Hydrogen fuel cells for sustainable energy: Development and progress in selected developed countries

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Abstract. The sustainable development goals concept towards zero carbon emission, set forth by the Paris Agreement, is the foundation of decarbonisation implemented in most developed countries worldwide. One of the efforts in the decarbonisation of the environment is through hydrogen fuel cell technology. A fuel cell is an energy converter device that produces electricity via the electrochemical reaction, with water as the by-product. The application of fuel cells is strongly related to the economic aspect, including local and infrastructure costs, making it more relevant to be implemented in a developed country. This work presents a short review of the development and progress of hydrogen fuel cells in a developed country such as Japan, Germany, USA, Denmark, and China (in transition between developing to developed status); which championed hydrogen fuel cell technology in their region.

Keywords: Hydrogen; Sustainable Energy; Fuel Cell; Decarbonisation.

1. Introduction
The technology of fuel cells is one of the innovations established and developed worldwide in many countries. Compared to traditional power sources, fuel cell systems have been noted for their multiple benefits, such as high performance, decent durability, less time-consuming, and even environmentally friendly. As for that, as this technology is rapidly evolving all over the globe, particularly in developed countries, many countries are trying to substitute ordinary power sources with fuel cells from time to time. A fuel cell can be described as an electrochemical cell in which the chemical energy of conventional fuel is transformed directly and effectively into electrical energy [1]. The fuel cell also does not differ radically in its activity from the primary cells known to all of us as the Leclanche and Mercury-Oxide-Zinc dry cells [2]. In 1932, Francis Bacon invented a fuel cell derived from hydrogen [3]. In 1959, a team headed by Harry Ihrigh designed a 15kW fuel cell tractor for Allis-Chalmers, which was seen at state fairs around the USA. In 1838, the first fuel cells were invented by Sir William Grove [3]. Since the discovery of the hydrogen-oxygen fuel cell by Francis Bacon in 1932, fuel cells’ first commercial use came more than a century later. Since the mid-1960s, alkaline fuel cells have been used in NASA space programmes to produce electricity for satellites and space capsules, known as the Bacon fuel cell after its inventor [4]. During that time, the hydrogen fuel cell is considered an exclusive-costly technology because it has been utilized in high-end applications such as NASA spaceship. Similar to other technology, the hydrogen fuel cell continues to develop as time passes by. One of the main developments and effort in achieving a low-carbon society is through the utilization of the fuels cell and hydrogen technology. Hydrogen is
an energy transporter, but it can be contained in numerous ways and transported in various modes without exceptions. Together with a fuel cell, the hydrogen provides a stable and carbon-free route to produce electricity that is flexible and decentralized in many zero-emitting applications. In many other uses, fuel cells have to be used because of that. In the commercial, industrial and residential buildings and remote or inaccessible areas, fuel cells are used for primary and back-up control. Power cells, including forklifts, trucks, taxis, vessels and submarines, are also used in the vehicle.

Recently, to support decarbonisation effort, several countries are focusing on hydrogen fuel cell technology. Fuel cell technologies have been known for their advantages, such as high efficiency, good reliability, less time-consuming, and environmentally beneficial compared to conventional power sources. Many countries are trying to replace the familiar power sources with fuel cell by time to time as this technology is developing rapidly all over the globe, especially in developed countries. Among these countries, the developed country like Japan, Germany, USA, Denmark and China seems to lead the research and development in a hydrogen fuel cell in their region and the application of this technology. This paper aims to discuss the development, applications, achievements and challenges in bringing the hydrogen fuel cell technology into the local and global market in the as-mentioned developed countries briefly. The hydrogen fuel cell development or approach reviewed in this work will help others understand the overall aspects of utilizing hydrogen fuel cell technology.

2. Japan

Moonlight and Sunshine Project are among the initiatives initiated in the 1970s, proving the Japan involvement in hydrogen and fuel cell technology for almost 40 years, attaining the global leading expertise and experience in its sector. For the records, as polymer electrolyte fuel cells (PEFCs) were developed for the first time in the 1950s by Generic Electric. Meanwhile, in space application advancement, a 1 kW fuel cell was integrated. The development of PEFC in Japan began in 1992 as part of the Sunshine initiative led by the Ministry of Economic Affairs, Trade and Industry (METI) [5]. In 1993, R&D activities began via the New Energy and Industrial Technology Development Organisation (NEDO) projects as part of the New Sunshine Initiative's sequel. Since 2000, more specific projects on real applications are being formulated and implemented within the Millennium Plan's scope, including a start-up production and a development project on the popularisation of fuel cells.

The development work of phosphoric acid fuel cells (PAFCs) already began in 1981 to design and build cells close to those already developed in the United States under the Moonlight Program of the Department of Industrial Science and Technology (now the National Institute of Advanced Industrial Science and Technology) [5]. Current Sunshine Scheme continues in making the innovation possible until 1997 while the current trend is more focussed on research for commercialization. Fundamental studies on molten carbonate fuel cells (MCFCs) were carried out from 1981 to 1986 and then expanded to 100 kW stack research from 1987 to 1994. The device studies were conducted between 1994 and 1999 and between 2000 and 2004 based on practical implementations. Besides PAFCs, research works for MCFC has begun under the Moonlight Initiative. Since 1988, its activities have been guided by the MCFC Research Association. The development currently ranges from analysis to practical execution. The manufacturing of PAFC has gained traction that can contribute to earlier commercial viability than other forms of PAFCs since 1980. About 200 models of PAFC, including prototypes, are developed in which more than 20 units can be used for more than 40,000 hours. Dozens of units have been sold every year for field trials since the early 1990s.

2.1. Applications

The fuel cell is a device that utilises the reaction process of hydrogen and oxygen in producing energy and heat and reversing the electrolysis of water. Fuel cells can be categorised through electrolytes employed, such as PEFC, PAFC, MCFC and solid oxide fuel cell (SOFC). In the early 1980s, the government and multiple other corporations have begun to develop fuel cells in Japan. Several decades have passed, Japan and other countries are still actively researching fuel cells. The study
focussed can be narrowly divided into the following four groups which are PAFC, SOFC, MCFC and PEFC [6].

The bright future of Japan’s hydrogen fuel cell is anticipated due to the support of the government as well as giant companies [5,7,8]. As this country is prone to the natural disaster such as earthquake, the needs to vary the energy source and power distribution not just for stationary used but also for mobile/portable application becomes Japan’s main aim. This aim can reduce the dependence on the grid. With this spirit, Japan installed 265,000 residential used ENE-FARM units in 2018 with up to 5 kW capacity. Japan is currently planning to deploy about 5.3 million of these housing units by 2030 [10,11]. The exclusion of these fuel cells from the power grid moves Japan towards a future of self-sustaining energy. Japan has been planning to have more than 80,000 fuel cell vehicles and 1200 buses running on the roads by 2030 which is seen as initiatives to elevate the development of transportation of fuel cells and hydrogen thrived by the market growth and government initiatives. Fuel cell industrial use has also continued to progress, with the goal of 10,000 fuel cell forklifts operating in Japan by 2030 as well [10]. Japan’s contribution to fuel cells has enhanced its drive towards a stable and clean energy future.

