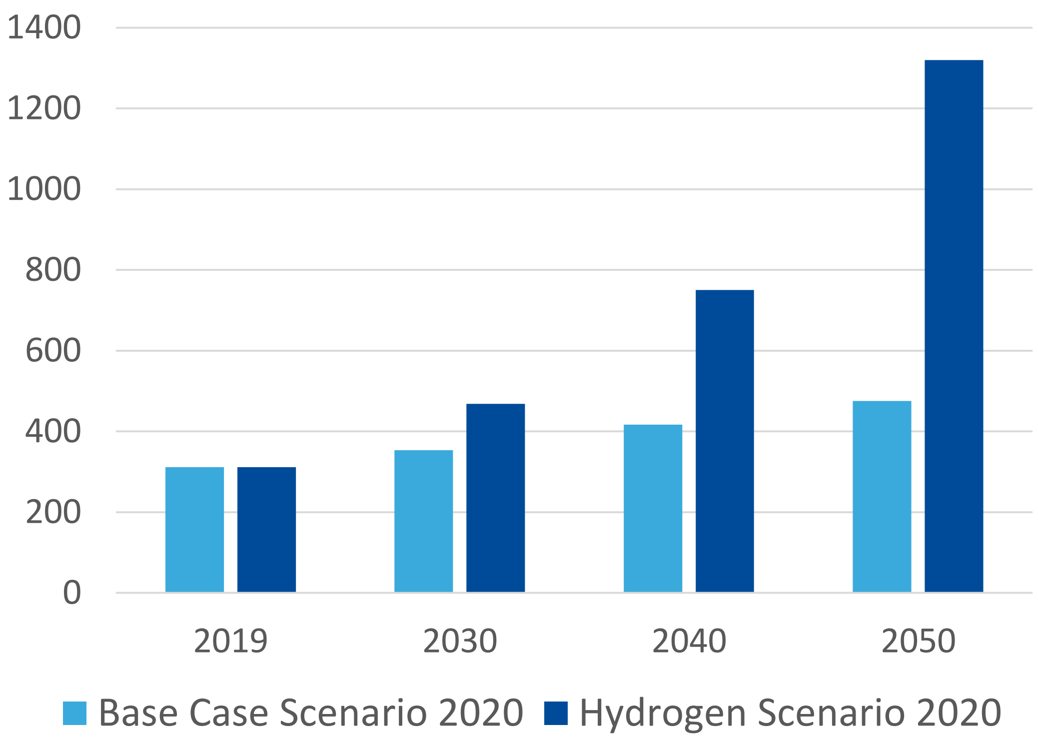
Hydrogen Scenario (2020)

Results (1)

Sectorial share for hydrogen demand



Hydrogen demand outlook (mtoe)



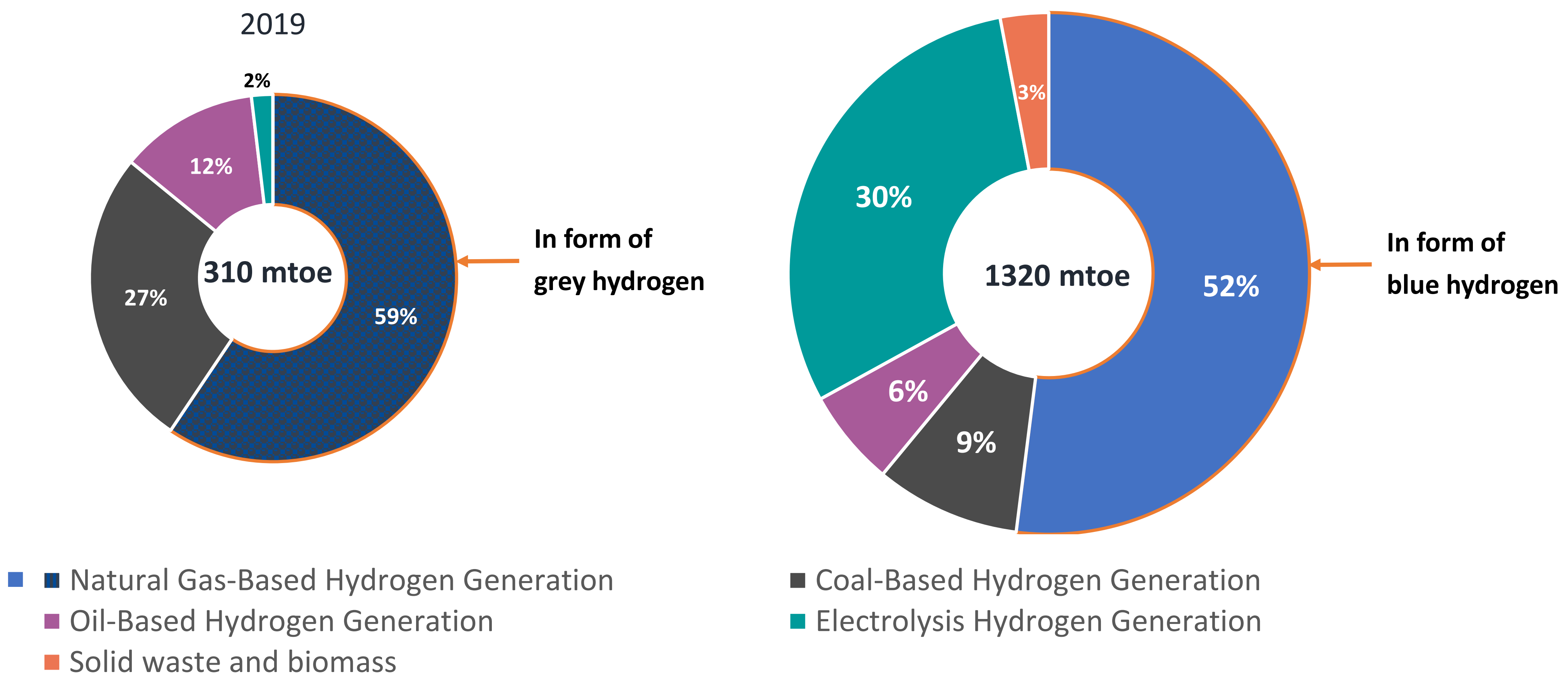
Results (1)

