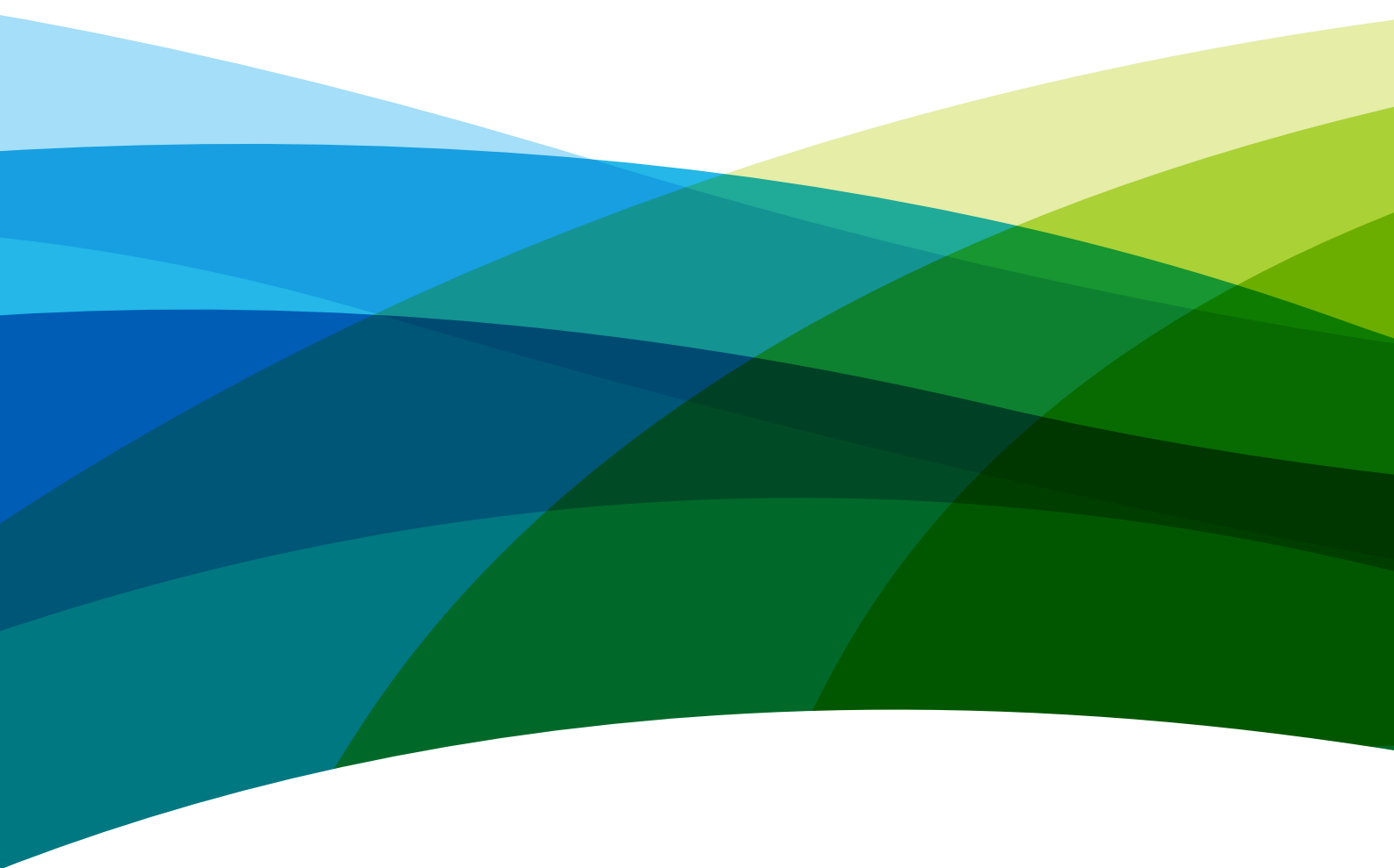


Hydrogen

Case Study: Aberdeen



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Purpose

Over the past eight years, Aberdeen has established itself as a centre of excellence for hydrogen and fuel cell technologies. A wide range of initiatives have been implemented throughout the City, including: the initial deployment in 2015 of ten fuel cell buses with a renewed fleet of 25 double deck vehicles now being delivered between 2020-22; the introduction of light duty fuel cell vehicles into Council fleets and a local car sharing club; trials of hydrogen-fuelled refuse trucks and road sweepers, and commissioning of a megawatt-scale stationary fuel cell as part of Aberdeen's new conference centre development. The City has two publicly accessible refuelling stations for supplying this growing fleet: Kittybrewster, operational since 2014 and recently upgraded to accommodate all vehicles, and ACHES (Aberdeen City Hydrogen Energy Storage), operational since 2017 and able to refuel most 700bar and 350bar vehicles.

Aberdeen City Council is actively delivering an energy transition and has supported the development of a number of renewable projects in and around the city. As an indication of Aberdeen's ambitions, the Council approved a Net Zero Vision to become a climate positive city and a Strategic Infrastructure Plan in 2020 to support this. In addition, the Council also approved plans to replace all its fleet vehicles with alternative powered vehicles where these are available.

Aberdeen City Council is currently working with public and private sector stakeholders to develop a commercially viable 'Hydrogen Hub' in the city. The key requirement of the hub is to make hydrogen available at a price which makes further deployment of hydrogen vehicles (and other non-transport related demands) economically viable. This will require the stimulation of enough demand to ensure sufficient economies of scale in the production and distribution of hydrogen that it reaches cost-parity with diesel.

The purpose of this document is to highlight how hydrogen will play a key role in Aberdeen's energy transition and showcase the City's achievements and aspirations in hydrogen technology.

Background

Climate Change is an existential threat. Continuous use of fossil fuels has resulted in a drastic increase in the level of greenhouse gases (mostly notably Carbon-Dioxide) in the atmosphere. Greenhouse gases have the potential to trap the sun's solar energy in the atmosphere and consequently heat up the Earth. This has led to dramatic climatic events such as wildfires, droughts, storms, and flooding becoming more frequent and more severe.

