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Analysing the economic opportunity for Aberdeen of hydrogen energy sector development

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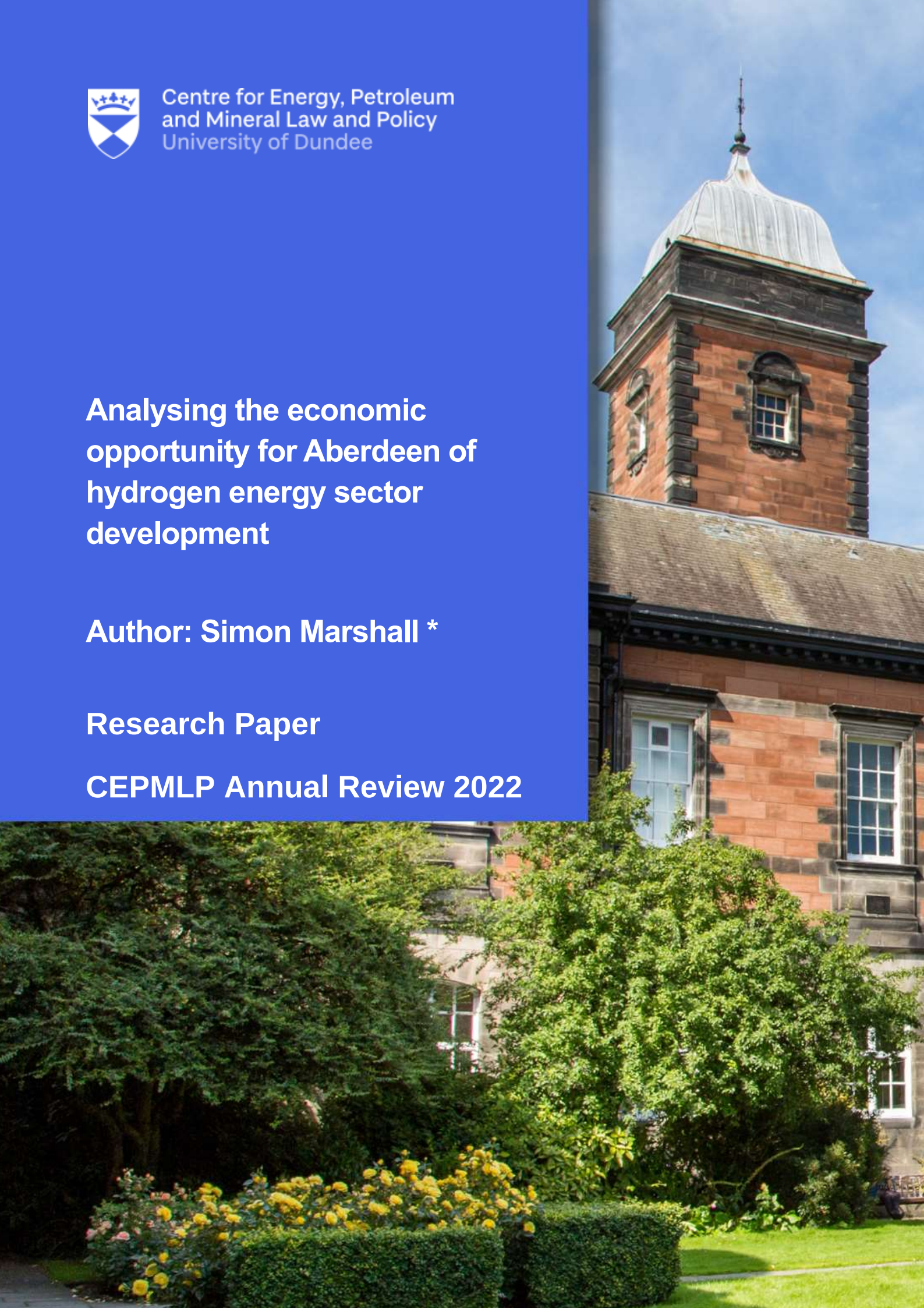

Abstract

Hydrogen is an emerging energy fuel source that may, via associated ongoing technological and sectoral development, provide multiple opportunities and threats facing the wider energy sector. Upstream petroleum companies looking to diversity their operational and/or investment portfolios, renewable energy operators with scope to produce "green hydrogen,"[1] and electricity transmission and distribution companies and municipalities looking to adopt, or foster the adoption, of hydrogen all have a potential material stake in its emergence as a viable and zero emissions alternative fuel source to fossil fuels or, colloquially, "skin in the game."

For the industry to truly take-off, production would have to happen at-scale, a large and diverse customer base would need to emerge and a vibrant supply chain servicing the sector, would all need to take place. Should these preconditions be met, Aberdeen would be a likely *de facto* UK Continental Shelf (UKCS) energy hub for the sector given its existing human and physical infrastructure and resources, a legacy of past and present UKCS upstream petroleum sector development regarding which it has long held pre-eminence alongside London.

However, there is no guarantee that upstream petroleum economic history will repeat itself with respect to hydrogen. In fact, key questions and uncertainties remain with respect to its economic viability, requisite political will, and the so-called "social license to operate," i.e. broad societal acceptance and legitimacy.

This paper seeks to address the economic realities of hydrogen both as a fuel of the future and with respect to the potential for Aberdeen to reinforce its status of one of the UK's two dominant energy hubs, alongside London, through achieving a leadership position in its development. Hence, it will address the political, social and economic threats to such sectoral development, including specifically with respect to Aberdeen, and analyse the possible and likely scale that the hydrogen economy may reach in the future.

[1] Namely, hydrogen produced utilising renewable electricity to split water into its constituent elements

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Contents

1. Introduction

Energy is the most fundamental of all industries, providing the fuel that powers all others. Alongside agriculture and water resources, it underpins modern humanity.

Through recorded history, energy production has relied upon the combustion of biomass or biomass-derived fuel source. The industrial revolution of the nineteenth century CE sparked rapid economic and technological advances, resulting in vastly increased levels of industrial output in Western nations, and an explosion in both the pace of change and the demand for more energy to fuel the advance to new industrial frontiers.

What is clear, however, when one analyses the various systemic shifts in energy use is that it occurs at the nexus of political, social and economic will. One of these levers may provide the initial push but it takes all three in unison to truly embed a systemic shift. Coal use was propelled by its ease of use and, adhering to the resource-based view of energy policy, those Western countries with ready access to that fuel source, when coupled with innovative working practices, led the way - notably the UK, the USA, and Germany.

During this coal-fuelled age, economic choices were made at the time within the context of a dynamic technological frontier, with horizons constantly expanded as new inventions, innovations and efficiencies were achieved. Social structures emerged around the coal industry that truly embedded its necessity, a coupling of prosperity and job security to the incumbent energy type.