- In the Hydrogen Scenario, more than 1320 mtoe of hydrogen is demanded by energy sectors by 2050, much more than the value of 470 mtoe forecasted in the Reference Case Scenario 2020 and, by far, more than what was forecast in Reference Case Scenario 2019 that was less than 100 mtoe.
- Penetration of hydrogen into the market is forecast to accelerate after 2030, and more than half the expansion is expected to realise in between 2040 and 2050.
- The promising role of hydrogen in the future of the transportation sector is also forecast in Base Case Scenario 2020. Hydrogen Scenario assumes more potential for this sector, specifically in heavyweight vehicles, trains, marine sector and aviation.
- As can be seen in the pie chart transportation will be the primary driver of demand for hydrogen, followed by the industry, power sector and domestic sector (mostly residential and commercial).

Results (2)

Outlook for hydrogen production by source

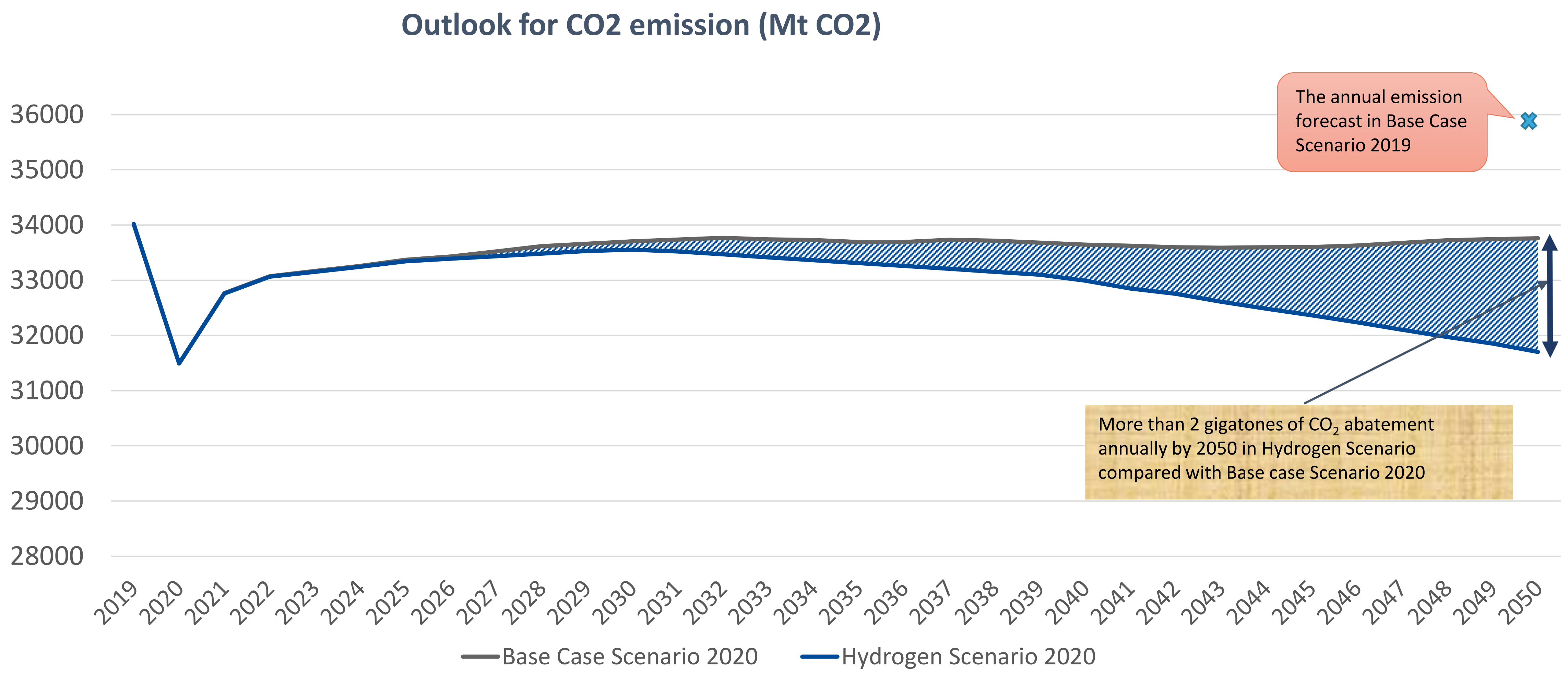
2050
Hydrogen Scenario (2020)