In light of this, various commitments to reduce carbon emissions have been made by governments at European, UK and Scottish levels:

- In June 2019, the UK government committed to reduce its net carbon emissions by 100% relative to 1990 levels by 2050.
- Petrol and diesel cars and vans will be phased out in all public sector fleets by 2025 and privately by 2032 in Scotland and UK.
- Scottish government committed to introducing Low Emission Zones in Scotland's main cities by 2020.
- Scotland aims to source 50% of all energy in transport/heating from renewables by 2030.
- Scottish Government published an Energy Strategy with a 2050 vision for electric and hydrogen futures.
- The Scottish Government released a Hydrogen Policy Statement in December 2020 setting out the vision for Scotland to become a leading hydrogen nation in the production of sustainable hydrogen.
- The European Commission published a Hydrogen Strategy in June 2020 noting hydrogen's importance in achieving carbon neutrality.
- The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) published the Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition. The study states hydrogen can account for 24% of final energy demand and 5.4 million jobs by 2050.

Scotland has made great strides to reduce carbon emissions in various sectors; emissions in 2017 were 46.8% lower than they were in 1990 .

SOURCE EMISSIONS

A measure of the actual emissions or removals in Scotland. Includes international aviation and shipping. Used for UK and international comparisons.

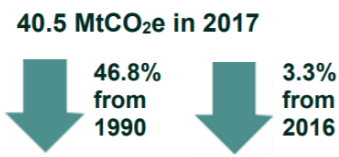


Figure 1: Sources of Scottish Greenhouse Gas Emissions in 2017 (published in 2019)

However, transport continues to be the largest emitter of carbon dioxide in Scotland. In 2017, transport emissions were 14.9MtCO₂e, by far the largest source of greenhouse gas emissions.

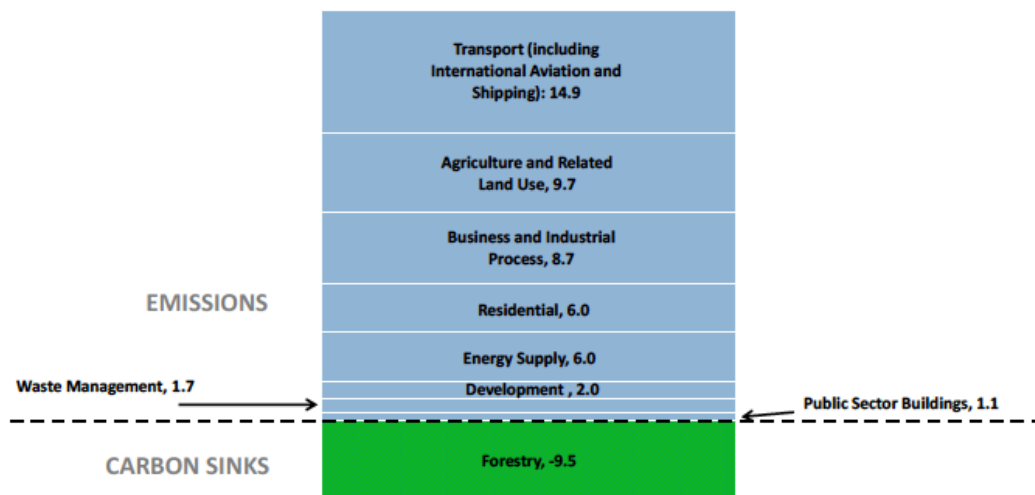


Figure 2: Sources of Scottish Greenhouse Gas Emissions in 2017, 2019. Values in MtCO₂e

Across Europe, transport represents almost a quarter of greenhouse gas emissions, as 92% of transport in Europe is oil based. Over the past five years use of renewable energy sources in transport is 8.2%, compared to 32% in electricity and 21% in heating and cooling in 2018, showing that the savings accrued in other sectors have not been so readily felt within transport.

Furthermore, transport is the main cause of air pollution in cities. Air pollution has a negative impact on the health of citizens, animals, and the planet:

'The combined effects of ambient (outdoor) and household air pollution cause about seven million premature deaths every year, largely as a result of increased mortality from stroke, heart disease, chronic obstructive pulmonary disease, lung cancer and acute respiratory infections.' World Health Organisation

Hydrogen offers a solution to decarbonise not only the transport sector but other sectors including industrial processes, power and buildings. It can be used as a feedstock, a fuel or, an energy carrier and storer. More importantly, it emits zero carbon emissions and has almost no air pollution when used. There has been a rapid growth and global interest in hydrogen in Europe and around the world. Hydrogen will therefore be essential in supporting Scotland's effort to reach carbon neutrality while working towards zero pollution.

Introduction to Hydrogen

Hydrogen is the most abundant element in the universe, making up about 75% of the mass of the universe. It rarely exists as a gas on Earth; rather, it is usually present in a compound bonded to other elements. For example, when combined with oxygen, it forms water: H₂O.

Hydrogen is a colourless, odourless, tasteless and non-toxic gas. When burnt, it releases heat. Hydrogen can also be reacted with oxygen electrochemically in a fuel cell to produce heat and electricity.

Hydrogen can be used as an energy vector, to move, convert and store energy. It is potentially one of the most flexible and broadly applicable energy vectors available. It could have a role in almost every part of the energy system. If produced in a low carbon way, hydrogen can be used to decarbonise any sector it penetrates.

Hydrogen can be produced from diverse resources, including fossil fuels, nuclear energy, biomass, and other renewable energy sources such as wind, solar, and geothermal. It can be produced using a wide range of processes; however, the most common processes are electrolysis and steam methane reforming:

1. Electrolysis – splitting water into hydrogen and oxygen using electricity.
2. Steam methane reforming – steam reforming hydrocarbon feedstock to produce synthesis gas (syngas) which is primarily a mixture of hydrogen and carbon monoxide.

Hydrogen can also be generated through energy from waste facilities, recovery from biogas and/or biomass, and as a by-product from other processes. Several industries (such as the chemical industry) produce large amounts of hydrogen as a by-product which is often unused. This can be an efficient way of using existing resources and reducing emissions.

Although hydrogen is colourless scientists often refer to colours to describe where the gas is sourced from:

- “Grey hydrogen” is usually produced from natural gas via steam methane reforming or produced via water electrolysis straight from electricity from the grid without green tariff. This process can cause carbon emissions.
- “Blue hydrogen” also usually produced from natural gas via steam methane reforming but with the carbon dioxide captured from a new technology called Carbon Capture and Storage (CCS). This process captures the carbon emissions.
- “Green hydrogen” which is the product of electrolysis of water using renewable electricity. This process has close to zero net carbon emissions.

Hydrogen in Transport

Using hydrogen rather than fossil fuels can radically reduce tailpipe emissions and other pollutants that damage human health, thus helping to meet emissions targets and tackling air pollution.