Politically coal was an obvious choice for the time, a “no-brainer.” Its use enabled rapid industrialization and modernization, a strong hold over the fortunes of a vast amount of the populace due to its energy-intensive usage and a thorough cheapness of both extraction and use. Petroleum emerged as both a socially desirable product due in part to the awful build-up of horse excrement on the streets of New York City’s Manhattan Island and other urban centres that rendered daily life unpleasant but also politically as a lever of colonialism and a rapid speeding up of naval power. Winston Churchill, in his role at the time as First Lord of Admiralty, switched the Royal Navy from coal to oil use in a prescient move that helped, through the resulting higher fuel performance, ensure continued British naval

dominance of the waves, leveraging the benefits of recent oil finds in British dominions in the Middle East.

In developed nations, oil and coal, combined with hydropower where topography and hydrology combined to afford that opportunity, dominated the fuel supply for a century or more after the Industrial Revolution. Nuclear power, a seemingly inexhaustible energy source born out of the nuclear weapons research and development Manhattan Project of World War 2, also constituted a lever of political and military power restricted to a few select holders in Western and, later, Communist countries. Nothing else really embedded itself until the tail end of the 20th Century when innovation and pace of change has hugely accelerated and hydrogen being merely the latest *de-rigueur* “game-changer”.

Technology often advances faster than the political, economic and social acceptance and then disappears just as fast if these three levers do not catch up. The UK has often changed faster than others but even here, witness the lack of progress in fuel types that, prior to the advent of hydrogen’s public discourse emergence as a potentially viable at-scale future fuel source, were seen as the next “big thing.” In that country, use of biomass as a “green” fuel was championed for a while with grand plans and political support and funding yet now is reduced to one very large facility, called “Drax” and located in the northern English county of Yorkshire, and the societal support is now tangibly ebbing away as more becomes widely known about the true carbon impact of burning wood pellets, shipped from far off lands, that it would be better off environmentally to leave in situ instead, with the carbon safely sequestered within the wood.

Biofuels should also be considered. In Brazil a large percentage of automobiles run on bio-based ethanol (mainly sugar cane based) levels of adoption have been considerable, but where else globally can be seen to have truly transformed their transportation networks to run on biofuels? The Dutch particularly have made great strides in refining these fuels but have struggled to secure adoption by air, marine or road transportation providers.

The shipping industry has changed in order to comply with International Maritime Organization (IMO) 2020 regulations on the amount of sulphur content burned in ship engines, but there is no paradigm shift in fuel type used despite several years of promotion of methane, ammonia, Liquified Natural Gas (LNG); instead ships still largely burn fuel oil, albeit progress has been made in their shift to Low Sulphur Fuel Oil.

Renewables have really captured the *zeitgeist* and, particularly in Europe, have secured a significant portion of power generation. The UK has the world's largest offshore wind capacity and has recently relented on its moratorium on onshore wind development, but has this really led an energy sector paradigm shift? In power generation certainly but that is about it. The opponents of the hydrocarbons industry cling to this one aspect of energy usage as supposed proof that renewables can immediately supplant petroleum without acknowledging the fundamental role petroleum plays in the production of so much else that society relies upon – crude oil and natural gas are both feedstock for plastics, fertilizers, rubbers and near-everything else that a developed nation citizen now typically uses or consumes every day.

In summary therefore we can see pockets of innovation and decarbonisation in different areas of the energy sector but nothing truly transcendental regarding renewable energy that constitutes a paradigm shift akin to that of coal and the Industrial Revolution.

This paper posits that hydrogen in its various applications offers the prospect of just such a transformative paradigm shift. If so, what opportunity does it imply for the UK Continental Shelf (UKCS), that is the maritime area within which that country holds all mineral rights? In particular, what would that imply for the North Sea part of the UKCS (UKCS North Sea), and, even more specifically, for Aberdeen, a city that has retained unofficial UK energy hub status rivalled only by the country's capital city, London? We ask the question: can Aberdeen become the pre-eminent energy hub in western Europe for the new hydrogen economy as it emerges into, hopefully, a position of durable strength and high utility?

2. Context: UKCS Hydrogen Sector Development

2.1 "Blue Hydrogen", Carbon Capture and Storage, and Aberdeen's Acorn project

It is at this point that realization must dawn on the current progress made on hydrogen projects in the UKCS North Sea. Firstly, the scale of the overall market needs to be thoroughly assessed. There are a number of projects in the planning stage, but few close to Final Investment Decision (FID), so why such bullishness on development? In part, due to the stakeholders involved and that crucial nexus of political, social and economic leverage we outlined earlier. "Acorn" is a highly prominent, Aberdeen-based, project that consists of both a commitment to generate clean-burning "blue hydrogen", i.e. hydrogen produced from hydrocarbons and the likely first-move form of hydrogen generation at-scale, to provide a Carbon Capture and Storage (CCS) service offer, using existing offshore infrastructure built originally for petroleum sector development, notably including the St Fergus natural gas terminal, to speed development.[2]

CCS has had a tortured existence, previously well supported by UK government with funding[3] and a burgeoning carbon trading market for the captured product (recall the economic lever that is needed) that ultimately tanked due to a collapse in the carbon price and inequity in the way carbon trading certificates were used.[4] The clearing houses, price reporting agencies and banks amongst others were keen and involved but political push factors stalled and CCS as result faded into the background.

Nonetheless, the technology is proven and linking hydrogen production and CCS ticks two boxes in one project and can provide a catalyst and case study for adoption elsewhere. If successful, industry and policymakers globally can be expected to duly take note. The UK's licensing and regulatory Oil and Gas Authority (OGA) has issued the Acorn project with its requisite CCS license, and the European Union (EU) has already designated it as a Project

[2] Pale Blu Dot (now Storegga) "ACORN project overview" https://pale-blu.com/acorn/ , 25 Oct 2020
[3] European Commission "NER 300 Programme" https://ec.europa.eu/clima/policies/innovation-fund/ner300_en, 01 Nov 2020
[4] Carbon Market Watch "EU Carbon Market" https://carbonmarketwatch.org/our-work/carbon-pricing/eu-carbon-market/, 14 Oct 2020

of Common Interest and one could easily see industrial clusters in Rotterdam, Hamburg, across Scandinavia and beyond follow Acorn's blueprint if proven efficacious.

The possible tie-ins here are myriad. The UK's Transmission and Distribution System Operators alike are engaged through the ultimate use of hydrogen injected into the gas network and industry has shown willingness to align particularly in respect of taking CO2 from the Grangemouth petrochemicals and crude oil refining cluster for sequestration under the UKCS North Sea.