Results (2)

- Currently, more than 98% of the energy sources that are used to produce hydrogen are from fossil fuels. This share will significantly reduce to almost two-third (67%) by 2050 in the Hydrogen Scenario 2020. But, the absolute volume of hydrogen production from each source will rise due to the huge increase in total hydrogen demand.
- We can see that among fossil fuels, the only energy carrier that maintains its contribution is natural gas. Around 52% of the hydrogen production will be from natural gas by 2050 in Hydrogen Scenario 2020, mostly in the form of blue hydrogen.
- Electricity or electrolysis gain significant shares in total hydrogen production. It is forecast that more than 30% of the hydrogen by 2050 will be generated from electrolysis in the form of green hydrogen. This implies that renewable power stations needs to scale up in order to provide adequate electricity for the green hydrogen production.
- Biofuels, waste, and biomass also appear in the list of sources used for hydrogen by 2050 to 3%.

Results (3)


Outlook for CO2 emission (Mt CO2)
36000
35000
34000
33000
32000
31000
30000
29000
28000
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
The annual emission forecast in Base Case Scenario 2019
More than 2 gigatones of CO_2 abatement annually by 2050 in Hydrogen Scenario compared with Base case Scenario 2020
Base Case Scenario 2020
Hydrogen Scenario 2020

Results (3)

- The level of CO_2 is considerably reduced in the Hydrogen Scenario. The results of the scenario demonstrate that around 2 Gt of CO_2 can be abated on a yearly basis by 2050 compared with the Base Case Scenario. The level of abetment is much higher compared with the last year Base Case Scenario. In 2020, a lot of efforts regarding the climate concerns are considered in the main scenario. So the level of emissions is much reduced compared to the last year. Therefore part of the abatement associated with the clean hydrogen development is also captured in Base Case Scenario 2020. The level of annual emissions in Hydrogen Scenario 2020 is around 4.3 Gt CO_2 lower than the forecast in Base Case Scenario 2019.

- Another environmental advantage of hydrogen is to reduce other greenhouse gas emissions, such as NO_x and SO_x. In Hydrogen Scenario, both NO_x and SO_x emissions are expected to decrease compared with the Base Case Scenario.

Conclusion

- Over the last years, a lot of efforts on the development of the hydrogen have been witnessed. Several countries have adopted hydrogen strategy. So based on the political and technical developments hydrogen will gain share in the global energy system due to the varied benefits that it has to offer. The advantages include but are not limited to net zero-emission, the diverse application range in most end-use sectors (including electrification in high-grade industrial heat or heavy transport) and in off-grid or distributed generation, and enhancing energy security.

- Natural gas can contribute significantly to hydrogen production when carbon-capturing measures are employed, especially pre-combustion capturing. Blue hydrogen promises a very economical trajectory to meet hydrogen demand.

- The results of the Hydrogen Scenario admits that natural gas can play a significant role in the hydrogen economy development. Natural gas, along with the CCUS technologies, provides a very economical, competitive, reliable, and practicable option to produce hydrogen consistent with the sustainable development goals. Most type of greenhouse gas emissions, including CO2, can be abated significantly through blue hydrogen production, while the costs will still be competitive.

GECF