There are various ways to integrate hydrogen into transportation. Aberdeen has explored three options: dual-fuel combustion engine, range extended Battery Electric Vehicles and Fuel Cell Electric Vehicles.

Dual Fuel also known as (H2ICED®)

Dual fuel combustion is an interim technology for those first exploring hydrogen transport options. A diesel internal combustion engine can be converted to inject hydrogen into the engine, reducing tailpipe emissions by around 30%. Dual fuel combustion allows fleet operators to introduce and experience hydrogen reducing emissions in their current fleet. H2ICED is a useful bridging technology until such a time as the hydrogen vehicle market has matured to offer full fuel cell electric vehicles and economies of scale have developed.



Figure 3: Dual Fuel Conversion, ULEMCo

Fuel Cell Range Extended Vehicle (FC-REEV)

Battery electric vehicles (BEVs) can also incorporate hydrogen to extend their range. A battery vehicle can be retrofitted with a hydrogen fuel cell system and on-board hydrogen tank to extend the drive time and thus alleviate range-anxiety. Hydrogen range extended vehicles can be particularly useful for individuals living in remote locations where they need to travel further than the basic battery pack range would provide, or those who rely on their vehicle for lengthy, uninterrupted trips. This approach is also a viable option for larger vehicles that carry significant load which may not perform optimally on BEV alone, those that require "power take off (PTO) for on-board equipment and those with duty cycles which need to utilise the vehicle 24/7 and wouldn't have time to recharge, such as Taxis and Ambulances.

Fuel Cell Electric Vehicles (FCEVs)

FCEVs are electric vehicles powered by hydrogen. They have a fuel cell that intakes hydrogen from the tank and creates electricity on-board the vehicle to power the e-motor and drive the vehicle. FCEVs only produce water vapour as a tailpipe emission and, similar to battery vehicles, are zero-emission and therefore healthier for the planet and our lungs than vehicles that use hydrocarbon fuels. Being an electric vehicle, they have very good acceleration and are almost silent in operation. Unlike their equivalent Battery Electric Vehicles however, which use a lithium-ion battery, FCEVs have a smaller hybrid battery or supercapacitor to power the e-motor.

Benefits of FCEVs include that they take a similar amount of time to refuel as their diesel or petrol equivalents, and therefore are a potentially better option than BEVs for longer distance journeys. As an example, a Toyota Mirai has a range of approximately 300 miles on a full tank of fuel which only takes 3 minutes to refuel. This becomes even more important for larger vehicles travelling significant distances and/or carrying heavy loads. However, FCEV technology is still quite new and vehicles are only made in small volumes, or not yet commercially available, which results in higher unit costs when compared to their electric, diesel and petrol vehicle equivalents.

Battery Electric Vehicle (BEV)	A vehicle that derives all its power from electricity provided by an external electrical source such as a chargepoint and stored in an on-board battery i.e. include the Nissan Leaf car and the Nissan e-NV200 van.
Fuel Cell Electric Vehicle (FCEV)	An electric vehicle which derives its power from the conversion of hydrogen and oxygen to electricity in a fuel cell. FCEVs typically use a relatively small hybrid battery to capture regenerative braking energy and provide peak power support to the fuel cell. Examples include the Toyota Mirai and Hyundai Nexa cars.
Fuel Cell Range Extended Electric Vehicle (FC-REEV)	These have larger batteries which can be charged with electricity from a chargepoint, as well as a fuel cell which runs on hydrogen. Either or both power sources can be used to drive the vehicle and top up the battery, thereby providing the vehicle with longer range than a BEV variant. An example is the Symbio (now Renault) Kangoo ZE H2 light duty van.
Hydrogen Internal Combustion Engine (H2ICED®)	Hydrogen can be burnt in a combustion engine, and as long as the engine is designed and optimised for zero air quality emissions it could in the future, be a viable option for a range of vehicles like HGVs. In the interim it is possible to co-combust hydrogen with diesel in a conventional engine, such that the vehicle saves carbon by displacing the high carbon energy from diesel with zero carbon hydrogen. Examples are van and refuse collection vehicle (RCV) conversions by ULEMCo.

Table 1: Types of Transport Technologies

Case Study: Aberdeen

Aberdeen City Region Hydrogen Strategy and Action Plan 2015-2025

The Aberdeen Hydrogen Strategy is part of the city's vision to stimulate innovative hydrogen projects. It was published in 2015 and outlines key actions required over a 10-year period to ensure Aberdeen is a world class energy hub leading a low carbon economy and is at the forefront of hydrogen technology.

The overall aim is to position Aberdeen as a centre of excellence for hydrogen technology by utilising the transferable oil and gas expertise and the exceptional capacity for renewable energy generation in North East Scotland.

The Strategy and Action Plan has seven key objectives (see Table 2).

	Objective	Action
1	Vehicle Deployments	A range of local stakeholders deploy hydrogen vehicles.
2	Renewable Hydrogen	Hydrogen produced from renewable energy sources is widespread throughout the region.
3	Refuelling Infrastructure	An accessible, convenient, and safe refuelling infrastructure network is deployed across the City and beyond.
4	Non-Transport Applications	Non-transport applications are tried and tested including stationary power.
5	Supply Chain / Market Development	A robust, local hydrogen supply chain is developed which utilises the areas existing energy expertise.
6	Communication and Education	A greater understanding and acceptance of hydrogen technologies encourages widespread adoption.
7	Policy and Regulation	Hydrogen technologies are embedded in all relevant areas of policy and supported at a national level.

Table 2: Aberdeen Hydrogen Strategy Objectives

Within the lifetime of the Strategy, Aberdeen City Council has managed to secure investment for vehicle deployments initially, and new infrastructure investment.

Vehicles

Aberdeen aims to be a focal point of hydrogen transport, and as such has one of the most diverse hydrogen fleets in the UK. Presently, Aberdeen has 57 operational hydrogen vehicles on the road (see Table 3). Community Partners such as Sport Aberdeen, CFINE, NESCol and NHS Grampian each have access to hydrogen cars. A significant proportion of the hydrogen vehicles include cars and vans which are available to local businesses and members of the public to hire via the Co-Wheels car club – this acts to increase awareness and acceptance of hydrogen.



Table 3: Hydrogen Vehicles in Aberdeen

*This figure excludes 10 buses which were part of the European funded Aberdeen Hydrogen Bus project, a pioneering demonstration project showcasing fuel cell buses which came to an end in December 2019. These buses are now used by various organisations across the UK and Europe for educational, automotive training and demonstration purposes.

