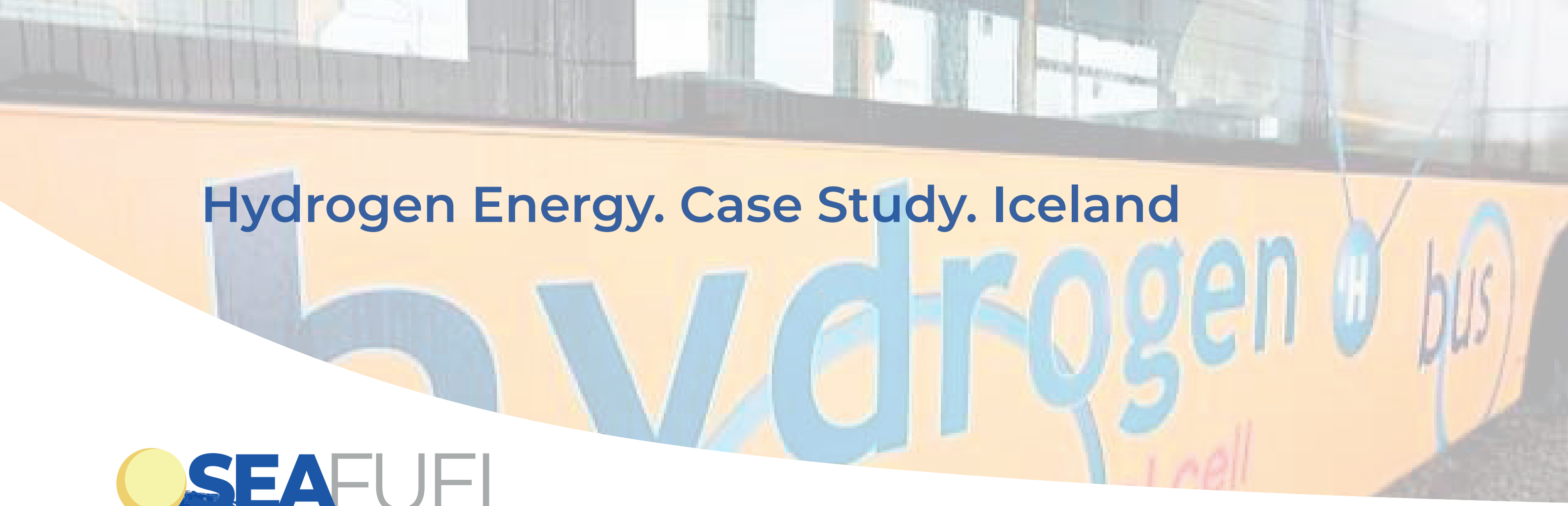
Hydrogen Energy. Case Study. Iceland



SEAFUEL

Ecological City Transport System (ECTOS) Reykjavik and Beyond

1 Total population of Iceland - 357,000 (2019)

2 Iceland lies in the Arctic Region of Northern Europe

3 Largest settlement and administration centre: Reykjavik, capital, and largest city of Iceland

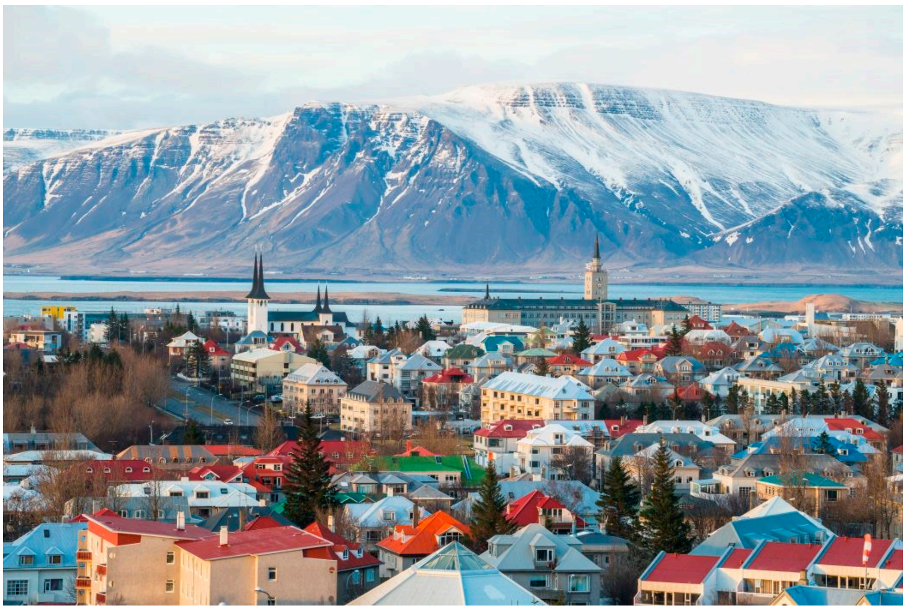


Figure 1 (*source: https://cruise-adviser.com/ports-of-call-reykjavik/*)

Background

Until the early 1970s, the largest share of Iceland's energy consumption was derived from imported fossil fuels (oil). At this time fossil fuels were subjected to significant price fluctuations due to several crises affecting world energy markets[1].

[1] United Nations: UN Chronicle (n.d.) Iceland's Sustainable Energy Story: A Model for the World?, Available at: *https://www.un.org/en/chronicle/article/icelands-sustainable-energy-story-model-world* (Accessed: 22nd October 2020).

Interreg Atlantic Area
European Regional Development Fund
EUROPEAN UNION

Background

This was the main driver for Iceland, in the transitioning of their energy system, to be built upon a stable and economically feasible domestic energy resource. Iceland's transition from fossil fuels to renewable energy represents a remarkable change in a short period of time. The transition was led by the strong cohesion between the municipalities, government, and the public to explore and exploit local green resources largely driven by energy costs and the need for energy security. Iceland quickly established itself as a leader in renewable energy production, the Icelandic government state that around 85% of the total primary energy supply in Iceland is derived from domestically produced renewable energy sources.

This makes Iceland the country with the highest share of renewable energy in any national total energy budget. In 2016, 65% of primary energy was supplied by geothermal sources, 20% hydropower and the remaining 15% fossil fuels[2]. Fossil fuel use in Iceland are made up predominantly of oil products for use in the transport sector. These figures demonstrate that Iceland has managed to position itself as the world's largest green energy producer per capita. Iceland's experience is a reminder that not only the rich developed countries can overcome cost and internal barriers for a green transition[3].

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[2] Government of Iceland: Ministries of Industries and Innovation (n.d.) Energy, Available at: *https://www.government.is/topics/business-and-indus-try/energy/#:~:text=About%2085%25%20of%20all%20houses,and%2027%25%20from%20geothermal%20power* (Accessed: 22nd October 2020).