As for May 2018, Toyota has announced plans to accelerate the fuel cell vehicle (FCV) technology which aims for 30,000 increments of FCVs in the market by 2020 globally [11]. The increment in FCV units will require an excellent hydrogen trail across the country. Several organisations’ collaboration is formed to develop a project that focuses on renewable energy - hydrogen supply chain involving Toyota City, Chia City, Toho Gas and Chubu Electric Power. This infrastructure is located at Toyota City and Chia City and sponsored the Aichi Low Carbon Hydrogen Supply Chain Promotion Organisation [11]. As fuel cell is shown high potential in the transportation sector, Toyota has upgraded the FCV from the light-duty passenger vehicle into fuel cell-powered bus (FCB) [12,13]. The 222 kW (111 kW/unit fuel cell stack) FCBs namely as Sora FCB was brought into the transportation market in March 2018 is powered by 10 units of 600 litres of hydrogen tanks. The Sora FCB is currently running in Tokyo Metropolitan Area and also will be used in Tokyo Olympic 2020 (postponed to 2021 due to pandemic Covid-19). The interesting fact about this Sora FCB is that the bus can also be used as 235 kWh portable power generator in case of emergency or disaster occurs [14].

![Figure 1. Sora Fuel Cell Bus in Tokyo.](image)

The continuous effort by Toyota results in a new partnership with Seven-Eleven Japan in June 2018 that agreed on the utilisation of hydrogen fuel cell technology at their distribution facilities [15,16]. Toyota has also announced the launch of a Hydrogen Mobility collaboration with the East Japan Railway Company (JR East) [17]. This collaboration aims to build hydrogen station on JR EAST facilities not just for the use of FCBs and FCVs, but also to develop hybrid battery- a hydrogen
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fuel cell-powered railway vehicle [18]. Besides, to support the transportation sector specifically fuel cell-powered forklift, Toyota has announced its intentions to generate and supply hydrogen to the Takahama's Aichi Prefecture facility using the Toshiba Energy Systems and Solutions (ESS) system [17].

Japan has been expanded the hydrogen fuel cell technology into the portable power market through the introduction of mobile charger namely as 500 JAQ Hybrid [19]. This Japan’s Power Sourcing Equipment certified fuel cell mobile charger had been sell by Lightec across Japan. By referring to all the progress mentioned above, it is no doubt that Japan is leading in hydrogen fuel cell technology. From stationary to mobile and portable application, with power ranging from mW to MW, Japan made a significant remark involving hydrogen fuel cell technology in all of the related applications.

2.2. Future plan
The opportunities for fuel cells in Japan are being deepened. For example, they were planned to use the 2020 Olympics as a forum to show the pledge that fuel cells are like simple hydrogen technologies. By 2050, they aim to turn hydrogen as a modern approach to green energy. CO2-free hydrogen is the aim that Japan is planning to accomplish with this simple hydrogen strategy. They would also substitute gas generation, replace gas stations, replace traditional fuel versatility and replace current suburban electricity networks with large FCVs.

3. Germany
In Europe, Germany is undeniably the number one fuel cell nation. The fuel cell company includes several thousand workers at universities, research institutes, and businesses. From the early days of the fuel cell, several of these organisations have already been involved. E.g., Siemens, which has been working since the 1950s on many different fuel cell technologies. The German Association of Hydrogen and Fuel Cells (DWV) is the national body for the commercial adoption of hydrogen and fuel cell technologies. DWV supports the introduction of hydrogen, especially in the oil and transport industries, as an energy carrier. It brings together specialists, corporations, research institutes, etc. to encourage them to share their expertise, contribute to the distribution of results, and foster public interest in the matter.

3.1. Background of fuel cell technology in Germany
The hydrogen fuel cell in Germany is used in cogeneration applications based on fuel cells (also known as combined heating and control, CHP). SOFC and polymer exchange membrane fuel cell (PEMFC) are the most widely used type of fuel cell. The utilization of SOFC in Germany market for residential usage is known as a micro-CHP system and mini fuel (Figure 2). In 2018, the deployment pace recently increased significantly as a minimum of 3600 mini fuel cell units installed. And this number keeps rising and reached 5500 units and expected to continuously increase due to the support by the Ministry of Economic Affairs and Energy (BMWi) [20]. Prices are a significant barrier to the dissemination of these systems on the market. It is still projected that some CHPs based on fuel cells can be mounted to some 3 million buildings.

Germany has the most SOFC based-CHP cell device built under the Ene.field Project which mostly utilized synthetic gas [22]. The International Environment Agency (IEA) (2019) lists around 500 active passenger cars, 15 currently in operation for fuel cell bus (50 units to be launched) [20]. With 75 hydrogen filling stations in service and another 28 in planning or growth, Germany is officially ranked 4th in the world in the hydrogen fuel cell. Besides passenger vehicles (car and bus), Germany launched its first fuel cell train in 2018 using the existing non-electrified railway. So far, fuel cell technology usage has been very limited in the naval application, which only hydrogen fuel cell-powered tourist cruise available in Hamburg. In 2010, an alliance called as Clean Power Net consisting of playmakers from the research and business industries was created with regard to Uninterrupted Power Supply (UPS) systems to advance market adoption of UPS fuel cell applications. Approximately 200 fuel cell-powered UPS systems were installed from 2010 to 2016, e.g. at police
and fire stations as back-up power supplies for the digital radio network. They were funded by the Federal Ministry of Transport and Digital Infrastructure (BMVI) [23].

![Diagram of a compact micro CHP unit](image)

**Figure 2.** A compact micro CHP unit (BlueGEN) unit installed in residential and commercial buildings in addition to an existing heating system [21].

In addition, under the financing guideline for the 2018 BMVI market activation, 505 UPS fuel cell systems are financed for the wireless radio network. At the moment, these ventures are already ongoing. Several further fuel cell demonstration ventures are underway in different fields but only with a limited number of fuel cell systems including in sensor technology, water supply, traffic system and many more. The German Federal Government launched the first German National Hydrogen Programme at the end of 2019. The European Collaborative Undertaking for Fuel Cells and Hydrogen (FCH-JU) includes the European Commission, Hydrogen Europe's manufacturing stakeholders and Hydrogen Europe's research stakeholders. This public-private partnership focuses on the financing of fuel cell and hydrogen technology systems R&D and demonstration projects. The expenditure for the first cycle (2014-2020) is EUR 1.3 billion.

Joint R&D programs to promote clean energy supply for Europe would be available for financing, including converting and conserving renewable energy, based on a Directive agreed between the two countries. Hydrogen and fuel cells are specifically referred to as targeted innovations. The Promoter Jülich shall administer the support. As a division of the German Government for Hydrogen Innovation and Sustainable Mobility, the National Association for Hydrogen and Fuel Cell Technology (NOW) is one of the key stakeholders. Acting as a gateway between politics, academy and industry, NOW coordinates and facilitates operations across national and foreign networks. The National Development Program for Hydrogen and Fuel Cell Technology (NIP) and the Financial Recommendations for
Electromobility and Charging Facilities are some of today's most visible activities. In addition, the Mobility and Fuel Strategy (MKS) program has been set up to allow projects related to the usage and production of alternative fuels, including PtX. The Renewable Energy Export Program has expanded its activities on behalf of the Environment (BMU) to evaluate and facilitate hydrogen and fuel cell technology used worldwide. The NIP I was the global hydrogen technology platform from 2007 to 2016. In this period, EUR 1.4 billion has been invested in hydrogen and fuel cell technologies, generated in almost equal amounts by private and public sectors. The NIP II started in 2017 and is projected to continue until 2026 [24].