There are plans to introduce 18 more hydrogen vehicles into the city in 2021-22:

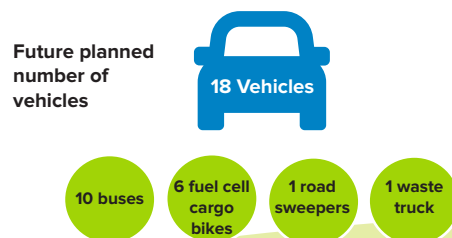


Table 4: Planned Hydrogen Vehicles in Aberdeen

Figure 4: Aberdeen Hydrogen Vehicles Fleet



Figure 5: RGU Co-Wheels Car Club Fleet Launch



Individual types of hydrogen vehicles in Aberdeen

Hyundai ix35



Figure 6: Hyundai ix35

The Hyundai ix35 was the first fuel cell car the Council purchased. It has a 5.64kg hydrogen tank, which only takes 3 minutes to refuel at 700bar, and delivers a range of 369 miles.

Some of the Hydundais were put onto the Co-Wheels car club fleet for members of the public to trial. The vehicle is only available in left-hand drive, which has meant it is more appropriate for a European market.



Figure 7: Hyundai ix35 Specs, taken from the Hyundai website

Toyota Mirai



Figure 8: First-generation Toyota Mirai

The Mirai has a 5kg hydrogen tank, which takes 3 minutes to refuel at 700bar pressure and delivers a range of 300 miles. Aberdeen has the largest fleet of Mirais in the UK. Many of Aberdeen City Council community partners, including NESCoI, have trialled this first-generation FCEV. Toyota Mirais are available on the Co-Wheels car club fleet for public use.

Hyundai Nexo



Figure 9: Hyundai Nexo

The Nexo is the second generation of fuel cell cars manufactured by Hyundai. It has a 6.3kg hydrogen tank, which only takes 5 minutes to refuel at 700bar, and delivers a range of 414 miles. The Nexo is available in right hand drive and is also on the Co-Wheels car club fleet. The Lord Provost uses a Nexo for civic duties.

Renault Kangoo

The Renault Kangoo is a 22kWh battery electric van with hydrogen range extender. It has a 2kg hydrogen tank which takes 8 minutes to refuel at 700bar, this delivers a range approximately of 220miles. The hydrogen tank is located towards the back of loading space of the vehicle.



Figure 10: Renault Kangoo with Hydrogen Range Extender



How does it work

- 1 The electric motor ensures zero emission propulsion.
- 2 The hydrogen fuel cell produces electricity on board.
- 3 Both battery and hydrogen fuel cell power the motor. When the powertrain does not require energy, the fuel cell charges the battery.
- 4 The battery recharges from the grid, hydrogen at the station.

Figure 11: Excerpt from Renault Kangoo ZE H2 Manual Symbio, 2017

Nissan eNv200



Figure 12: Nissan eNv200 with Hydrogen Range Extender

Similar to the Renault Kangoo, the bespoke Nissan eNV200 is a battery electric van. It has a 74l hydrogen tank fitted onto the roof which means the storage capacity is not compromised for the increased range. The electric mileage is 106 miles (real life – 90 miles) and the inclusion of hydrogen increases this by an additional 45 miles. This has ensured that the vehicle is able to achieve the average miles per day of a delivery van on one charge, drastically increasing the productivity.

Dual Fuel Road Sweeper



Figure 13: Road Sweeper Retrofit DAF LF 220 FA Johnson Sweeper 16 Tonne

The road sweeper has hydrogen injected into both diesel combustion engines (one for powering the sweeping mechanisms and the other for propelling the vehicle). The retrofitted road sweeper comes with two 74l (1.5kg) hydrogen tanks which reduces emissions of the vehicle by 30%, or a combination of a 74l tank and a 204l (4.8kg) tank which can reduce emissions by 40-50%. Aberdeen has 3 dual fuel road sweepers with a combination of varying tanks. The road sweepers all take approximately 8 minutes to refuel.

Dual Fuel Waste Truck



Figure 14: Dual Fuel EURO VI Mercedes Waste Truck

The waste truck has a combustion engine that runs off a mixture of diesel and hydrogen thus reducing the carbon-footprint and capitalising on the pre-existing vehicle.

As of November 2020, Aberdeen City Council has two waste trucks which both have 2 tanks capable of holding 9.6kg (205 litres) of hydrogen. They take approximately 8 minutes to refuel at 350bar. This amount of hydrogen can last for three days on the current routes of the vehicles and helps to reduce carbon emissions by over 20%. There are plans to increase the amount of dual-fuel waste trucks in the Aberdeen City Council fleet and experiment with varying hydrogen tank sizes.

Van Hool Fuel Cell Hydrogen Bus



Figure 15: Van Hool FC, part of the Aberdeen Hydrogen Bus Project

Figure 15 shows the original hydrogen FCEV buses that were a flagship project in Aberdeen's hydrogen journey. The bus is powered by a Ballard fuel cell and the chassis is a Van Hool model. It holds 45kg of hydrogen, takes 12 minutes to refuel at 350bar and has a range of 260 miles. The batteries and tanks are located on top of the bus while the fuel cell is on the back.

The 10 hydrogen buses operated in the City for 4 years (2015-2019). They provided transportation for over 2 million passengers and travelled in excess of 1.15 million miles. As a FCEV they produced no tailpipe emissions except water vapour. It is estimated that compared to a Euro VI vehicle the buses saved over 100 tonnes of carbon dioxide emissions from entering the atmosphere. During colder seasons, the buses require a small electrical current to prevent the battery from freezing.

Following the conclusion of the 4-year demonstration project, Aberdeen City Council has gifted the buses to other institutions for various purposes. These include:

- Technical Colleges (UK and Europe) to use for automotive training, demonstration and teaching purposes;
- A Transport Museum for use as an educational display and exhibition for school children and the general public; and,
- A University/Research and Education Institute to be used within a world-leading demonstration project.

JIVE Double-Decker Fuel Cell Hydrogen Bus



Figure 16: Wrightbus Streetdeck Double-Decker

Figure 16 shows the new FCEV buses in Aberdeen. The bus is powered by a Ballard fuel cell and the chassis is a Wrightbus streetdeck double-decker model. They are the very first deployment of hydrogen in double decker buses in the entire world. It is estimated that each bus will have a tailpipe saving of 84 tonnes of CO₂ per year. Aberdeen currently has 15 buses and 10 more are expected to arrive in 2022.