[3] United Nations: UN Chronicle (n.d.) Iceland's Sustainable Energy Story: A Model for the World?, Available at: *https://www.un.org/en/chronicle/article/icelands-sustainable-energy-story-model-world* (Accessed: 22nd October 2020).

The Vision

As a remote island nation this has allowed Iceland to make energy production for its population more sustainable, affordable, and reliable. However, there remains a reliance on fossil fuel imports and the government have been clear that this needs to be reduced to meet climate and emission reduction targets. Iceland's emissions profile is different to other countries such as the UK, as almost all heating and electricity generation is provided by renewable energy sources. Typically, energy production would be the largest source of emissions and presents the greatest potential for mitigation. In Iceland, this is not the case and instead the greatest sources of emissions have been identified as industrial processes, road transport, agriculture, fisheries, and waste management.

The Climate Action Plan (CAP) is Iceland's main instrument to reach its commitment in the Paris Agreement, more specifically its emissions goals for 2030. The Icelandic government presented the latest version of their CAP in June 2020 which detailed 48 actions aimed at reducing greenhouse gas emissions and increasing carbon uptake from the atmosphere. Within the CAP the Icelandic government have set an emission reduction target of 35% by 2030 with an aim to be carbon neutral by 2040[4], which is ambitious but not unrealistic given Iceland's pioneering status in renewable energy. The Icelandic government have also appeared to be ahead of the mark in relation to hydrogen as the replacement of imported fossil fuels with domestically produced hydrogen or hydrogen-based fuels have been discussed extensively in Iceland. The government first indicated that this was a consideration for Iceland in 1998, when a statement was issued which indicated that Iceland wished would pursue a hydrogen economy – the first of which in the world. The Icelandic Hydrogen and Fuel Cell Company Ltd was then established with the sole purpose of investigating the potential for the replacement of the use of fossil fuels with hydrogen[5]. Iceland therefore became a pilot country for demonstration of the hydrogen economy. Over the years, Iceland has been a key partner in several hydrogen projects which are discussed in more detail below.