Clearly though one isolated project, impressive though its range of stakeholders is, will not a paradigm shift make, so what else is in the hopper in the North Sea to propel the production of hydrogen?

2.2 UKCS North Sea "Green Hydrogen" development

"Green hydrogen" is hydrogen that is produced utilizing renewable energy sources rather than hydrocarbons. Its development in a UKCS North Sea context suggests a different group of stakeholders, and at-scale offshore development.

Green hydrogen is typically produced by offshore wind arrays where excess electricity production is used to split seawater into its constituent parts and the hydrogen then fed into existing gas pipelines and onwards into the grid as normal. The UK's first mover here, the Dolphyn project, comprises ERM (an environmental risk consultancy), ENGIE (a French integrated energy provider) and ODE (a British offshore engineering company).[5]

Green hydrogen brings offshore renewable energy operators into this new paradigm, combining existing UKCS midstream and upstream petroleum infrastructure, which by serendipity can be used by this new energy sector too, and "green"/ renewable energy to power hydrogen production.

In this emerging scenario, offshore wind does not simply entail the generation of renewable electricity but a critical fuel type that can drive de-carbonization of UK energy usage through multiple, hydrogen energy, utilizations, notably: as an alternative or perhaps complementary

[5] Andrew Lee, RECHARGE News, 13 Sep 2019 https://www.rechargenews.com/wind/floating-wind-to-hydrogen-plan-to-heat-millions-of-uk-homes/2-1-670960, 05 May 2020

energy source for electric vehicles (EVs); a fuel for heating and cooking through the grid; and as a feedstock for industrial processes such as the production of ammonia.[6]

As for carbon trading markets, supply/ demand/ price dynamics, liquidity, and stakeholder-buy in will all be important factors shaping this nascent sectors evolution.

Encouragingly, the UK Committee on Climate Change (CCC), an independent, statutory body established under the UK's Climate Change Act 2008, has predicted that hydrogen will supplant natural gas in the UK's energy system,[7] but its opinion is hedged between whether "blue" or "green" forms are the optimum. This outcome remains unknown, and is outwith the scope of this research paper. For our purposes, we are not focused on the means of hydrogen production, but instead the political, economic and social impetus exists for hydrogen as a fuel type.

The major upstream petroleum companies have also taken note; a high-profile example being Royal Dutch Shell, which is exploring the feasibility of a massive green hydrogen project tied to the development of a hydrogen industrial cluster in the Netherlands.[8]

A rising tide may "lift all ships", but there is doubt as to whether Aberdeen can achieve the position of being the leading energy hub for hydrogen within western Europe. Ports in the Netherlands, on the European continent and benefitting from being part of the EU single market, are obvious competitors for this status – especially the country's most commercially important port city, Rotterdam.

Even domestically within the UK there exists competition in the development of the pre-eminent hub with five projects being supported by UK government,[9] although only two of them are production facilities (one in Aberdeen, the aforementioned Acorn project, and one in a corridor stretching from Merseyside to north Wales (HyNET, see below) with the other

[6] Hydrogen Europe "Hydrogen Applications" https://hydrogeneurope.eu/hydrogen-applications, 07 June 2020
[7] Climate Change Committee "Hydrogen is a credible option for the future", 22 Nov 2018, https://www.theccc.org.uk/2018/11/22/hydrogen-is-a-credible-option-for-the-future-the-uk-must-now-prepare-for-the-key-decisions-on-zero-carbon-energy/, 18 March 2020
[8] J Parnell, GreenTech Media "Shell Exploring World's Largest Hydrogen Project", 27 Feb 2020 https://www.greentechmedia.com/articles/read/shell-exploring-worlds-largest-green-hydrogen-project, 06 June 2020
[9] A Fawthrop, NS Energy " The 5 UK Hydrogen projects awarded government development funds", 20 Feb 2020 https://www.nsenergybusiness.com/news/hydrogen-production-plants-uk/, 21 July 2020

three in Humberside (focusing on hydrogen energy usage), Cranfield University (with a technology focus), and the Dolphyn project, mentioned above, with respect to UKCS deep offshore.

The HyNet project has much of merit, multiple stakeholders in both the production and usage of hydrogen and large amounts of potential users both household and industrial in the surrounding areas. Natural gas of any type is at its most economically viable when transported over as short a distance as possible. Either way we should look to the social lever here and welcome these five projects' positive impacts, not least regarding enabling public engagement with the fuel type, in the aggregate. Overcoming "NIMBYism", a suffixed word extending the acronym "Not In My Back Yard" (NIMBY), in the UK is no small deal, particularly in the context of hostile public attitudes towards coal and continuing skepticism over nuclear energy too, hence societal acceptance of hydrogen to its efficacious development.

3. Stakeholder analysis

The tenor of this piece has so far been future-facing with exciting pilot projects and projections of scaled-up deliver into the 2030s.

Does that imply then that widespread uptake of hydrogen energy is a long-off goal and that potential customers on the consumption side are not yet ready to take a lead? Whilst uncertainty abounds on that question, a cause for optimism is the credibility of stakeholders involved. One such stakeholder, Cadent, is both lead partner in HyNet and the number one distributor of natural gas in the UK. National Grid, the UK's monopoly high-pressure transmission operator has opined high hopes[10] regarding hydrogen as a fuel source, and has itself in operation a project called "HyNTS" to explore the development on a sectoral cluster model basis.[11]

Granted, this is primarily about the future not the present, but with a near-term goal of 20% of hydrogen blend target in domestic, UK, natural gas supply one can see a dual-speed evolution happening with the projected generation being matched by consumption locally and nationally.

Keele University has successfully injected hydrogen into a closed-loop network on-site at a 20% blend[12] levels as a means of viability testing. In Aberdeen, a rollout of hydrogen-fueled buses has been successfully-trialed[13] which together with the building of a new housing development fueled by hydrogen[14] and a new events venue, "The Event Complex Aberdeen", fueled by a hydrogen fuel cell[15] showcases three disparate usage scenarios in the demonstration of a "hydrogen economy."