It holds 26kg of hydrogen, takes 9 minutes to refuel at 350bar and has a range of 190 miles. The batteries are located next to the rear wheel-arch, while the fuel cell and tanks are at the back. To protect against the cold, the buses require a small electrical current to continuously pass through their battery overnight, so frost protection points must be connected.

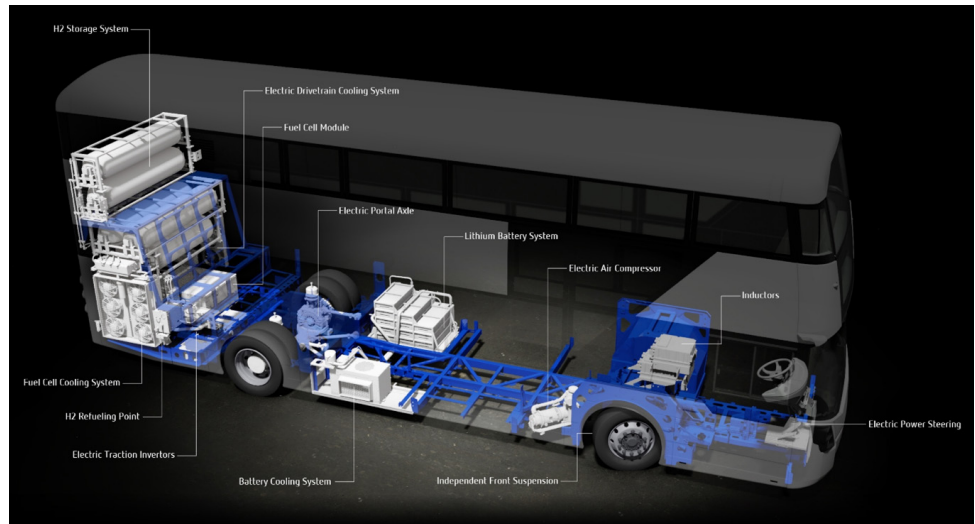


Figure 17: Inside our Wrightbus Double-Decker Hydrogen Buses, taken from Wrightbus

Future Vehicles

HECTOR Fuel Cell Electric Waste Truck



Figure 18: FC waste truck expected in Summer 2021, and will be the first of its kind in the UK

Figure 18 shows the new FCEV waste truck being assembled; it is set to arrive in Summer 2021. The waste truck is powered by a Hydrogenics fuel cell and the chassis is a Mercedes Eonic low entry cab in an electric configuration. It holds 20kg of hydrogen (4 tanks), takes 8 minutes to refuel at 350bar. With a range of 120km the truck will be able to undertake its duty cycle without needing to refuel. It will be the very first deployment of a fuel cell waste truck in the United Kingdom and is being deployed as part of a North West Europe funded project HECTOR.

Fuel Cell Cargo Pedelects



Figure 19: Prototype of Fuel Cell Cargo Pedelects expected in Autumn 2021

A Pedelect is a cycle whereby the rider is assisted by a small electric motor. The cargo pedelecs have a 28l hydrogen tank which helps the cyclist to propel their 2m³ container. It will take a matter of minutes to refuel at 350bar. The cargo bikes are expected to be deployed in Autumn 2021 as part of the Interreg North West Europe FCCP project.

Refuelling in Aberdeen

Aberdeen has 2 publicly accessible hydrogen refuelling stations (HRS): Kittybrewster and Aberdeen City Hydrogen Energy and Storage (ACHES).

Kittybrewster

The Kittybrewster station was built by BOC and opened in 2015 when the VanHool buses arrived in Aberdeen. It is operated and maintained by BOC and is the largest and most reliable dedicated bus refuelling station in the UK. It can dispense up to 360kg hydrogen per day and has the capacity to store 420kg on-site. The station has dispensed over 160 tonnes of hydrogen over the last four years. In 2018 the station was upgraded to allow the refuelling of cars and vans at 700bar, in addition to the buses.

In 2020, Kittybrewster station won the Transport Times' Award for Contribution to Sustainable Transport.

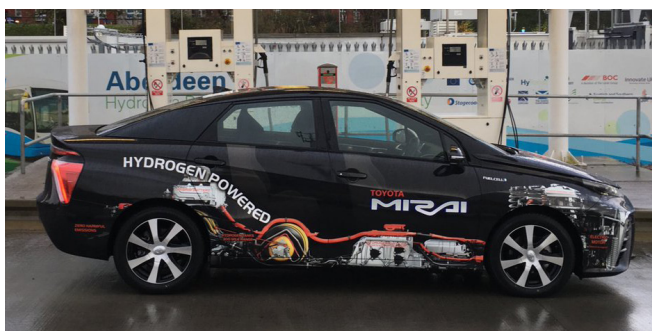


Figure 20: Toyota Mirai Refuelling at Kittybrewster HRS

Adjacent to the Kittybrewster HRS, there is also an adapted maintenance facility for working on hydrogen vehicles at the Council's fleet depot and workshop. There are currently two dedicated bays comprising the necessary safety vents, anti-static flooring, freeze protection points and detection systems which are required when fixing hydrogen vehicles. In the future the Council intends to expand the number of hydrogen safe bays and increase the number of staff trained to deal with hydrogen vehicles.



Figure 21: VanHool Bus in for Schedule Maintenance at the Aberdeen Hydrogen Maintenance Facility in Kittybrewster Depot

Aberdeen City Hydrogen Energy Station

The second refuelling station at Cove is our dedicated car and van refuelling station. It was built by Hydrogenics, opened in 2017 and is owned by the Council. Aberdeen City Hydrogen Energy Storage (ACHES) has a smaller capacity than Kittybrewster, but still manages to produce 130kg of hydrogen per day. It also has an additional 150kg of storage. It can dispense at both 700 and 350bar, providing fuel resilience for the City. As well as hydrogen, it is also possible to charge EV vehicles at ACHES - making it a one-stop-shop for sustainable transport energy.



Figure 22: Toyota Mirai Refuelling at ACHES HRS

Having an additional HRS in the city gives confidence to drivers and makes Aberdeen a more attractive location for hydrogen vehicle deployments. Not only does ACHES provide hydrogen security in the city, the station also boasts a training space that facilitates events and tours. HRS tours are undertaken on request and as part of events with delegates from across the UK, mainland Europe, Canada, USA, Australia, and Japan.