Although transport remains insight in industries, further funding will be geared towards the market introduction and integrated ventures in hydrogen regions. Regional initiatives are also underway in Germany, such as the Baden Württemberg Fuel Cell Project, a network to promote the development and expansion of renewable fuel cells and battery-based energy generation and storage technologies for stationary, mobile and portable applications. HySOLUTIONS in Hamburg is a public-private partnership that promotes fuel cells, hydrogen and power supply systems. To expand the hydrogen fuel cell market and to speed up the commercialisation progress, the North-Rhine Westphalia Fuel Cell and Hydrogen Network is linking related players in the hydrogen fuel cell field [20].

3.2. Applications
The fuel cell and hydrogen market in Germany encompasses a wide variety of companies and events. This market covers all levels of device growth and nearly all forms of fuel cell types and implementations. Siemens and SiemensWestinghouse (submarines and stationary SOFC), DaimlerChrysler, Opel, BMW, VW, MAN, MTU CFC Solutions (stationary MCFC), Umicore (MEA), Smart Fuel Cell (portable direct methanol fuel cell), Ballard (PEMFC), Proton Motor (PEMFC), Vaillant (CHP), Linde (gas and infrastructure) and ARAL (gas and infrastructure) are some of the best-known German firms with fuel cell operations. In CHP technology, waste heat is stored during service and can be used for space heating, domestic hot water preparation, hot water washing, and swimming pools or spas. CHP decreases the amount of energy lost by almost half, and the device can supply power with an efficiency of more than 90% while dramatically reducing emissions per kWh generated. CHP can be defined as the sequential or simultaneous generation of multiple forms of useful energy within a single integrated system. The CHP device's cumulative utility can be expressed as the ratio of the sum of the net power to the useful thermal energy output divided by the total energy of the fuel consumed. Energy efficiencies of up to 85 % to 90 % (combined electrical and thermal power) can be produced by CHP systems, which is much higher than the power of systems producing electricity and usable heat in separate processes. This change in energy efficiency will decrease costs in contrast to traditional ways of producing heat and power separately and will reduce greenhouse gas (GHG) emissions [25]. Countries in cooler climates, such as Germany or the United Kingdom, use more than 70% of their energy for room heating and 9% of their energy for water heating. Worldwide development of FC-CHP systems is now taking place. Germany leads the way in Europe in showing and improving domestic FC-CHP programmes. CHP accounted for approximately 12.6 % of Germany's total electricity, with an installed capacity of 21 GW in 2005. New CHP laws in Germany are projected to double the output of electricity by 2020 [26]. Germany is well equipped for smaller-scale industrial and residential applications in both the biogas CHP and m-CHP. Germany ranks second in the implementation of FC-CHP systems with 350 systems were deployed between September 2008 and the end of 2012 under the CALLUX lighthouse initiative of the National Organisation for Hydrogen and Fuel Cell Technology [27]. Panasonic and Viessmann formed a European development agreement. Panasonic role is to create the fuel cell in Japan then transported to Germany for Viessmann integration. With a total efficiency of 90%, the machine produces 750 W of electricity and 1 kW of thermal energy. In Germany, it is anticipated that device sales under field tests will commence [28]. As for the portable application, SFC Smart Fuel Cell AG together with German Federal Army's Military Vehicle and Tank Technology Department WTD 41 announced their collaboration in developing portable fuel cell power supply namely SFC C20-II in 2005 [29].
3.3. Future plan
The hydrogen fuel cell plan for this country lies under Germany's National Hydrogen Strategy [30]. There are several aims and goals for under this strategy, including establishing the hydrogen chain not just in Germany, but also across Europe. Besides that, this country also aims to focus on trading the blue hydrogen in the European market. The German government's goal is to use green hydrogen (CO$_2$-neutral), support a rapid market ramp-up, and establish corresponding value chains. As the hydrogen market growth, it also becomes their goal of pushing down the hydrogen price globally with promoting the decarbonisation via utilisation of hydrogen energy and fuel cell technology [30].

4. United States of America
U.S. Energy reported in 2019 that the total carbon emission originated from petroleum use at about 46%, 33% belongs to burning of natural gas and 21% from burning of coal where the transportation sector itself emits more CO$_2$ compared to the industrial sector due to the massive dependence on petroleum fuels [31]. Most of this carbon output is partly related to light-duty vehicles (LDVs), including light-duty trucks and passenger car. To minimise the release of CO$_2$ and the other types of greenhouse gases originated from engine combustion, the government have developed and introduced their own regulatory and economic policies to reduce the emissions from LDVs [32]. In complying the newly designed legislative, the utilisation of hydrogen as future transportation is mainly attributed to its feature as a high potential for domestic production and fuel cell, which can operate with zero-emission and high efficiency.

The fuel cell can operate at two or three times more efficiently than a gasoline-powered internal combustion engine. Thus, fuel cell research and development's primary subject is more focused on hydrogen use in vehicles. Besides, a few vehicle manufacturers have started to make a light-duty hydrogen fuel cell electric vehicle in several regions equipped with hydrogen fueling stations such as Southern and Northern California. Not to mention that the test vehicles were already made available even though only in limited numbers charged to organisations with easy access to hydrogen fueling stations. For example, hydrogen-fueled vehicles are mostly automobiles and transit buses operating on the electric motor powered by a hydrogen fuel cell. Despite the excellent features of this technology, the major production and implementation of this application are still limited due to the high cost of fuel cells and the restriction on the number of available hydrogen fueling stations [33]. However, this problem will not become a constraint as fuel cell applications' usage expands over the years in this country.

4.1. Applications
The fuel cell and A hydrogen fuel cell can generate energy through the mixing process of hydrogen and oxygen atoms. The electrochemical process will then occur that is almost similar to that of a battery system to generate electricity [34]. Besides, the products are water and a small quantity of heat as a result of the process. There are several different types of fuel cells suitable for a wide variety of applications. The smaller fuel cell version may operate laptop, computers, mobile phones and not limited to military applications. Meanwhile, a larger version of fuel cell could provide additional electricity or energy for as a reserved or backup power in a particular building and supply power to the areas that were not connected to the electrical power grid [35]. It was reported at sometime around the end of October 2019 that there have been approximately about 80 fuel cell power plants that already operated in the United States with the sum of 190 MW of electricity generation capacity. The largest power plant equipped with a capacity of 27 MW and utilized hydrogen, which was derived from the landfill gas to power the fuel cell located in Red Lion Energy Centre, Delaware [33].

Amongst the early step taken onto the futuristic green energy application, Government of the USA in the United States the Federal Transit Administration established the national Fuel Cell Bus (FCEB) program in 2005 to advance commercialization FCEBs that were enacted in Public Law 109-59 [36]. The program has provided nearly $90 million since 2006 to promote the development and testing of cleaner, greener sources of fuel for the transit industry. As of August 2013, there are 18 active FCEBs
in demonstrations at six locations where 14 of the 18 busses are in California [4]. Since then, the demonstration of FCEB progress across the country was administered by the US Department of Energy (DOE) and US Department of Transportation (DOT, through the Federal Transit Administration [FTA]) [37]. A prominent aspect of the DOE/DOT FCEBs ventures is the FCEB fuel economic program was aimed at 8 MPDGE (miles per diesel gallon equivalent, or 3.4 km/l). Both DOE and DOT are making collaboration in 8 MPDGE goals in 2012, relying on the pre-2012 FCEB vehicle research and performance reviews and the stakeholders’ input as a common transit bus operated on diesel achieved about 4MPDGE, while the 8 MPDGE targets for the FCEBs program gave off to a fuel economy to the ratio of 2.