[10] National Grid plc, "High Hopes for Hydrogen" 04 Feb 2020, https://www.nationalgrid.com/high-hopes-hydrogen , 11 Aug 2020
[11] National Grid plc, "Gas Transmission: Network Innovation Allowance", 2019 https://www.nationalgridgas.com/document/127991/download, 12 Aug 2020
[12] J Murray, The Guardian, "Hydrogen Injected in Gas Grid for first time", 24 Jan 2020, https://www.theguardian.com/environment/2020/jan/24/hydrogen-uk-gas-grid-keele-university, 07 Sep 2020
[13] Aberdeen City Council, "Aberdeen Hydrogen Bus" , 2020, http://www.h2aberdeen.com/home/H2-Aberdeen-hydrogen-bus.aspx , 10 Sep 2020
[14] Clover Hill, "Hydrogen Scheme", 2019 https://www.cloverhillaberdeen.co.uk/hydrogen-scheme/, 11 Sep 2020
[15] Robertson plc, "UK's largest hydrogen fuel cell arrives at TECA", 2019 https://www.robertson.co.uk/news/uks-largest-hydrogen-fuel-cell-arrives-teca, 03 March 2020

As of 2020 and the authorship of this research article, we remain an awfully long way from having such a “hydrogen economy” but a positive here is that there exists in the UK a myriad of potential uses, users and stakeholders, rather than the nascent sector having to rely upon a single-use business case.[16]

As things stand, UK hydrogen energy usage is still minimal and is still predicated around technological development, innovation, proof of concept, and production infrastructure development. Even looking forward just one year, relief may come to those sweating the sector’s development: Dolphyn is expected to go to FID in 2021.

[16] A Vaughan, New Scientist “UK could use hydrogen instead of natural gas” 14 June 2019 https://www.newscientist.com/article/2206546-uk-could-use-hydrogen-instead-of-natural-gas-if-it-can-make-enough/, 08 Feb 2020

4. Political Will and Public Policy

Political flirtations with emerging energy types may be fleeting, suffer from lack of focus, momentum, economic stimulus or a combination thereof. The renewable energies industry, particularly wind energy, benefited hugely from sustained government stimuli in the form of Feed-In Tariffs (FITs) and Contracts for Difference which assuaged any first-mover concerns that returns would not be commensurate to the requisite level of up-front investment,[17] and led to a proliferation of small-scale projects in addition to the rapid deployment of large-scale arrays installed by the likes of Ibedrola (Scottish Power), Orsted, Vattenfall, SSE and others easily evidence by the seven-fold increase in capacity over the period of the FITs scheme.[18] So much so that the cost of generation of offshore wind now equates favorably to any other power generation type[19] with offshore wind now cheaper per kWh than existing gas turbine plants.

Despite the often-incendiary coverage of British energy policy in some part of the British press, the UK has in actual fact demonstrated tremendous, sustained political leadership in the promotion of wind power which is exactly what is required if the hydrogen economy is to take off. The pace of adoption can often seem slow however and a leading think-tank piece dated 2018 already seems out-of-date with its predictions of progress[20] with arguably little political impetus in the subsequent two years.

EVs have a first-mover advantage and some progress has been made in the infrastructure required to scale-up usage with investments from the likes of BP and Tesla amongst others but others have argued that hydrogen-fueled transportation versus EV is at a "VHS-Betamax" moment (in the sense that VHS videotape adoption won out over Betamax primarily for reasons of circumstance) and that existing pipeline, lorry and gas station infrastructure better supports a quick scaling of hydrogen-use vehicles.

[17] OFGEM, "Feed-in Tariffs", 2020 https://www.ofgem.gov.uk/environmental-programmes/fit/about-fit-scheme/changes-fit-scheme, 03 June 2020
[18] Statista.com, "UK wind power capacity", April 2022 https://www.statista.com/statistics/421861/wind-power-capacity-in-the-united-kingdom/ 22 June 2022
[19] Energy Saving Trust, "Wind Power Generation Record Low Prices", 2019 https://energysavingtrust.org.uk/blog/wind-power-generation-record-low-prices, 04 July 2020
[20] Policy Exchange, "Are we really on the cusp of a hydrogen economy", 18 May 2018, https://policyexchange.org.uk/are-we-really-on-the-cusp-of-a-hydrogen-economy/, 22 Nov 2019

The aforementioned five cluster projects do have the benefits of some degree of political support and a £28m fund to support technology development,[21] a derisory figure considering the scale of the energy challenge transition faced, and with Brexit, UK access to the EU's Clean Hydrogen Alliance[22] has now ended too.[23]

Prior success in establishing the carbon market that helped prop up CCS pilot projects was EU in scope and meant that UK projects had access both to National and European funding and support. It is therefore worrying unless a major step-up in political support nationally is not forthcoming. The EU has a significant track record in championing natural gas as a "transition fuel", focus on energy efficiency as a "fifth fuel" and more recently the European Battery Alliance which corralled more than £3bn of funding and upon which the hydrogen alliance will be based. When we analyse scenarios later, this creates major doubts as to Aberdeen's potential as the leading hub in the region. The UK CCC has extant recommendations and projected timelines[24] but pulled back from advocating full use of hydrogen instead readjusting and promoting "near term deployment at scale of hybrid heat pumps". A fairly flimsy solution in other words for decarbonizing heating at scale and removing one of the main stool legs upon which large-scale adoption of hydrogen sits. Indeed in one of the other main pillars of use, transportation, the recommendations are similarly moribund and state that for the decarbonization of cars and vans, "battery vehicles are now well-placed" but hydrogen fuel-cell vehicles could "play an important role for heavy duty vehicles" and "potentially important role in decarbonizing shipping." Even assuming total adoption across these transportation types, without the wholesale usage in personal vehicular transportation, prospects become dim. Notably, the adoption of IMO2020 restrictions on sulfur content burned in ship engines took many, many years and led only to the use of low and ultra-low sulfur fuel oils rather that wholesale switches to ammonia, LNG, methane or any other substitute far less hydrogen. Even more alarmingly, the UK Committee on Climate Change report advocates for the uptake of "low regret hydrogen

[21] A Frangoul, CNBC, "UK Govt announces funding for low carbon hydrogen production", 18 Feb 2020, https://www.cnbc.com/2020/02/18/uk-government-announces-funding-for-low-carbon-hydrogen-production.html 09 July 2020

[22] Fuel Cells & Hydrogen Joint Undertaking, "E.C. announces clean hydrogen alliance", 10 March 2022, https://www.fch.europa.eu/news/european-commission-announces-clean-hydrogen-alliance , 03 Sep 2022

[23] European Commission, "Criteria for membership in the European Clean Hydrogen Alliance", 2020, https://ec.europa.eu/docsroom/documents/45564/attachments/1/translations/en/renditions/native, 03 Sep 2020

[24] Committee on Climate Change, "Hydrogen in a Low Carbon Economy", November 2018, https://www.theccc.org.uk/wp-content/uploads/2018/11/Hydrogen-in-a-low-carbon-economy.pdf, 25 Sep 2020

uses" in the 2020s suggested that climate change goals and (carbon emission) Net Zero aspirations should be met by a hodge-podge of different solutions inclusive of energy efficiency measures, electrification, heat pumps etc. and that hydrogen be used in applications that "do not require major infrastructure changes". The report also points to "low public awareness of the need to move away from natural gas", a worrying position given the public's role in the backlash against nuclear, although this may change as climate change organizations like Extinction Rebellion gather more adherents, and/or as a result of recent domestic energy price spikes. Almost all energy companies have negative Net Promoter Scores (NPS), indicating widespread UK public displeasure with energy retailers. The uncertain status of energy companies' "social license to operate" has long been an issue for the upstream petroleum sector too, and should be on the radar for hydrogen economy promoters in their scanning of the domestic threats to their emerging business models.