[4] Government of Iceland (23rd June 2020) New Climate Action Plan - Iceland will fulfil its commitments and more, Available at: *https://www.government.is/news/article/2020/06/23/New-Climate-Action-Plan-Iceland-will-fulfil-its-commitments-and-more/* (Accessed: 22nd October 2020).
[5] Arnason, B. and Sigfusson, T.I., 2000. Iceland—a future hydrogen economy. International Journal of Hydrogen Energy, 25(5), pp.389-394.

Ecological City Transportation System (ECTOS)

The Ecological City Transportation System (ECTOS) project was launched in 2001, it was a 4 ½ year project in Reykjavik, Iceland. The purpose of the project was to demonstrate and evaluate hydrogen-based infrastructure for public transport and demonstrate the benefits for the society at large to operate the future transport system on hydrogen.

The city of Reykjavik was chosen as the test-bed for the ECTOS project, the bus fleet in the city was relatively small and the hydrogen buses represented 4% of the total fleet which made them more visible in the city[6]. The ECTOS project was designed to become a learning experience that had the potential to facilitate the large-scale use of hydrogen in Iceland. The outcomes of which could be used to identify both barriers and drivers within the future hydrogen economy and inform political decisions.

The ECTOS project, funded by the European Commission saw the introduction of three fuel cell buses brought into commercial operation in Reykjavik and the installation of a hydrogen refueling station to support the fleet. The buses operated much more effectively than anticipated and as a result the original timeframe of two years in operation was extended to three years. The project provided a valuable insight into the practicality of a hydrogen economy in Iceland. The availability of the buses remained high throughout the project. In total the buses had 5,216 hours of operation and have covered 89,243km during the project timeframe[7]. There were unanticipated small technical issues such as failures of the CVM (cell voltage monitor) board, pumps, and inverters however, these were quickly and easily repaired. In addition, more than 90% of the public surveyed in Reykjavik indicated that they had a 'positive' or 'very positive' attitude towards hydrogen as an alternative fuel source for transportation[6].

In summary, a successful demonstration had taken place in Reykjavik, proving that the current state of technology and infrastructure in the early 2000s, could be integrated into modern society[6]. In conclusion, the project deemed the current stage of technology at the end of the ECTOS project, as not commercially economical for Iceland, but highlighted the potential for a hydrogen economy to become a reality for Iceland within the next few decades. ECTOS became a forerunner to simi-lar tests in other European cities under the Clean Urban Transportation for Europe (CUTE) project (2001-2006).

[6] ECTOS-project group (2006) Final Report ECTOS-Project , n.p : ECTOS-project partners.
[7] Maack, M.H. and Schucan, T., 2005. Ecological City Transport System. Case Study prepared for the IEA HIA, found at: *http://www. ieahia.org/case_studies.html*.

HyFLEET:CUTE

The buses in Iceland, were then put to use in the HyFLEET:CUTE demonstration project which commenced in 2006 and concluded in 2009[8]. HyFLEET:CUTE was co-funded by the European Commission and 31 industry partners through the Commissions 6th Framework Research Program and is the world's largest hydrogen powered bus project[9]. The project was an extension of the ECTOS, CUTE and Sustainable Transport Energy Project (STEP) projects which took place between 2001-2006. The HyFLEET:CUTE project aimed to facilitate the development of hydrogen powered bus technology and associated infrastructure using the lessons learnt from the previous hydrogen bus projects. The project introduced 47 hydrogen powered buses (both fuel cell and internal combustion engine) in regular public transport services in the following cities: Amsterdam, Barcelona, Beijing, Berlin, Hamburg, London, Luxemburg, Madrid, Perth and Reykjavik.

Figure 2: HyFLEET:CUTE buses used in the demonstration project[10]

The HyFLEET:CUTE project successfully demonstrated the performance of both fuel cell and in-ternal combustion engine hydrogen powered buses within public transportation systems throughout Europe. The collective performance of the vehicles can be seen presented in table 1, and it is worth nothing that the operational statistics are much higher for the hydrogen fuel cell vehicles as there were significantly more of these in operation within the project.