As of February 2020, reported in Fuel Cells Bulletin, the heavy-duty transit buses named The Xcelsior Charge H2™ were distributed by New Flyer of America Inc, a subsidiary of global bus manufacturer NFI Group [38]. The buses include a fuel cell of 85 kW from Ballard Power Systems and deliver a range of more than 265 miles (425 km). The buses were also fitted with the ability to take advantage of regular regen incidents, high-speed service, and to stretch range if the bus was out of fuel [39]. Figure 3 are the models of Xcelsior Charge H2 supplied by New Flyer. The launch of new fuel cell buses incorporated into the OCTA (Orange County Transportation Authority) fleet to start operating in regions. The current hydrogen refuelling platform in the Santa Ana Bus Depot of OCTA is the largest public transport fast-fill facility in the US capable of refuelling up to 50 fuel cell buses per day. The station can fuel up the transit buses with an average of 28 kg of hydrogen per bus in just 6–10 min while offering back-to-back bus refuelling for up to 30 buses and several lanes for continuous refueling [40].

![Figure 3. Xcelsior Charge H2™ model [41].](image)

![Figure 4. Parts of Xcelsior Charge H2™ models adapted from [39].](image)
In July 2020 as reported in Fuel Cells Works news, Intelligent Energy announced that a manufacturing company named Zepher in the US specialized in aerospace and defense had purchased its 800 W PEM Fuel Cell Power Modules (FCPMs). This FCPMs will then be designed into something of a custom-built electric vertical take-off and landing (eVTOL) unmanned aerial vehicle (UAV, or drone) being developed for the US Army [42]. Intelligent Energy has also established a distribution agreement with Parry Labs in the US as confirmed in Intelligent Energy news in July 2020 [43]. Meanwhile, Zepher intends to make the UAV technology accessible during the first 12 months of the contract. To provide more detail on the project is funded in support of a US Army Special Operations Command requirement. Intelligent Energy technologies have been chosen due to their ability in delivering longer flight time considerably, work silently and last but not least require little maintenance. If the first integration has been completed, Zepher will have a concept approach ready for initial development. The architecture will incorporate two 800 W FCPMs [FCB, October 2018, p6] with IE's Power Path Module (PPM) connecting them to a 1.6 kW output. The goal of the flying time of this technology is 14 hours [44].

For the past decade, the implementation and development of stationary fuel cell development have been growing in a strong pace, currently being led by the United States and South Korean market with almost 95% of the installed capacity. There are still significant variations in the methods employed at the national level within the United States, mostly with the bulk of the capability built-in two states, California and Connecticut. To facilitate large-scale stationary fuel cell operations, fuel cell producers are also primarily dependent on public support, whether by technology drive or demand-pull activity [45]. Bloom Energy is another prominent player in the advanced distributed energy generation platform that operates for 24 hours without a break serving the highest efficiency of any power solution globally. Bloom Energy had supplied their product in various sectors where most of the fuel cell technology used SOFC. In July 2018, Bloom Energy based in California, made a headline as their 1.8 MW onsite SOFC technologies power up the SUNY Downstate Medical Centre in the New York City borough of Brooklyn [46]. In January 2019, Bloom Energy, based on California, offered help to Partners Healthcare in Massachusetts with SOFC-based power systems. The Eaton Blackout Tracker announced that it experienced more than 100 electrical power outages in 2017, the last 55 hours in total, which affected more than 630 000 people across Massachusetts. Thus, Partners have agreed to extend to improve the reliability at particular facilities by installing 4.1 MW Bloom Energy’s OFC-based power system at a location across Massachusetts [47].

4.2. Future plan

Although the horrific coronavirus contagion continues to impact many businesses, individuals and cities adversely, the new hydrogen economy is expected to shed light, as many rallies behind a green revival, with hydrogen and fuel cells playing a significant role in this endeavour. 2020 portrayed the first year of growth and achievements for the US hydrogen economy. Ever since a new year is on the horizon, H2 Perspective is focusing on several of the highlights of the US hydrogen and fuel cell sector since the hasty year, and how those activities would positively affect the country's advancement [48]. A report made by The Navigant regarding the promising development of the stationary fuel cell industry in the US over the last few years has been propelled by the foreign governments’ interest in scalable and efficient energy sources as well as global demand that could rise more than 50 GW. Soon, approximately 2.5 million telephone towers will be powered by a fuel cell-based reserved power system globally by the end of 2020 [45].

5. Denmark

Denmark is a developed country which spends more on hydrogen than any other country in the world. The Danish energy source is strongly dependent on renewable energy technologies. Nearly half (47%) of Danish power output in 2013 comes from renewables, primarily from wind farms [49]. From 1996 to 2019, Denmark was self-sufficient in net energy because of oil and gas output. Independence has only ended in recent years due to reduced production for supply and Denmark is forecast to be a major
exporter of petroleum by 2020 and gas by 2035 [50]. Consequently, Denmark has signed an aggressive 2020 political energy deal to this, for example, to double the output and power supply of wind power. The Danish government has further endorsed an ambitious goal of making the energy sector renewable towards fossil fuel-free and fossil-fuel-free economies by 2035 [51]. Denmark is currently the highest exporter for a renewable energy source in the Europe region through its transmission with Netherland, Sweden, Norway, and Germany. However, during the last decade, the trend of electricity import in Denmark is decreasing. To maintain as the biggest supplier in renewable energy in Europe, Denmark has to venture into new technology [52]. Hydrogen is expected to play an essential role in this future scenario [53].

Denmark has been one of the world leaders in hydrogen and fuel cell developments and becomes the world's first country to establish an effective chain of hydrogen refuelling stations. Denmark is increasing compliance in fuel cell technology, from R&D to manufacturing and hydrogen development to deployment of infrastructure. In Denmark, the government agreed on an ambitious energy strategy for 2012-2020, which specified by 2050, the national infrastructure would be completely carbon-free, including transport. Therefore, hydrogen and fuel cells are given priority as a possible key technology in Denmark, facilitating the required energy system balance [49]. The Danish hydrogen and fuel cell strategy are divided into hydrogen technology development and fuel cell technology development. For hydrogen technology, it involves electronics, hydrogen infrastructure, and hydrogen storage while developing fuel cell technology will be focused on research, development, and testing. Two different applications of hydrogen have had the broadest social impact. The first is strength. In 2012, the Danish government signed an ambitious energy agreement, with the key concerns relating to the transition from fossil electricity production to wind-based renewable energy. This approach inspired entrepreneurs to participate in the hydrogen fuel cell technology's business development projects in the electricity sector to store electricity, offset the charges, and be considered a great potential, at least in principle, concerning residential heat and power solutions. Residential heating and power solution have growth potential of approximately 20% of Danish homes, a proportion not related to district heating [54].