It is therefore with hope that regional and local project clusters pick up pace in such a way as to demonstrate the potential which then morphs into a coherent national strategy. Aberdeen City Council has been bullish on how far it wants to push the hydrogen economy which is elucidated through a ten year action plan[25] but has largely thus far restricted its ambition to securing "investment for vehicle deployment."

Subsequent objectives call for expanding "production of renewable hydrogen" and "developing hydrogen refueling infrastructure", with developing the supply chain some way down the list. A multi-stakeholder group set out the usage case for hydrogen in London[26] focused mainly around transportation and the benefits to the air quality enjoyed by Londoners with a notional timeline of 2025 onwards for "opportunities at major deployment". The (English and Welsh) North West cluster around Ellesmere Port ties in Manchester, Cheshire, Merseyside and north Wales in a consolidated hydrogen-CCS-decarbonization opportunity.[27] Travelling all the way eastwards to England's North Sea coast along the M62

[25] H2 Aberdeen " Aberdeen Hydrogen Strategy 2015-2025", 2020, http://archive.northsearegion.eu/files/repository/20150918111637_AberdeenHydrogenStrategy_March2015.pdf , 18 Dec 2019

[26] Hydrogen London, "London a capital for Hydrogen", April 2016 , https://www.london.gov.uk/sites/default/files/london_-_a_capital_for_hydrogen_and_fuel_cell_technologies.pdf, 23 Sep 2020

[27] Net Zero Northwest, 2020, https://northwestcluster.co.uk/, 23 Sep 2020

motorway, the Humberside cluster led by Drax doing likewise[28]. The relevant local, regional and indeed national (i.e. Welsh government) political jurisdictions that this sector development is taking place in have, in general, more progressive and interventionists prevailing politics and public policy to that of the (Conservative) UK government, with progressive mayoral and/or city council decisions supporting by extant industrial stakeholders which fits perfectly with developing a coherent strategy. The extent to which other regions will follow suit with similar levels of hydrogen adoption supported by interventionist public policy is less clear. Such regional initiatives fit squarely within the remit of the CCC's Net Zero Report published in 2019[29] which early in its findings clearly enunciated what we have been alluding to here that net zero targets are not credible unless "policy is ramped up significantly" and for the purposes of this analysis we again point to the fact that hydrogen is just one of multiple solutions towards this goal and one which requires more of a push than most due to the infrastructure changes and investment required.

[28] Drax plc, "Leading energy companies announce new zero carbon partnership", 27 May 2019, https://www.drax.com/press_release/energy-companies-announce-new-zero-carbon-uk-partnership-ccus-hydrogen-beccs-humber-equinor-national-grid/, 21 June 2020

[29] Climate Change Committee, "Climate Change Committee Net Zero Report 2019", April 2019, https://www.theccc.org.uk/publicationtype/0-report/01-net-zero-reports/, 28 Aug 2020

5. Scenarios

5.1 High Impact Scenario

In a 'high impact scenario' Aberdeen becomes the main European hub for the hydrogen economy; and establishes itself to as the production and technological lead. But what is needed for that scenario to become reality?

Thus far we have demonstrated that the road ahead is far from clear for hydrogen in general as an emerging nascent energy sector, and far less specifically for Aberdeen's potential as the pre-eminent hydrogen economy hub for western Europe. Whether the city has a chance to assert itself in this way will again come down to that triangulation of economic, social and political levers plus more importantly utilising the knowledge base and mature supply chain that has built up in the oil and gas sector over the past forty years.

Aberdeen and the UKCS are seen globally as mature regions in the field of oil and gas extraction and emerging regions globally have long beat a path there to adopt and adapt technological innovations and expertise gleaned over the period of North Sea development. At present more than 40% or £16bn of the £40bn annual supply chain revenues comes from export revenues[30] which is to say UK (principally Aberdeen) companies exporting engineering expertise, technology and equipment globally.

The UK regulatory Oil and Gas Authority (OGA) has a twin role in regulating exploitation of UK hydrocarbons resources and promoting UK excellence globally and will need to take a similarly robust role in the promotion of hydrogen if this high impact scenario is to be achieved. Looking at a broader UK picture, the Energy Industries Council is the predominant entity for the promotion of British energy excellence overseas but in its recent "Survive and Thrive" report[31] has reported a contraction in interest in exporting amongst its members attributable to a very tight domestic market and the downward price pressure on original equipment manufacturers within the supply chain. They proclaim that the findings that

[30] North Sea Transition Authority, "Supply Chain Overview", 2020, https://www.ogauthority.co.uk/supply-chain/overview/, 30 Sep 2020

[31] The Energy Industries Council, "Survive & Thrive Report Volume III", 2019 https://www.the-eic.com/portals/0/Website/Publications/InsightReports/SurviveandThrive3-report.pdf, 22 Dec 2019

uptake on export as a key pillar of strategy has dropped from 19% to 12% proclaiming frustration that many companies view exporting as a "risky strategy."

5.2 Contextual Analysis

5.2.1 Aberdeen's existing offshore expertise and supply chain

The reader may see a disconnect here between the nascent nature of the hydrogen economy, restricted as it is to pilot projects, proof of concept and expertise, but the reality is that for Aberdeen to assume the lead role, such measures will have to go hand-in-hand. Hydrogen is a well understood commodity and many of the domestic supply chain companies from energy sector Tier 1 Contractors (i.e. main not sub-contractors) like Wood Group, Petrofac and Weir Group through companies that manufacture processing, compressing, transportation and storage equipment plus the gamut of flow rate metering, automation, instrumentation and ancillary devices have substantial and/or headquarter operations in Aberdeen. Similarly, most of the large International Oil Companies (IOCs), whose deep pockets and engagement will be critical, and overseas contractors maintain substantial presences in Aberdeen.[32] An innovative and influential local entity, the Oil and Gas Technology Centre (OGTC) together with supply chain stakeholders has already mapped out how offshore expertise can be requisitioned to the creating of a hydrogen economy[33] advocating the use of "existing infrastructure and already sunk investment." In truth this is the latest incarnation of a survival strategy the UKCS has been going through for many years but far more positive in its outlook. The assumption having always been that late life extension and ultimately decommissioning would be the way to go for a mature basin with declining assets and that worldwide renown could be developed in these fields. Some spoke of £40bn opportunity over thirty years but with the ultimatum being a closed basin to all intents and purposes.