The tours offer an introduction to hydrogen production for those with no knowledge but are also beneficial in increasing operational knowledge of hydrogen for those with transferable skills from the oil and gas industry. The station is currently operated by Norco Group (since 2018) and this marks their first step into the hydrogen supply chain from an electrical energy systems background.



Figure 23: Aberdeen City Hydrogen Energy and Storage station (ACHES)

Green Hydrogen

In both Hydrogen Refuelling Stations in Aberdeen, hydrogen is produced via electrolysis on-site using a green electricity tariff from the National Grid. This means the electricity provided is sourced from renewables (solar/ wind) and therefore the well-to-wheel carbon emissions are zero. Well-to-Wheel is a concept which captures the whole system of emissions (see Figure 24). Since Aberdeen produces hydrogen fuel from green electricity the extraction and processing component of the cycle is carbon zero. Aberdeen's onsite production ensures that no transportation is necessary, resulting in zero emissions. Finally, the usage of the fuel is entirely carbon-free as water is the only tailpipe emission, making the whole system green!

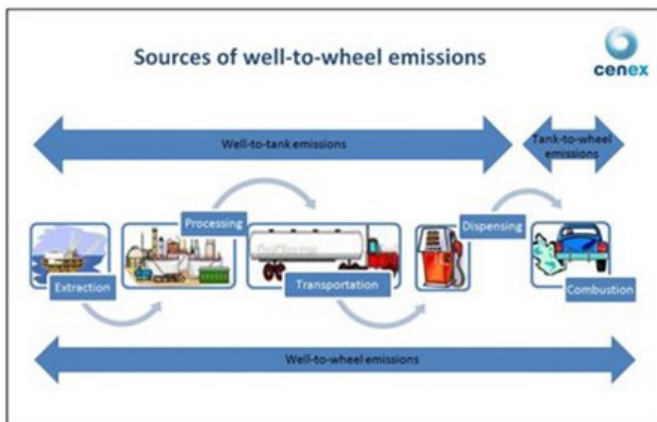


Figure 24: Well-to-Wheel Emissions System, Cenex 2018

Producing hydrogen from renewables results in better well-to-wheel emissions than from steam methane reforming of natural gas and is therefore better for the environment. In addition, hydrogen has the potential to store energy which allows intermittent solar and wind farms to operate at maximum efficiency - storing

energy in times of curtailment. In many regions around the world the periods of most intense sun or wind do not always align with the largest draw periods from the electricity grid. Curtailment issues arise when renewable sources do not take full advantage of the weather conditions but instead match the electrical demand required, which can result in wastage. Producing hydrogen at times when there is little demand from the electrical grid (i.e., middle of the night) but there is a large supply of renewable sources (i.e., very windy), ensures there is little wasted energy.

Key storage applications that hydrogen can deliver include:

- long-duration energy storage over months or longer in order to meet seasonal peaks in electricity and heat demand;
- medium term storage over days and weeks to manage the variability and uncertainty in the output of wind, solar and marine resources, and to balance the generation and use of energy;
- short term storage over hours, providing important services such as system balancing, inertia and voltage control on the electricity system.

Figure 25: Taken from Pg10, Scottish Government's Hydrogen Policy Statement 2020



Figure 26: European Offshore Wind Deployment Centre (Aberdeen Bay Wind Farm) is located off the Coast of Aberdeen, taken from Vattenfall website



Figure 27: Kincardine Offshore Wind Farm located to the South East of Aberdeen (9 miles off the Coast of Stonehaven); picture taken from World of Energy News

Aberdeen Hydrogen Hub

The Aberdeen Hydrogen Hub is a model aiming to achieve a cost-effective supply of green hydrogen which will be made available on a commercial basis to the market to support existing and proposed hydrogen projects. Aberdeen is already at an advanced position when it comes to the roll-out of hydrogen technology. ACC expects that the Hydrogen Hub will establish a whole system approach to hydrogen supply and demand, allowing for increased innovation and skills, and supporting expansion of the supply chain.

The Hydrogen Hub model will allow Aberdeen to pursue its ambitions to become the hydrogen powerhouse which produces and exports worldwide.

Case Study - Aberdeen Hydrogen Hub

The **Aberdeen Hydrogen Hub** is a regional collaboration proposal, involving Aberdeen City Council, Scottish Enterprise and Opportunity North East, taking a whole-system approach to hydrogen production and demand to drive scale and economic growth.

The 'Aberdeen Hydrogen Hub' aims to deliver a commercially scalable and investable, growth-focussed hydrogen production site making use of the region's offshore wind resources. This will kick start growth of the hydrogen sector in the region, initially for transport, with further opportunities for growth in heat, industry and beyond in the future. If successful, this is a model which could be suitable for replication in various regions of Scotland.

The Hub is among one of the projects being supported by Scottish Government funding via our £62m Energy Transition Fund (ETF), launched in June 2020.

The project has so far been awarded £4.5m enabling the procurement of an additional ten hydrogen double decker buses to add to the existing hydrogen bus fleet in Aberdeen to help anchor hydrogen demand and enable future buildout phases of the Hub.

Figure 28: Hydrogen Hub Case Study, Scottish Government Hydrogen Policy Statement

The Hydrogen Hub comprises three distinct phases as shown below.