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[8] Icelandic New Energy (n.d.) HyFLEET:CUTE 2006-09, Available at: *http://newenergy.is.w1.nethonnun.is/en/projects/research_and_demonstration_projects/hyfleetcute/* (Accessed: 22nd October 2020).

[9] Eltis (2015) HyFLEET:CUTE is the world's largest hydrogen bus demonstration and research project., Available at: *https://www.eltis.org/discover/case-studies/hyfleetcute-worlds-largest-hydrogen-bus-demonstration-and-research-project* (Accessed: 22nd October 2020).

[10] Fuel Cell Electric Buses knowledge base (n.d.) HYFLEET-CUTE (2006-2009), Available at: *https://www.fuelcellbuses.eu/wiki/history-fuel-cell-electric-buses/hyfleet-cute-2006-2009* (Accessed: 10th November 2020).

Table 1: operational statistics gathered from the HyFLEET:CUTE project demonstration[10].

HyFLEET:CUTE Operational statistics	Fuel Cell (33)	Internal Combustion Engine (14)
Distance travelled	>2.1 million km	>415,000 km
Operational hours	140,000	29,000
Bus availability	>92%	>89%
Passengers transported	>8.5 million	

The HyFLEET:CUTE project also demonstrated that the infrastructure to produce, supply and dis-tribute hydrogen for transportation purposes can be implemented efficiently and with no fundamen-tal obstacles .The project saw the successful demonstration of 10 hydrogen station units with no accidents associated with operation/maintenance of the stations. The collective performance of the hydrogen infrastructure installed as part of the HyFLEET:CUTE project can be seen presented in table 2.

Table 2: Operational performance of hydrogen infrastructure installed as part of HyFLEET:CUTE project demonstration[10].

HyFLEET:CUTE Infrastructure statistics	
Hydrogen station units demonstrated	10
Availability of units	>89.9%
Hydrogen refuelled	>555,000 kg

The HyFLEET:CUTE project has demonstrated a way forward for hydrogen through identification of the existing challenges which are essential for the future successful integration of hydrogen fuelled public transport. Some of the key challenges identified were the purchase price of the buses which must be significantly reduced for the commercialisation of hydrogen fuelled transport to be a viable option for many counties10. In addition, the hydrogen bus technology must be able to operate with minimal special support within a standard public transport bus fleet. For hydrogen to be as cheap and clean as possible it should be produced using renewable electricity. The project high-lighted the need for progression of hydrogen transport projects from development to demonstration involving large fleets of buses.

[11] HyFLEET:CUTE Project Partners (2006) A Report on the Achievements and Learnings from The HyFLEET:CUTE Project 2006 – 2009, Germany: Hyfleet:CUTE partners.

Sustainable Marine and Road Transport (H_2)