What better news could there be should thousands of jobs and millions of pieces of equipment be transitioned to this burgeoning hydrogen economy?

[32] Offshore Energies UK, "Contractor Members", 2019 https://oilandgasuk.co.uk/contractor-members/, 22 Nov 2019

[33] The Oil & Gas Technology Centre (OGTC), "Phase 1 Project Report", 2019 , https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866379/Phase_1_-_OGTC_-_Hydrogen_Offshore_Production.pdf, 23 Jan 2020

The means of production identified include steam reforming of methane (a well understood method and compatible with the use of North Sea natural gas) and electrolysis by way of offshore wind. The former being <20% of the production cost of electrolysing seawater in floating wind platforms. Specific mention is made of the suitability of existing pipelines to transporting the produced gas noting that more modern carbon steel pipelines would be needed and particularly those used for natural gas transportation as crude oil pipelines would require too much heavy cleaning. The Acorn project envisions using the extant Goldeneye pipeline from the North Sea Shell field into St Fergus terminal however that is for captured carbon going the other way and using the decommissioned field for CCS.

More broadly though, the St Fergus Terminal currently accounts for >50% of all imported natural gas into the National Grid transmission system[34] and, although in need of a refit may represent the optimum location for a hydrogen import terminal at scale. The recent acquisition by PX Group[35] is arguably positive given that company's diversified nature and not being tied explicitly to offshore oil and gas operations. Current capacity is, is 75 million standard cubic feet per day (75MSm3/D). The National Grid, as the pre-eminent "customer" for hydrogen in its usage for decarbonizing heating and cooking has multiple options for a scaled-up terminal[36] but there seems little sense in a preference for anywhere except St Fergus given existing capacity and know-how. What is clear is that many ports, industrial clusters and cities, long envious of Aberdeen's oil and gas boom will be stiff competition for this lead role but, in general, progress is easiest when reusing existing infrastructure is possible rather than large capital expenditure (capex) on new solutions.

5.2.3 Aberdeen and the UK

We have seen from previous sources that the hydrogen economy can mean many different things and its versatility as a new energy source is potentially its downfall. Transportation, domestic use for heating and cooking, industrial feedstock all constitute hugely enticing options but by far the largest at scale is that of hydrogen supplanting natural gas within the transmission network. We have seen already that a number of localized clusters intend to demonstrate the use of hydrogen in low pressure, close-loop distribution networks (e.g.

[34] National Grid plc, "40th Anniversary check for St Fergus", 19 Jan 2017, https://www.nationalgridgas.com/news/40th-anniversary-check-st-fergus, 21 Jan 2020
[35] PX Ltd., "St Fergus gas terminal", 2019, https://www.pxlimited.com/case-studies/st-fergus-gas-terminal/ 30 Apr 2020
[36] National Grid plc, "Network Route Maps", 2019, https://www.nationalgridgas.com/land-and-assets/network-route-maps, 30 Apr 2020

Keele University and HyNet) but it is the large-scale adoption by the National Grid that will really push forward the market. Does politics play a part here?

At present the (UK political) Union still exists and a UK-wide transmission provider, the National Grid, dictates usage codes and strategy but what if Scottish independence reared its head again and a decoupling happened north of the English/ Scottish border? Does this embolden decisive steps in energy strategy or is there an obvious conflict where >50% of the National Grid's feedstock comes in through Aberdeenshire whereas the vast majority of the demand is South of the border? The answer to this question is uncertain.

Could the UK proceed with dual strategies for the adoption of hydrogen and use this cluster-based approach to hub and spoke the adoption of hydrogen through first an import terminal or industrial cluster then fanning out usage over the localised distribution network first? Nonetheless if we assume that strategic decision-making generally follows the path of least resistance, utilising existing infrastructure at St Fergus as the principal hub for hydrogen economy development seems logical. Within a UK context, the logic is for Aberdeen to lead the way. Within a western European context, it is likely to face stiffer competition.

5.2.4 Aberdeen and Western Europe

We started this discussion with thoughts around Aberdeen's potential as the pre-eminent western European hub and, even at this wider horizon, there remain reasons to be bullish in terms of possible future pre-eminence.

Aberdeen (along with Stavanger, in Norway, and Esbjerg, in Denmark) is Europe's representative in the Global Energy Cities partnership, an alliance of the key production hubs globally.[37] The city historically known as "The Oil Capital of Europe" is well positioned to transition to cleaner energy sources given the large amounts of human capital and decades of experience built up within the supply chain. Hydrogen is a commodity well understood by the offshore upstream petroleum community that finds its pre-eminent UK operational base, in the city. We should appreciate that scale will require the adoption of hydrogen production, processing and usage by IOCs and it is this that gives Aberdeen an edge *vis-à-vis* other European centres.

[37] World Energy Cities Partnership, "Member Cities", 2019, https://energycities.org/member-cities , 22 Mar 2020

The obvious competitor in the production space being the Netherlands with its world-leading ports, industrial capacity, maritime experience and political will towards clean-energy switching however most of the scalable projects have been based around hydrogen from renewable electricity[38] or from cracking of residual industrial gases.[39] Noble aims but clearly limited in scale by the extent of the Port of Rotterdam (the country's main hub) and the fast-tracking of green hydrogen production technologies (here again scale is an issue due to the number of wind turbines required). Most recent estimates of petroleum sector production from the UKCS display a robust near-term outlook[40] published before any pending UK or Scottish government interventions to insure future viability.

However we have yet to see the UK government nail its colours to the mast in the way the Dutch or the German governments have[41] in establishing a national strategy on hydrogen. Germany in particular is an interesting test case given the existential pains caused by its *Energiewende* (energy transition) strategy which was supposed to be the death knell of coal and nuclear and, at least in the former case, has proven anything but. There is a huge industrial capability, leadership in renewables and policy and public will but crucially again we see this gap in the offshore oil and gas sector in that there is none to speak off. The German strategy seems to call for a federal plan of hubs and creating hydrogen through industrial gases or renewable power as with the Netherlands but without the heft of a global powerhouse of a port to enable the growth of a hub. Natural as hubs tend to emerge where not only supply and demand can be paired but also a trading environment can spring up around and the financial community can hedge across sophisticated financial instruments. These entities tend to be geo-agnostic and will quote futures contracts where opportunity presents so although London as the world's major trading centre seems to confer advantage to Aberdeen as its domestic partner, in reality this adds nothing to the play. Both Platts and Independent Commodity Intelligence Services have announced pending price assessments

[38] Wind Europe, "Europe's largest renewable hydrogen project starts in Groningen", 28 Feb 2020, https://windeurope.org/policy/topics/offshore-wind-ports/europes-largest-renewable-hydrogen-project-starts-in-groningen/, 31 Aug 2020

[39] Port of Rotterdam, "H-Vision Blue Hydrogen for a green future", 2019, https://www.portofrotterdam.com/en/news-and-press-releases/h-vision-blue-hydrogen-for-a-green-future, 07 Jan 2020

[40] North Sea Transition Authority, "OGA Medium Term Projections", Feb 2020, https://www.ogauthority.co.uk/media/6406/oga-medium-term-projections-feb-2020.pdf, 23 Apr 2020

[41] S. Amelang, Clean Energy Wire, "German hydrogen strategy aims for global leadership in energy transition", 10 Jun 2020, https://www.cleanenergywire.org/news/german-hydrogen-strategy-aims-global-leadership-energy-transition, 11 Jun 2020

for hydrogen[42] but whether ultimately these become North Sea benchmarks as was the case with Brent is unclear.