Aberdeen Hydrogen Hub

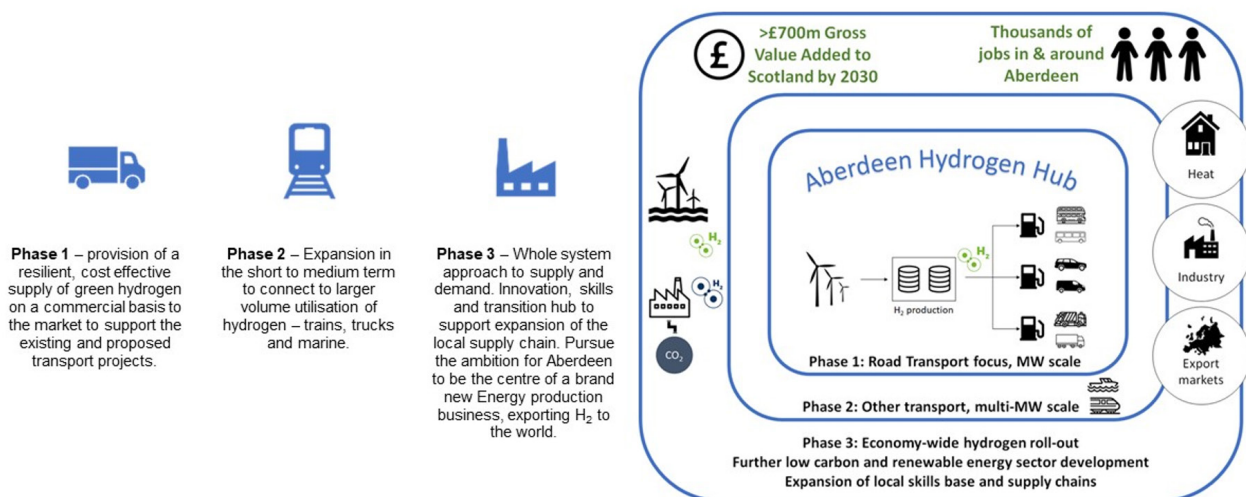


Figure 29: Phases of the Aberdeen Hydrogen Hub

- **Phase 1:** ACC is seeking a supplier to provide hydrogen at cost parity to diesel. In order to drive demand and bring down prices, ACC is focusing on increasing hydrogen for transport uses. By 2022, Aberdeen will have 25 double-decker hydrogen buses – these will each require up to 20kg of hydrogen every day. In addition, there are ongoing discussions with public and private sector organisations in the North East to encourage hydrogen uptake in transport, which again could provide significant hydrogen demand.
- **Phase 2:** ACC will increase hydrogen demand by exploring how hydrogen can be incorporated into trucks, trains, marine transport.
- **Phase 3:** ACC will explore non-transport uses of hydrogen such as heat, and industry, and pursue the exportation of hydrogen worldwide. This will result in a diverse supply chain and expansion of local skills and jobs.

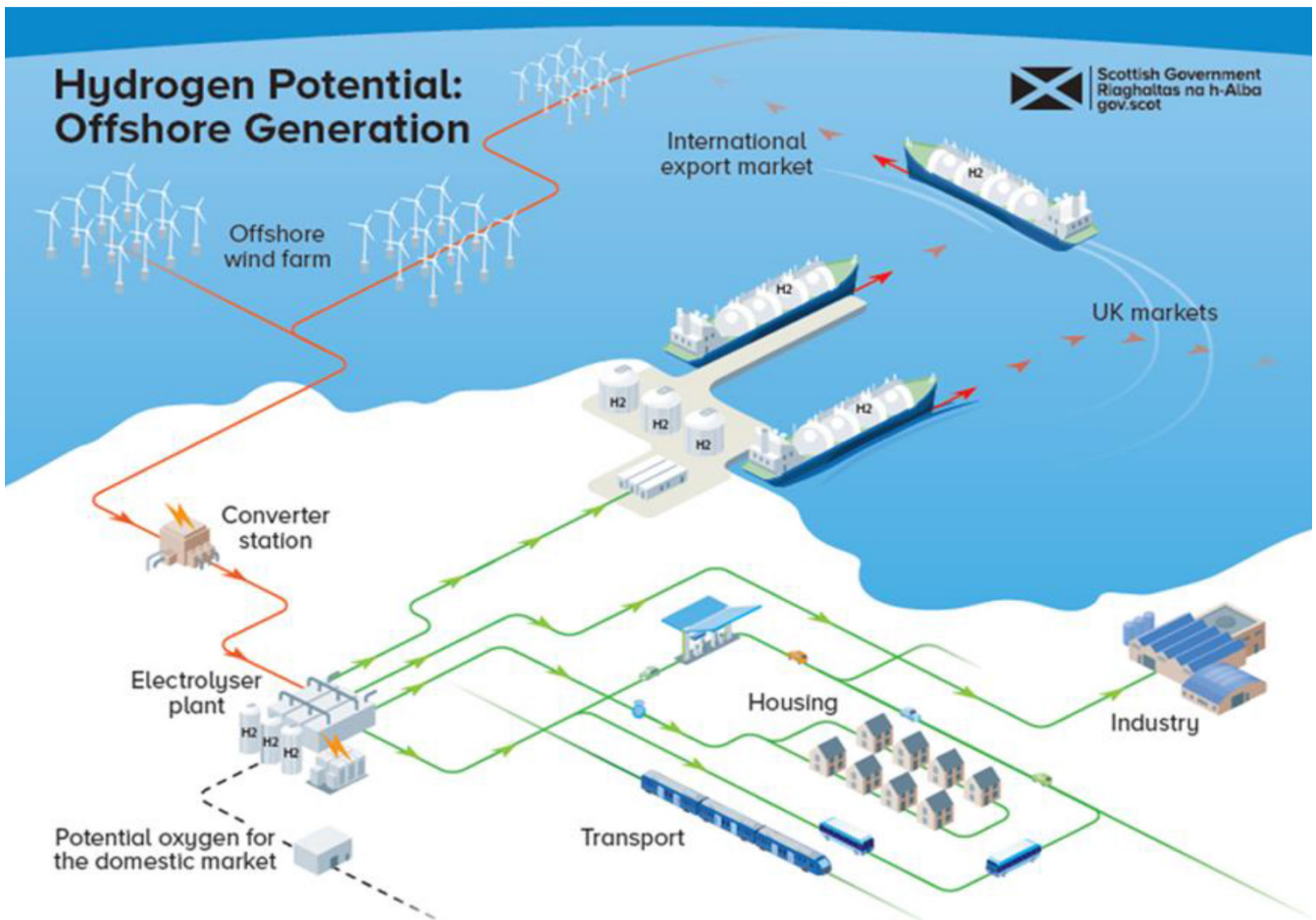


Figure 30: Illustrative Hydrogen Hub Export, Scottish Government Hydrogen Policy Statement

Non-Transport Applications

Other than transport, hydrogen can be used across a variety of sector such as heat, and industry. It can be used in heating – either by incorporating small amounts of hydrogen into current natural gas boilers without any necessary changes, or by installing fully hydrogen boilers.

Aberdeen is exploring a range of non-transport uses of hydrogen:

- **Heat:** the use of fuel cells for combined heat and power (CHP) particularly because the City has a well-established district heating system. As with transport, fuel cells for CHP are maturing and technology costs remain high for most applications.
- **Electricity and Heating/Cooling:** The Event Complex Aberdeen (TECA) has an onsite Energy Centre with 3 Fuel Cells which provide the energy required to deliver electricity, heating and cooling to the Exhibition Centre and 2 existing onsite hotels. The Energy Centre will be able to cope with the increased demand as the area is developed and more sites come online.