As concerning mobility, a comparatively small $1.8 million has been allocated to hydrogen infrastructure. Despite these challenges, Denmark is the most expensive country in Europe to purchase and own a vehicle[55]. Hydrogen cars are also excluded from entry tax and vehicle excise duties, making them more economically efficient for customers. However, no tax or price incentives are in place to use hydrogen petrol technologies. For Denmark, the future short-term growth potential is mainly restricted to the production and implementation of maintenance and hydrogen petrol stations. According to the internal research carried out by H2Logic, a leading hydrogen fuelling station manufacturer and HydrogenLink, a network of hydrogen road production, about half the Danish automotive industry would in 2050 be made of hydrogen fuel cell cars corresponding to around 1.4 million automobiles [56].

The hydrogen fuel cell landscape in Denmark consists of about 20 local firms and a few supporting organisations and networks. They are mostly small and medium-sized companies (SME) engaging in public/private collaboration research and development work with Danish universities, but only 3 Danish companies in the top 200 worldwide in the fuel cell business. The Danish hydrogen and fuel cells collaboration promotes cooperation with a partnership with a formal organisation and enables threefold cooperation and promotes the production and marketing of technology for fuel cells. In addition to the alliance, there is a range of smaller networks with broader targets. One of them is Cemtec, a network promoting industry for businesses based in Denmark's regional region and the hydrogen transportation network HydrogenLink, which work together with other Scandinavian countries and automotive manufacturers internationally to extend their hydrogen vehicle networks.
5.1. Applications
Public transport and freight transport account for around 25% of carbon emission in Denmark. The introduction of zero-emission electric fuel cell buses will contribute significantly to Danish climate policy, which is promising 70% below carbon emission by 2030 and will achieve complete carbon neutrality by 2050 [57]. Danish municipalities play an important role in developing a potential public transit infrastructure, but trade actors need to work together to create zero-emission buses. Several major players in the hydrogen fuel cell chain have founded the H2BusEurope consortium committed to supporting the fuel cell electric bus (FCEB) infrastructure to advance de-development.

For more than ten years, FCEB has already been in the commercial venture in places around the globe. In March 2020, the first three FCEBs were deployed in Denmark [58]. The three busses represent a very significant step or public transport with zero-emission in Denmark, as the busses fill the gap between demonstrations and the broader usage of FCEB. In the city of Aalborg, Denmark, the first three fuel cell buses were operational. The three coaches are part of the ambitious EU-funded 3Emotion project which is financed by the FCH-JU program. This project is one of Ballard, and 17 other investors' several projects are taking part to support fuel cell in Denmark. Keeping fuel cells technology would minimise reliance on fossil fuels and protect the expansion of fuel cells. This 12-meter A330 bus can carry up to 78 passengers. Van Hool builds the vehicle, while Ballard built the fuel cell system for this bus. Siemens provides the electric drive with up to 160kW of output for the A330 bus. This bus's hydrogen tanks can carry up to 38 kilograms hydrogen, which should be 350 kilometres long enough until the next hydrogen fuelling station. FCEB is operated as a traditional bus with a range of up to 400 kilometres depending on the hydrogen tank size, rendering it the most versatile zero-emissions option.

Denmark is a pioneer in introducing clean energy sources such as wind turbines and by electrolysis surplus. Thus, in Denmark wind power can be transformed into hydrogen as an alternative zero-emission replacement for fossilised fuel combustion engine vehicles. Hydrogen production will also meet much of the balancing needs for clean energy integration in Denmark by 2050. Under the H2BusEurope programme, 1,000 FCEBs are deployed by 2023 with 200 buses for Denmark. The hydrogen fuel cell bus from H2BusEurope is anticipated as the cheapest proper zero-emission choice that possible, with the target single-decker bus price below EURO375,000, hydrogen costs between EURO5 and EUO7 per kilogram, and the bus operation price below EURO0.30 per kilometre. This amount could be achieved by the link of FCEBs across Europe countries and cities including London, Aberdeen, Cologne, Hamburg, Oslo, Aalborg and others. The more prominent usage of the fuel cell will reduce the cost of the technologies itself.

In the Copenhagen area, the Danish partnership aims to merge the demand and supply of renewable fuel with a vision to become one of the world's largest electricity and sustainable energy facilities. The electrolyser will be installed in three phases, with a 1.3-GW electrolyser system provided by renewable energy from offshore winds. COWI and BCG advisory groups serve as consultants for the initiative funded by the Copenhagen municipality. Airport Copenhagen, shipping giant A.P. Møller Maersk, DSV Panalpina, DFDC Shipping firm, SAS airline operator and Orsted have developed an alliance to establish an advanced facility for the manufacture of hydrogen and e-fuel by 2023 [59]. The plan will provide green hydrogen to support the fuel cell buses operating from the Movia transit agency, heavy-duty lorries from the DSV Panalpina, aircraft form A.P. SAS, air freight from Moller-Maersk and clean jet fuel from Copenhagen airport. This project would mark a significant supply of renewable energy that could be generated through an offshore wind farm at the Orsted Ronne Banke site in Bornholm Island.

A 10 MW electrolyser is the first phase that could be operational in 2023, that will deliver green hydrogen for the direct use of refuelling buses and trucks. The second phase will involve a 250 MW electrolyser system, which will be operational by 2027. This phase is targeted to operate when the first offshore Bornholm wind power facilities are ready. This facility will integrate green hydrogen production with sustainable carbon capture from points in the greater Copenhagen region to generate marine renewable methanol and aviation e-kerosene. For the third phase, which could become
operational by 2030 when Bornholm offshore wind potential is fully developed and operate. In this stage, it will raise the electrolysis capability's ability to 1.3 GW and produce more carbon dioxide; enough to provide sustained fuels for all transportation involve to more than 250,000 tons per year [60].

Denmark is one of the world leaders within hydrogen and fuel cell technologies and was the first country in the world to establish a nationwide network of hydrogen refuelling stations. Denmark is also fully engaged in fuel cell technology; from R&D to product manufacturing and hydrogen production to infrastructure deployment. There is an 11-hydrogen station built across Denmark (Figure 5). There are 6 hydrogen stations with an onsite electrolyser, 3 hydrogen station operate with the hydrogen is supplies from the Strandmollen electrolyser plant, 1 hydrogen station under construction, and another under planned. Every station has a pressure of 70MPa, which is consistent with new hydrogen fuel cell vehicle, and it is derived from the electrolyser of renewable electricity [61]. An internationally uniform refuelling dock is used at the 700-bar. SAE J2601 refuelling standard is applied in the whole hydrogen fuelling station across Denmark. This standard is the same uniformly in hydrogen refuelling at less than three minutes for each fuel cell vehicle refuelling [62].

![Figure 5. Hydrogen Fuelling Station in Denmark [61].](image)

5.2. Future plan

For Denmark, when the facilities complete in 2030, it will provide an annual amount of 250,000 tons of fuel to power fuel cell buses, cars and vehicle. It is a target to minimizing annual carbon emission up to 850,000 tons. The link of hydrogen fueling station will connect through Europe and enable more fuel cell vehicles to be used across Denmark and Europe. Infrastructure for building the Scandinavian hydrogen route will form about half of the Danish car market by 2050 of hydrogen fuel cell vehicles,
which around 1.4 million cars. Denmark’s possible short-term growth opportunity is mainly constrained to create and deploy support for fuel cell and expand fueling station for hydrogen.