If Aberdeen can tie itself to the North Sea and UKCS and the global trading market where the world sees a major hub of production coupled with a reliable and transparent trading environment in London then that may seal the deal. Whether a global hydrogen benchmark is possible is very much up for debate given there is no difference chemically in the product as there is with crude oil and so would therefore only transpire due to liquidity and preponderance of market players. Perhaps the argument for the UK-Aberdeen-UKCS as the pre-eminent player may be best understood in the forty-to-fifty year time period of oil as a traded commodity where, despite exploration and production having gone global and the majority of the major producers being in regions without global benchmarks (Middle East, Russia), the twin price markers of Brent and West Texas Intermediate (WTI) still dominate. Could we see something similar with hydrogen? The reason Brent and WTI share global pre-eminence as benchmark crude oils is not due to the production numbers which are small but due to having that crucial nexus of production-supply-demand-trading and multi-stakeholders, transparency and trust. But why would a Brent equivalent spring out of the UKCS in the same way for hydrogen when that fuel is the world's most simple chemical element with no variation in blend or type? The only differentiator in hydrogen is how it is made, not what it is constituted of. One possible answer is that "St Fergus green hydrogen" could become the equivalent benchmark to those crudes but as a measure of cost of production (and specified to renewable energy-generated hydrogen), with potentially a positive knock-on "halo-effect" for Aberdeen as, potentially, western Europe's leading energy hub for the new hydrogen economy.

Lastly, we should acknowledge the progressive local politics at play within Aberdeen. It is a city that has as many downs as ups and is at present investing heavily in a future that is much less dependent on hydrocarbons. We have seen investment in a new Energy Transition Zone at the harbourside[43] to attract new entrants into the city. Opportunity North East (ONE)[44] was established by local industrialist Sir Ian Wood to lend private sector

[42] S&P Global, "Platts Hydrogen Assessments", 2020, https://www.spglobal.com/platts/en/our-methodology/price-assessments/natural-gas/hydrogen-price-assessments, 25 Nov 2020
[43] Aberdeen City Council, "Aberdeen Energy Transition Zone feasibility report", Feb 2020, https://www.aberdeencity.gov.uk/sites/default/files/2020-04/ETZ%20Feasibility%20Study%20Report.pdf,12 Apr 2020
[44] Opportunity North East, "Energy Transition Projects", 2020, https://www.opportunitynortheast.com/transformational-projects/energy-transition, 02 Sep 2020

financing to Aberdeen Harbour's £350m investment. Innovation being the key here in not only leaning on 40 years of oil and gas expertise but encouraging new entrants with lateral thinking to the problems faced and embed Aberdeen's future as one of a hub of innovation as much as energy.

5.3 Low impact scenario – Hydrogen as a marginal component of the energy sector with small, pilot projects

The trouble with positing with gusto that hydrogen is set to become the next big standalone energy vector, reducing the carbon component of the oil and gas sector, filling in the gaps where renewables don't and taking up a considerable component of our usage across industrial use, domestic heating and cooking and transportation is that recent history is littered with "nearly weres". Biomass, once trumpeted as one of these silver bullets now makes up <6% of UK fuel and heat consumption.[45] The extant UK renewable energy roadmap[46] "went big" on wind power particularly offshore where the UK is a noted world leader but had only a derisory nod towards renewable energy sources for transportation, all of which to come from electrification with no nod to hydrogen. Given how long these pivots take to come to scale, this is concerning and must cast doubt as to the national strategy that could be employed for the use of hydrogen. As this paper is written, countless lobbying bodies have called for a UK hydrogen strategy, some in increasingly virulent terms.[47, 48] In these documents it is interesting to observe hydrogen included as a renewable fuel, presumably due to its potential model of production from floating offshore wind rather than its carbon free credentials. Should it be definitively identified as such in media and public policy narratives, this can only increase its chances of wider adoption in the UK – again, via a "halo effect", in this case with respect to the (overall) positive public perception of renewable energy domestically.

[45] International Energy Agency (IEA), "UK Country Report 2018", 2019, https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_UK_final.pdf, 12 Jan 2020

[46] Department of Energy & Climate Change (DECC), "UK Renewable Energy Roadmap", July 2011, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48128/2167-uk-renewable-energy-roadmap.pdf, 06 Jan 2020

[47] ReNews, "Trade bodies call for UK wide hydrogen strategy", 07 July 2020, https://renews.biz/61488/trade-bodies-call-for-uk-wide-hydrogen-strategy/, 02 Aug 2020

[48] C. Keating, Business Green, "Trade bodies push chancellor to develop UK wide hydrogen strategy", 08 July 2020, https://www.businessgreen.com/news/4017481/trade-bodies-push-chancellor-develop-uk-wide-hydrogen-strategy, 09 July 2020

A more pessimistic scenario sees twenty years of proving the business case, inspiring interest in the offshore energy sector and a decline in the cost of production. And here is the rub – it is only in the offshore sphere that hydrogen can truly be considered a renewable fuel, using excess electricity from floating wind-power arrays to electrolyse seawater. The other modes are decidedly easier and readily achievable with current infrastructure but are far from renewable whether that be from coal (brown hydrogen) or coupled with CCS and through cracking natural gas.