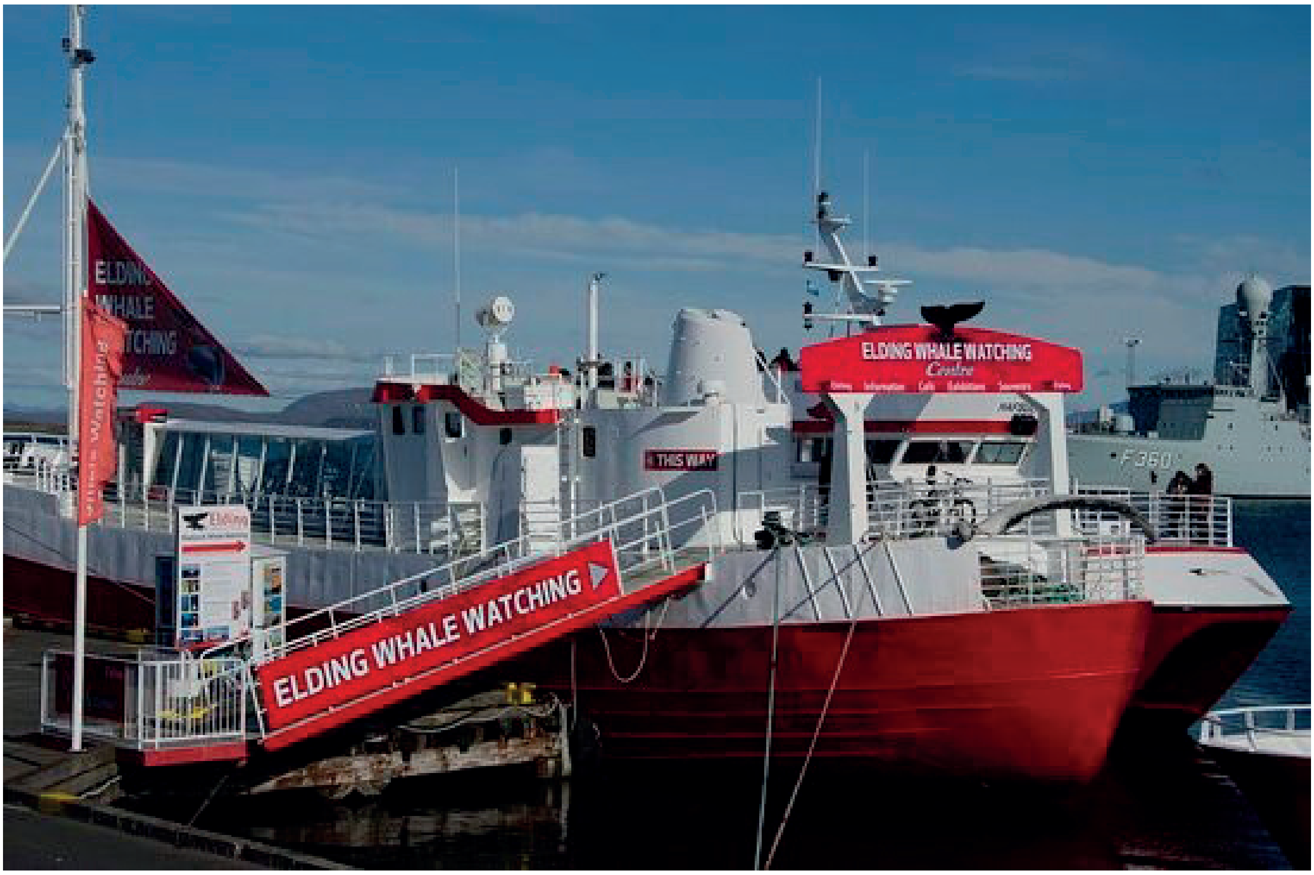
Following the demonstrations as part of the ECTOS and HyFLEET:CUTE projects, Icelandic New Energy (INE) and VistOrka launched their own hydrogen project in Iceland. The Sustainable Marine and Road Transport (SMART H_2) project which ran between 2007–2010. SMART H_2 was a fur-ther demonstration project which shifted the focus in Iceland from hydrogen fuelled public transport to hydrogen fuelled vehicles and vessels. The overarching aim of the SMART H_2 project was to develop knowledge surrounding how new fuel types (hydrogen) fits within the Icelandic context i.e. local availability, production costs, performance of vehicles, necessary infrastructure, public ac-ceptance and other factors[12].

The project saw the demonstration of a fleet of hydrogen cars, with various engine types including internal combustion engine vehicles and fuel cell vehicles from a range of different vehicle produc-ers. The project identified several key constraints the first of which was the age of the vehicles be-ing used in the demonstration. Most vehicles were between 3-6 years old, technical capabilities meant that adaptation of older vehicles restricted them to accepting hydrogen at 700 bar – a pres-sure which the Icelandic infrastructure was not capable of delivering[13]. The project made use of the existing infrastructure such as the hydrogen production, storage and filling station established during previous projects. The extended use of these facilities was extremely beneficial to Iceland as it al-lowed the accessibility and reliability of the infrastructure for different users to be assessed. There were challenges with availability as passenger cars created new demand which could not be met with one filling station. The demonstration therefore highlighted the need for further development and expansion of hydrogen infrastructure in Iceland to facilitate their transition to a hydrogen econ-omy.

In April 2008, the SMART H_2 project also demonstrated the use of an Auxiliary Power Unit (APU) i.e., a fuel cell battery unit that ran on hydrogen onboard the Elding whale watching ship in Iceland[11] – the first of its kind in the world. The APU was used to fuel the ships

[12] Icelandic New Energy (n.d.) SMART- H2 (2007 - 2011), Available at: *http://newenergy.is.w1.nethonnun.is/en/projects/research_and_demonstration_projects/smarth2/* (Accessed: 22nd October 2020).