6. China

In an era of revolution, many developed countries worked to take part in current evolving technologies of fuel cell energy. This country included The Great Wall country or well-heard China. As one of the developed countries, China is currently focusing on enhancing hydrogen fuel cells' utilisation in their country. Hydrogen is the central pillar in the contribution of a low-carbon to meet the Paris Agreement 2015 commitment, hence, zero-emission energy system [63][64]. According to Yinfie et al., stated that three main reasons why using hydrogen energy are crucial. (1) Hydrogen is one of the key proponents to lead to a low-carbon or zero-emission energy system. (2) Hydrogen is theoretically to be considered as energy storage. (3) Hydrogen is commonly used in a variety of industries (International Energy Agency) [63]. Due to these alternatives, China announced to utilise hydrogen fuel fully. Besides, China was reported to have a significant amount of hydrogen energy; thus, these reasons lead to the alternative made [65].

6.1. Applications

China has been focused mainly on the primary factor in developing fuel cell technology which is research and development. Research and development industry (R&D) play a vital role in developing a product, business, and others to achieve the said goals or purposes. China is said to have done many kinds of research in developing the application of fuel cell technology. China is said to have started its research 45 years ago and continued developing its research throughout the 1990s' reaching over a dozen Chinese universities and institutes, involving in the study of various cell fuel types. However, China started to fall behind in developing fuel cells when its research had faced several problems. Its research started to become smaller, irregular, and incomparable to the level of investments exemplified by other industrial countries. Besides that, China had spent thinly in all research institutes, including fuel cell-related topics that had caused the nation's overall fuel cell development to become weak. However, in 1996, China started to rise again in the development of fuel cell technology. The Global Environmental Facility (GEF) had provided great international assistance in developing fuel cell vehicles which included a kind of study or research about the fuel cell vehicle. The contribution of GEF also benefited in the way of capturing the China government's attention and support to increase the research and development of the fuel cell vehicle in China.

There are several applications and developed technologies of hydrogen fuel cells were invented by China [53,63,73,65–72]. But, the most dominant application is in transportation (MAXUS, Feichi Bus and Zhongtong Bus). China's government has announced a range of policies and initiatives to promote fuel cell vehicles (FCVs) [66]. China took serious in developing the fuel cells vehicle in the industry because it gives advantages to China in many ways such as enhancing energy security, greater industrial competitiveness, improving urban air quality and reducing greenhouse gas emissions. The development of this sector in China can be seen when the government used Olympics 2008 and World Expo 2010 to show their capabilities to the world. During the Beijing Olympics 2008, the government used 20 fuel cell cars and 3 fuel cell buses to transport special guests, press and officials from the Olympics organising committee. According to Zhang and Cooke (2010), the cars used were designed by Shanghai's Volkswagen Passat while the buses were developed by Tsinghua University and Beiqi Foton Motor Co [74]. Two years after the Olympics, the World Expo 2010 was held in Shanghai. According to Gupta, Basile and Veziroglu (2016), the government used 196 fuel cell vehicles, including 90 fuel cell cars, 6 fuel cells buses and 100 fuel cells tourist vehicles. This vehicle's function is to transport visitor in and around the exposition site [75]. 2 permanent and 2 mobile hydrogen refuelling stations were constructed and operated at the Expo.

National Development and Reformation of China reported that 20% of energy consumption in China comes from transportation. This report shows the transportation sector requires much energy consumption compared to another industry [73,76]. Hydrogen-based fuel vehicles are essential due to
their aptitude to reduce the greenhouse gas effect plus air pollution. This fuel cells vehicle is also a great choice due to its ability as a life-cycle carbon-free option for the transportation system [69]. Refer to the news from China, the city of Changshu planned to open a hydrogen station for the transportation of hydrogen-based vehicles in 2022. Most of China's developers and investors got an eye-catching on this developed hydrogen-based fuel cells vehicles. This reason comes with the better service from these new hydrogen vehicles because these hydrogen fuel cells vehicles have improved service life, cell power density also millage. Those explanations lead to these vehicles' hydrogen fuel cells as an alternative to safer and conventional future technology [65].

Besides the fuel cell application in the transportation sector that is already synonymous in China, this country is also planning for its first hydrogen-based ENE-FARM in northern Hebei province's Guyuan county [77]. This ENE-FARM project aims to power up the Winter Olympic 2022 and already 95 % finish. This project combines wind farm (200 MW) with 10 MW electrolyser system [77]. In addition, the hydrogen yields from electrolysis are said to replace the usage of gas and oil, e.g. in the transportation sector. This ENE-FARM project is funded by the Hebei Construction & Investment Group. The decarbonisation of energy also supported by one of the largest energy company in China, Sinopec. With the goals to implement hydrogen fuel cell vehicle during Winter Olympic 2022, Sinopac built its hydrogen production unit in Yanshan, Beijing [77].

On the other hand, there are minor drawbacks for the beneficiary. As a result of recent renewable energy shifts, these hydrogen fuel cells are currently in the in-house deployment process. Work is still under the jurisdiction of the government. The cons that were identified were the high cost of development, and the infrastructure's fragility also missed the quality. China's technology lags behind other developing countries, giving it a high cost of production. Other cons of this alternative concept of turning to hydrogen are commercial storage and the hydrogen filling network. This storage technology could give up a high cost of hydrogen if the handling method is inaccurate. The concern is that hydrogen can only be transported using the gas form, but that costs five times the storage and delivery of liquid hydrogen. Finally, there is a lack of regulation and a reference standard for handling hydrogen or a method in the industry that may contribute to the acceptance of the product and its spread. Plus, from an environmental point of view, the problems often emerge from the geographical variations in hydrogen supplies. However, the difficulties of getting society to embrace the latest invented technology fully may take some time as well as lack of infrastructures and policies [63,65,78].

To infer the above point, the development of hydrogen fuel cells energy contributes significantly to China's growth. It provides a green technology with less pollution and reduces the dependence of non-renewable energy. In contrast, it also has several drawbacks that require more research and development from the government. The weakness should be improved on the infrastructure if the hydrogenation stations, reduce the production cost also establish some reasonable policies and standard of procedures that can be used as the guideline. Overcoming the challenges of the drawback may be improved the smoothness of utilising hydrogen energy in China because China has a great potential to develop this hydrogen technologies due to its privilege as a developed country.

Table 1 summarised the major application that utilises hydrogen fuel cell in Japan, Germany, USA, Denmark and China. All countries have been focused on the transportation and energy production sector as these two sectors produce large carbon. Success in decarbonisation in these two sectors will result in a drastic reduction in carbon emission worldwide.
Table 1. Summary of the hydrogen fuel cell in major sectors (transportation and energy farm).