Current cost estimates however show that these methods are a quarter to a third of the cost of producing from renewables. This means that the advantage that Aberdeen possesses with respect to a mature offshore oil and gas sector on its doorstep, a competent workforce and strategic will from the IOCs is hugely reduced. If one is to produce hydrogen through the industrial gas or natural gas route then competition and natural advantage suddenly can be found across countless other hubs including Ellesmere Port, Humberside, Immingham, South Wales and essentially anywhere that has an industrial flavour, a local population that could benefit, and both the means and the will to bleed hydrogen into either the local distribution network, or a closed loop supply such as that at Keele University.[49]

These opportunities have been partly triggered by the UK Government's £90m fund for stimulating hydrogen trials[50] and due to enthusiasm shown by local institutions and councils, is an extremely small-scale example of the kind of public-private partnership that has been called for[51]. The ill-fated NER300 fund, the subject of European Court of Auditors investigation in 2018, for CCS technology and infrastructure by contrast was set at more than £2bn across the EU; in light of that fund's reported lack of efficacy,[52] the UK's £90m tranche of support barely is even less likely to catalyse any significant level of progress on (in this case, hydrogen economy) development. If governments are serious about hydrogen then this needs to rise by a factor of one hundred. Aberdeen itself may well benefit from

[49] Keele University, "UK's first grid injection hydrogen pilot", 02 Jan 2020, https://www.keele.ac.uk/discover/news/2020/january/hydeploy-goes-live/at-keele-university.php , 06 Apr 2020

[50] UK Gov Department for Business, Energy & Industrial Strategy, "Households and businesses will benefit from £90M to cut carbon emissions", 18 Feb 2020, https://www.gov.uk/government/news/90-million-uk-drive-to-reduce-carbon-emissions, 07 Mar 2020

[51] Financial Times, "Is it time to unlock the potential of hydrogen", Jan 2020, https://www.ft.com/content/8505cb1c-4354-11ea-abea-0c7a29cd66fe, 07 Jan 2020

[52] S. Morgan, Euractiv, "Auditors analyse EU's failed carbon capture projects", 24 Oct 2018, https://www.euractiv.com/section/energy/news/eu-funded-carbon-capture-storage-efforts-failed-say-auditors/, 02 Feb 2020

investment from the Scottish Executive such as the recent Energy Transition Fund[53] and the guile and financial support of the locally based ONE.[54] Here again the numbers are small though measured in the tens of millions. One could conceivably see Aberdeen emerging as a hub of innovation and technology that draws admiring visits from across the world as an example of a city making a transition from one dependent on the offshore oil and gas sector to one leading a third (or fourth?) industrial wave but not a hub city of scaled hydrogen production.

On an optimistic reading, it is possible to foretell a vibrant Aberdeen with leading-edge hydrogen economy projects, starting with Acorn, proving the fuel-source's viability case, and then (say) local housing taking a hydrogen bleed for their heating and cooking requirements,[55] a well-established municipal transportation network[56] using hydrogen fuel, with the IOCs as active market participants too. Whilst helping to generate the necessary momentum to help make Aberdeen a western European or even national hub for the hydrogen economy, it is by no means a sufficient condition for that result. Indeed, that outcome is far from inevitable.

As a cautionary parallel, it is perhaps instructive to compare and contrast with Kobe in Japan, a city that is widely recognized as being the world's pre-eminent "hydrogen city" and has done more than anywhere else to diversify the production and use of hydrogen[57] but does no more than offer "a hydrogen roadmap" i.e. it as yet has no stated aspirations to supply its new fuel across Japan far less export it globally. Kobe can lessen that part of Japan's dependence on imported (and expensive) LNG, perhaps reduce the nuclear component of the power generation mix and generally "clean up" the streets and air through burning hydrogen rather than gasoline or diesel and as a much larger city that Aberdeen does truly offer a roadmap. If that is the current horizon for Kobe, which o why should we

[53] ScotGov, "£62M fund for energy sector", 12 Jun 2020, https://www.gov.scot/news/gbp-62-million-fund-for-energy-sector/,03 Jul 2020
[54] Opportunity North East, "Energy transition, transformational projects", 2019, https://www.opportunitynortheast.com/transformational-projects/energy-transition, 12 Dec 2019
[55] BBC, "Plans for more than 500 homes", 24 Jul 2019, https://www.bbc.co.uk/news/uk-scotland-north-east-orkney-shetland-49095985#:~:text=Plans%20have%20been%20submitted%20for,%22pioneering%22%20hydrogen%20fuel%20cells.&text=The%20proposals%20include%2030%20homes,would%20be%20first%20for%20Scotland., 13 Feb 2020
[56] Aberdeen City Council, "Aberdeen launches hydrogen fuelled bus routes", 2019, http://www.h2aberdeen.com/home/h2-aberdeen-hydrogen-bus.aspx,09 Jan 2020
[57] Mayor of Kobe Japan, "Hydrogen smart city Kobe initiative", 2019, http://media.firabcn.es/content/S078018/download/13NOV_UE_ENERGY_KN.pdf, 02 Aug 2020

be more optimistic with regards to Aberdeen and any ambitions for it to become pre-eminent as a hydrogen energy hub within the UK, first, and across western Europe, second?

6. Conclusions

Above we have played out two very different scenarios for the uptake of hydrogen as the next big fuel and a crucial driver of efforts to reduce global warming. We have explored the fact that three critical drivers must come together for scale to be achieved, namely political will, economic viability and social license to operate. There are questions marks around all three. In reverse order, hydrogen hasn't achieved the sort of prominence where local communities or the media have properly engaged in a way they have done with fracking or nuclear. Is hydrogen a truly accepted fuel type or are parochial concerns around its explosiveness likely to surface? Are communities ready for high pressure storage tanks under their streets or under their car seats? On the economic viability side, the costs are still very high especially when combined with CCS and there is no current price benchmarks indicative of the fact that this is not yet a traded commodity.

There is likewise huge deviation between the cost of production via electrolysis with renewable energy versus the blue hydrogen solution of splitting methane or industrial gases. From a climate perspective the former solution is far preferably but much more far out in both project timelines, technology and economic veracity. Lastly political will has been tentative and as yet nowhere near the push that offshore wind received. Will there be a national or European effort to artificially support hydrogen projects with Feed-in tariffs or subsidies as was the case with wind? Will hydrogen be treated as a renewable energy type or just another gas? This is critical from a political support point of view as it will dictate the extent to which hydrogen can be included in special funds on offer. Will large institutional investors get on-board and demand that IOCs invest heavily in the hydrogen economy as part of a decarbonisation strategy? Or will these fund managers be purely interested in pure-play renewable energy projects in wind or solar?

Hydrogen energy advocates must be clear in how they position the fuel in both public policy and competitive terms. Logic and rationale dictates its betterment *vis-à-vis* natural gas but has the world shifted too far already and will see it as an extension to the gas business? A scouring of the energy press and the mass media shows a real momentum and enthusiasm, much has been written and grandiose visions are everywhere but this is anything but a done deal and Aberdeen, to gain the hydrogen energy hub pre-eminence posited in this research paper, will need the UK to firstly coalesce positive answers to those three drivers and then settle on that city as the home for its hydrogen vision. At the time of writing, 2020, we have

regretfully not reached even first base yet on either part of that equation and therefore the question remains an open one as to Aberdeen’s future hydrogen economy fate.

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