[13] Hydrogen Europe (2019) Icelandic New Energy Ltd., Available at: *https://hydrogeneurope.eu/member/icelandic-new-energy-ltd#:~:text=In%202007%20the%20SMART%2DH2,fuel%20cells%20in%20marine%20applications.&text=The%20goal%20in%20Iceland%20was%20to%20connect%20the%20RD%26D%20part,fuel%20cell%20electric%20vehicles)%20vehicles* (Accessed: 22nd October 2020).



lighting system, electrical equipment, and navigation machinery when the main engine was switched off. The demonstration was an important step in testing hydrogen technology in marine conditions and gaining information that could led to the expansion of marine fuel cell systems.

Hydrogen Mobility Europe

Iceland is also a partner on the Hydrogen Mobility Europe project (H2ME) a flagship project which aims to deploy hundreds of fuel cell vehicles and associated refuelling infrastructure, across 8 countries within Europe. The project has been positioned as one of the most ambitious coordinated hydrogen development projects to take place in Europe to date[14]. The project receives support from the European Union through the Fuel Cells and Hydrogen Joint Undertaking (FCH2JU)[15].

The project was rolled out in two phases, H2ME (1) which commenced in 2015 and concluded in 2020 and H2ME2 which commenced in 2016 and will conclude in 2022[14]. The first phase of the H2ME project was a five-year project which aimed to increase the distribution of fuel cell vehicles as well as facilitating the creation of a pan-European hydrogen fuelling station network. Phase one of the project seen the deployment of over 300 fuel cell vehicles and 29 hydrogen refuelling stations across Europe[13]. The second phase of the H2ME project, a seven-year project, aimed to expand the fuel cell vehicle fleet further throughout Europe. In doing so, the H2ME2 project aims to confirm the technical and commercial readiness of vehicles, fuelling stations and hydrogen production techniques[13]. Phase two of the project aims to achieve deployment of a further 1,100 fuel cell vehi-cles and 20 hydrogen refuelling stations[13]. H2ME2 will continue until 2022 by which time 49 hydro-gen refuelling stations and 1500 hydrogen vehicles will have been deployed through the combined phases of H2ME[16]. The project aims to allow recommendations to be produced and gaps to be identified which may prevent full commercialisation of hydrogen fuel cell vehicles and refuelling infrastructure. The results from H2ME will be valuable to provide support for future investments.

[14] Hydrogen Mobility Europe (2020) About, Available at: *https://h2me.eu/about/* (Accessed: 10th November 2020).
[15] Hydrogen Mobility Europe (2020) Project Overview, Available at: *https://h2me.eu/publications/emerging-conclusions-2-5-may-2020/* (Accessed: 10th November 2020).
[16] Speers, P., 2018. Hydrogen Mobility Europe (H2ME): Vehicle and hydrogen refuelling station deployment results. World Electric Vehicle Journal, 9(1), p.2.

In 2018, Orkan opened two H2ME funded hydrogen refuelling stations in Iceland, one in Vesturlandsvegur in Reykjavik and the other in Fitjar in Reykjanesbær[17] . Orka Náttúrunar (ON Power), a company that has been in the forefront in the development of electrical vehicle infrastructure, will l produce the hydrogen provided by Orkan at its geothermal power plant at Hellisheiði[16]. In addition, the H2ME project saw the first multi-energy station inaugurated in Iceland in Reykjavik – the first combined station where biomethane, fast charging and hydrogen are all available under the same canopy[18]. The FCHJU is supporting Iceland to become the model country for H2 transport in Europe, with three hydrogen refilling stations and 17 cars already deployed through the H2ME project.

[17] Hydrogen Mobility Europe (2018) Two new HRS open to the public in Iceland now, Available at: *https://h2me.eu/2018/06/15/two-new-hrs-open-to-the-public-in-iceland-now/* (Accessed: 10th November 2020).
[18] Hydrogen Mobility Europe (2019) Third Hydrogen Refuelling Station Opens in Iceland, Available at: *https://h2me.eu/2019/05/16/third-hydrogen-refuelling-station-opens-in-iceland/* (Accessed: 10th November 2020).