| Country  | Applications (including R&D phase) | ENE-FARM & Stationary Power Generator |
|----------|------------------------------------|--------------------------------------|
| Japan    | • Toyota Mirai                      | • Latest: Osaka ENE-FARM project     |
|          | • 222 kW SORA fuel cell bus (FCB)  | • 5.3 million of 5 kW residential units by 2030 |
|          | • > 800,00 fuel cell vehicles (FCVs), 1,200 busses & 10,000 forklifts on the roads by 2030 | |
|          | • Toyota-JR East hydrogen mobility alliance | |
| Germany  | • ~500 active fuel cell passenger vehicles, 15 buses with an additional 50 accepted for launch | • Ene.field project |
|          | • Hamburg tourist ship               | • 3,600 microCHP units deployed in 2018 |
| USA      | • National Fuel Cell Bus (FCEB) program in 2005 | • 5,500 microCHP units in 2019 sponsored by BMWi |
|          | • 18 active FCEBs (14 of the 18 busses are in the state of California) in 2013 | • 505 fuel cell UPS systems for the digital radio network of vital organisations funded by BMWi |
|          | • 85 kW Xcelsior Charge H2TMheavy-duty transit bus in Feb 2020 | |
|          | • 800 W unmanned aerial vehicle (UAV) or drone for military in July 2020 | |
| Denmark  | • 160 kW fuel cell electric bus (FCEB) with capacity of 78 passengers 350 km/full tank | • 1st phase: 10 MW electrolyser system by 2023 |
|          | • carbon-free option for the transportation system | • 2nd phase: 250 MW electrolyser system by 2027. |
|          | • hydrogen station for the hydrogen-based vehicles located at Changshu in 2022 | • 3rd phase: 1.3 GW electrolyser system by 2030 |
|          | • MAXUS, Feichi Bus and Zhongtong Bus (Fuel cell vehicles) | |
| China    | • carbon-free option for the transportation system | • 10 MW electrolyser system in northern Hebei province's Guyuan county by Hebei Construction & Investment Group |
|          | • hydrogen station for the hydrogen-based vehicles located at Changshu in 2022 | • Sinopec hydrogen production in Yanshan, Beijing |
|          | • MAXUS, Feichi Bus and Zhongtong Bus (Fuel cell vehicles) | *both for 2022 Winter Olympic |
7. Conclusion
The fuel cell industry has evolved quickly, and a variety of research has been undertaken to bring the industry to light. As technology improves, deregulation and public assistance are projected to develop. Furthermore, non-renewable fuels such as oil, coal and natural gas are reduced through fuel cell utilisation. The fuel cell industry has faced obstacles as it meets a time of stagnation and completes the transition from R&D to commercialisation. Overall, the conditions have survived incredibly complicated. While some fuel cell businesses are still far from sustainable, future growth prospects are fascinating. In recent years, the popularity of some application segments means that a step has been made to integrate specific technology into a common reference design for a particular type of fuel cell. This situation has led to fuel cells being rapidly being developed as flexible energy technologies capable of serving various market segments, be they APUs or power devices such as unmanned aerial vehicles.

Conclusively, the development of fuel cell technology in the selected developed countries has grown rapidly and efficiently. This successful development happened with the contribution of a lot of parties. There was a lot of research institute had been built to conduct fuel cell research. A lot of research had been done by the experts, and many more are still ongoing. Fuel cell industry in those countries has gained a lot of support from the researchers, developers including the government itself to make sure that all the research conducted will ensure a worth return to the industry's development. It will give advantages and merits economically and helps to lift the country’s reputation.

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References
[1] Andújar J M and Segura F 2009 Fuel cells: History and updating. A walk along two centuries Renew. Sustain. Energy Rev. 13 2309–22
[2] Douglas D L and Liebhafsky H A 1960 Fuel cells: History, operation, and applications Phys. Today 13 26–30
[3] Brandon N 2004 Fuel Cells Encycl. energy 2 749–58
[4] Burke K 2012 Current perspective on hydrogen and fuel cells vol 4 (Elsevier Ltd.)
[5] Kato Y, Koyama M, Fukushima Y, Nakagaki T, Energy F, Based S and Beyond F T 2016 Energy Technology Roadmaps of Japan (Springer Nature)
[6] JETRO 2006 Japan ’ s Fuel Cell Industry
[7] Futamura S, Muramoto A, Tachikawa Y, Matsuda J, Lyth S M, Shiratori Y, Taniguchi S and Sasaki K 2019 SOFC anodes impregnated with noble metal catalyst nanoparticles for high fuel utilization Int. J. Hydrogen Energy 44 8502–18
[8] Nagashima M 2018 Japan’s Hydrogen strategy and its economic and geopolitical implications
[9] Popov S and Baldynov O 2018 The Hydrogen Energy Infrastructure Development in Japan E3S Web Conf. 69 1–11
[10] Chaube A, Chapman A, Shigetomi Y, Huff K and Stubbins J 2020 The role of hydrogen in achieving long term Japanese energy system goals Energies 13 1–17
[11] Toyota Motor Corporation 2018 Toyota moves to expand mass-production of fuel cell stacks and hydrogen tanks towards ten-fold increase post-2020 Toyota Newsroom
[12] Lucas L 2017 Toyota unveils Sora fuel cell bus, Fine-Comfort Ride saloon Fuel Cells Bull. 2017 2
[13] Lucas L 2018 Toyota begins sales of Sora fuel cell bus Fuel Cells Bull. 2018 2–3
[14] Association F C & H E 2020 Japan ’ s Hydrogen Olympics FCHEA 1–4
[15] Samantha O 2017 Seven-Eleven Japan , Toyota Partner on Hydrogen Test cspdailynews
[16] HLDGGS S 2020 Expansion of the Small Fuel Cell ( FC ) Truck Demonstration Experiment
Area 7andi.com

[17] Lucas L 2018 Toyota tech in fuel cell buses for Caetanobus, Japan rail partnership Fuel Cells Bull. 2018 2
[18] Corporation T M 2020 JR East, Hitachi and Toyota to Develop Hybrid (Fuel Cell) Railway Vehicles Powered by Hydrogen Fuel Cells Bull. 6
[19] Myfcpower 2018 myFC ships JAQ Hybrid order to Lightec in Japan Fuel Cells Bull. 2018 8–9
[20] Jensterle M, Narita J, Piria R, Samadi S, Prantner M, Crone K, Siegemund S, Kan S, Matsumoto T and Shibata Y 2019 The role of clean hydrogen in the future energy systems of Japan and Germany vol 6
[21] BlueGen HOW BLUEGEN WORKS Power, Solid
[22] Gandiglio M, Ferrero D, Lanzini A and Santarelli M 2020 Fuel cell cogeneration for building sector: European status REHVA J. 21–5
[23] Nina P 2019 FIVE FEDERAL STATES TO RELY ON FUEL CELLS https://www.now-gmbh.de/
[24] Commision E 2003 Hydrogen Energy and Fuel Cells
[25] Tom K 2009 CHP / DHC Country Scorecard: Germany IEA 1–12
[26] EPA 2007 Combined Heat and Power (CHP) Partnership Agency, United States Environ. Prot.
[27] Office A M 2016 Combined heat and power technology fact sheet series - Fuel Cells
[28] Anon 2013 Panasonic, Viessmann for European home cogen Fuel Cells Bull. 2013 1
[29] Shepard J 2005 SFC to Develop Portable Fuel Cells for German Federal Army
[30] Amelang S 2020 Germany ’ s National Hydrogen Strategy
[31] EIA 2019 Energy and the environment explained: Where greenhouse gases come from
[32] Borlaug B, Holden J, Wood E, Lee B, Fink J, Agnew S and Lustbader J 2020 Estimating region-specific fuel economy in the United States from real-world driving cycles Transp. Res. Part D Transp. Environ. 86 102448
[33] EIA 2020 Hydrogen explained: Use of hydrogen U.S. Energy Inf. Adm.
[34] Alaswad A, Baroutaji A, Achour H, Carton J, Al Makky A and Olabi A G 2016 Developments in fuel cell technologies in the transport sector Int. J. Hydrogen Energy 41 16499–508
[35] Mekhilef S, Saidur R and Safari A 2012 Comparative study of different fuel cell technologies Renew. Sustain. Energy Rev. 16 981–9
[36] Lee D Y, Elgowainy A and Vijayagopal R 2019 Well-to-wheel environmental implications of fuel economy targets for hydrogen fuel cell electric buses in the United States Energy Policy 128 565–83
[37] Alvarez-Meaza I, Zarrabeitia-Bilbao E, Rio-Belver R M and Garechana-Anacabe G 2020 Fuel-cell electric vehicles: Plotting a scientific and technological knowledge map Sustain. 12
[38] FuelCellBulletin 2020 Orange County unveils fleet of fuel cell buses, largest H2 station in US vol 2020
[39] California Transit Association 2019 Real life Experience with Fuel Cell Electric Buses
[40] OCTA Hydrogen Fuel Cell Electric Buses Orange Cty. Transp. Auth.
[41] Anon 2020 Xcelsior CHARGE H2™ Fuel cell-electric and zero-emission
[42] FuelCellsWorks 2020 Intelligent Energy UAV Fuel Cells Power Fixed Wing eVTOL Endurance Drone for the US Army (Loughborough)
[43] Energy I 2020 Intelligent Energy and Parry Labs LLC Announce New Distribution Agreement Intelligent Energy
[44] Brief I N 2020 Intelligent Energy fuel cells power endurance drone for US Army Fuel Cells Bull. 2020 5–6
[45] Rajalakshmi N, Balaji R and Ramakrishnan S 2021 Recent developments in hydrogen fuel cells: Strengths and weaknesses (INC)
[46] FuelCellBulletin 2018 Bloom SOFC systempowers SUNY medical centre in Brooklyn Fuel Cells Bull. 2018 7
[47] FuelCellBulletin 2019 Bloom onsite SOFC power for Partners HealthCare in MA vol 2019
[48] Burgess M, Cockerill R and Sampson J 2020 Hydrogen fuel cell developments in the US H2 View
[49] Andreasen K P and Sovacool B K 2014 Mapping and interpreting critical hydrogen stakeholders in Denmark Int. J. Hydrogen Energy 39 7634–7
[50] Sovacool B K 2013 Energy policymaking in Denmark: Implications for global energy security and sustainability Energy Policy 61 829–39
[51] Jillian Ambrose 2020 Denmark to end new oil and gas exploration in North Sea theguardian 1
[52] Aziz M and Huda M 2019 ScienceDirect ScienceDirect ScienceDirect Utilization of electric vehicles for frequency regulation in Danish The and Cooling Utilization electric vehicles for frequency regulation in Danish electrical grid electrical grid Assessing the Muhammad feasibili Energy Procedia 158 3020–5
[53] Ren J, Andreasen K P and Sovacool B K 2014 Viability of hydrogen pathways that enhance energy security: A comparison of China and Denmark Int. J. Hydrogen Energy 39 15320–9
[54] https://www.iea.org/ 2020 Danish Energy Agreement for 2012-2020 IEA/IRENA Renewables Policies Database 1
[55] Å U K and Kuhfeld H 2007 The diverse structures of passenger car taxation in Europe and the EU Commissions proposal for reform 14 306–16
[56] Workshop H L 2010 Danish Partnership for Hydrogen and Fuel Cells Public R , D & D budgets for Hydrogen and Fuel Cells in 2008 78
[57] Buses Z and Denmark I 2020 Fuel Cell Electric Buses Zero – Emission Fuel Cell Electric Buses for Denmark .
[58] Nina Hjorth 2020 Fuel cell electric buses: Hitting the road in Denmark and around the world https://blog.ballard.com/
[59] East S 2020 ABB control solution to
[60] Reuters Staff 2019 Offshore wind developer Orsted secures money for renewable hydrogen project https://www.reuters.com/ 10
[61] https://insideevs.com/ 2016 With 9 Hydrogen Fuel Stations, Denmark Is 1st Country With Basic National Network https://insideevs.com/
[62] Gmbh O 2011 Shell opens hydrogen station with Linde tech in Germany 2011
[63] Li Y and Kimura S 2021 Economic competitiveness and environmental implications of hydrogen energy and fuel cell electric vehicles in ASEAN countries: The current and future scenarios Energy Policy 148 111980
[64] Zhong X Z, Wang G C, Wang Y, Zhang X Q and Ye W C 2010 Monomeric indole alkaloids from the aerial parts of Catharanthus roseus Yaoxue Xuebao 45 471–4
[65] Pan A, Liu J, Liu Z, Yang Y, Yang X and Zhang M 2020 Application of Hydrogen Energy and Review of Current Conditions IOP Conf. Ser. Earth Environ. Sci. 526
[66] He X, Wang F, Wallington T J, Shen W, Melaina M W, Kim H C, De Kleine R, Lin T, Zhang S, Keoleian G A, Lu X and Wu Y 2020 Well-to-wheels emissions, costs, and feedstock potentials for light-duty hydrogen fuel cell vehicles in China in 2017 and 2030 Renew. Sustain. Energy Rev.
[67] Liu W, Zhang Z, Chen J, Jiang D, Wu F, Fan J and Li Y 2020 Feasibility evaluation of large-scale underground hydrogen storage in bedded salt rocks of China: A case study in Jiangsu province Energy 198 117348
[68] Zhou J, Guo Y, Huang Z and Wang C 2019 A review and prospects of gas mixture containing hydrogen as vehicle fuel in China Int. J. Hydrogen Energy 44 29776–84
[69] Zhang G, Zhang J and Xie T 2020 A solution to renewable hydrogen economy for fuel cell buses – A case study for Zhangjiakou in North China Int. J. Hydrogen Energy 45 14603–13
[70] Xu X, Xu H, Zheng J, Chen L and Wang J 2020 A high-efficiency liquid hydrogen storage system cooled by a fuel-cell-driven refrigerator for hydrogen combustion heat recovery Energy Convers. Manag. 226 113496
[71] Sun Z Y, Liu F S, Liu X H, Sun B G and Sun D W 2012 Research and development of
hydrogen fuelled engines in China *Int. J. Hydrogen Energy* **37** 664–81

[72] Tian M W, Yuen H C, Yan S R and Huang W L 2019 The multiple selections of fostering applications of hydrogen energy by integrating economic and industrial evaluation of different regions *Int. J. Hydrogen Energy* **44** 29390–8

[73] Chang X, Ma T and Wu R 2019 Impact of urban development on residents’ public transportation travel energy consumption in China: An analysis of hydrogen fuel cell vehicles alternatives *Int. J. Hydrogen Energy* **44** 16015–27

[74] Zhang F and Cooke P 2010 Hydrogen and fuel cell development in China: A review *Eur. Plan. Stud.*

[75] Ram B. Gupta, Basile A and Veziroglu T N 2013 *Compendium of hydrogen energy Volume 2: hydrogen storage, distribution and infrastructure*

[76] Li W, Long R, Chen H, Chen F, Zheng X, He Z and Zhang L 2020 Willingness to pay for hydrogen fuel cell electric vehicles in China: A choice experiment analysis *Int. J. Hydrogen Energy* **45** 34346–53

[77] Yihe X 2020 ENERGY China set to fire up wind farm-linked hydrogen scheme with Winter Olympics in its sights

[78] Ren X, Dong L, Xu D and Hu B 2020 Challenges towards hydrogen economy in China *Int. J. Hydrogen Energy* **5**