Figure 31: The Event Complex Aberdeen (TECA)

- **Carbon Capture:** ACC supports the Acorn Hydrogen Project which takes North Sea natural gas and reforms it into clean hydrogen, with CO₂ emissions safely mitigated through the Acorn Carbon Capture and Storage infrastructure.

acorn: making best use of the UK's built and natural assets

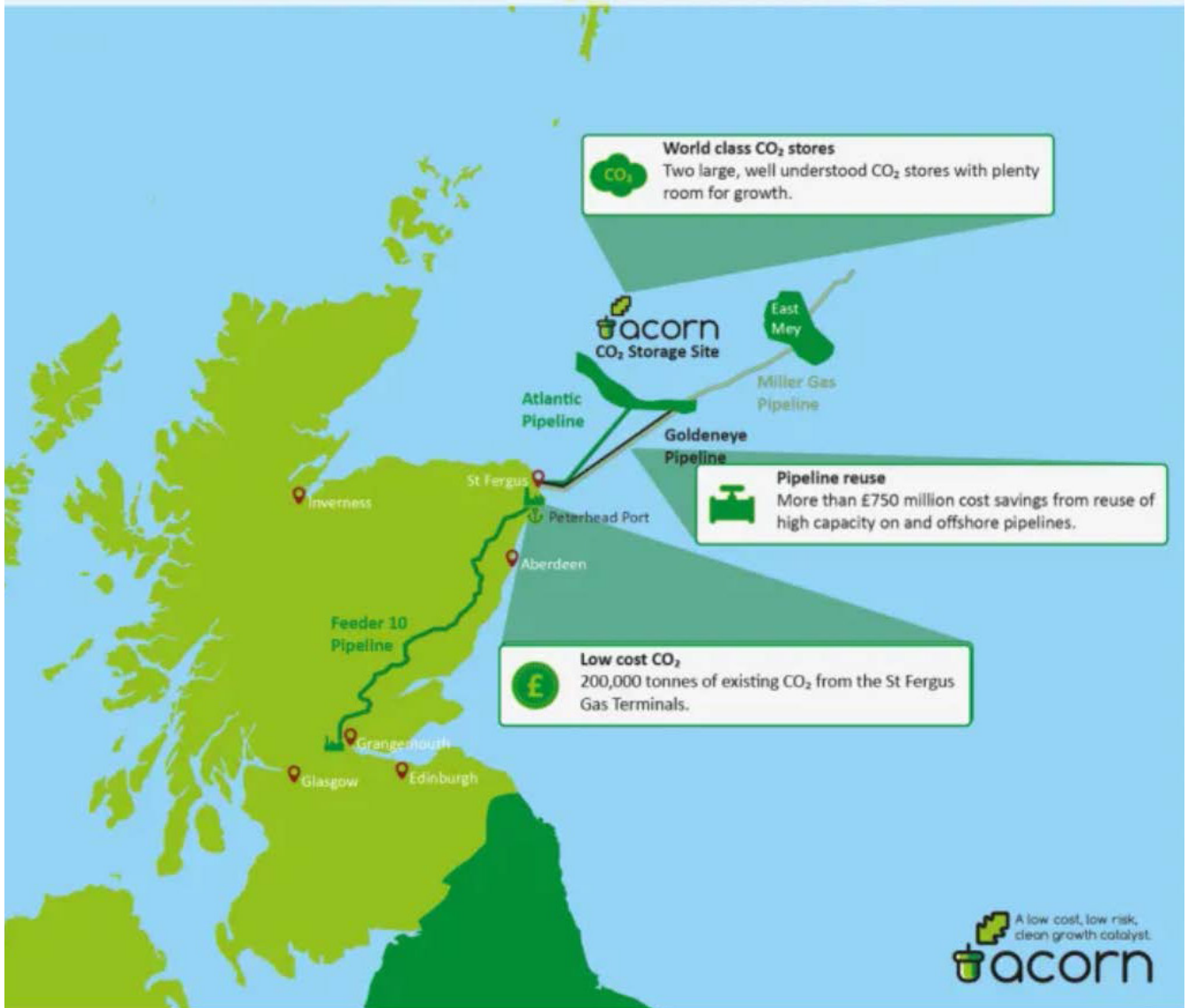


Figure 32: Acorn Project set to be operational in 2024

Further Resources

Websites

- H2Aberdeen <https://www.aberdeencity.gov.uk/services/environment/h2-aberdeen>
- JIVE – Fuel Cell & Hydrogen Joint Undertaking <https://www.fuelcellbuses.eu/projects/jive>
- HyTrEc2 Intereg North Sea Region Project: making a hydrogen transport economy in the North Sea Region <https://northsearegion.eu/hytrec2/>
- Hector Intereg North West Europe Project <https://www.nweurope.eu/projects/project-search/hector-hydrogen-waste-collection-vehicles-in-north-west-europe/>
- Smart HyAware Intereg Europe Project <https://www.interregeurope.eu/smarthyaware/>
- FCCP Intereg North West Europe Project <https://www.nweurope.eu/projects/project-search/fccp-fuel-cell-cargo-pedelecs/>
- Co-Wheels Car Club has hydrogen vehicles available to rent <https://www.co-wheels.org.uk/>
- EuroStats <https://ec.europa.eu/eurostat/web/main/home>

Videos

- H2Aberdeen playlist, includes educational videos about refuelling vehicles and a tour of the ACHES Refuelling Station https://www.youtube.com/playlist?list=PLTE1_F_XUlpT9rJw1HQAOmobiYUDS1RLt
- Kittybrewster Hydrogen Refuelling Station <https://www.youtube.com/watch?v=i3RdlPbrz9g>
- ACC Hydrogen double decker buses <https://www.youtube.com/watch?v=oajuY1JQl1Q>
- Toyota Fuel Cell – How does it work? <https://www.youtube.com/watch?v=LSxPkyZOU7E>
- How does the Hyundai Nexa work? <https://www.youtube.com/watch?v=gmtF-yPVUls>
- Fully charged show test of ACC's dual-fuel waste truck <https://www.youtube.com/watch?v=i4lq7zyLz6M>
- ULEMCo tanker dual-fuel conversion <https://www.youtube.com/watch?v=BP3NBDvFQmA>
- 'So, what is all this hot air about Hydrogen?' – TEDx talk <https://www.youtube.com/watch?v=jFYbmTV-itI>
- YouTube channel of Energy Observer, a revolutionary renewably powered vessel that is travelling the globe. Hydrogen is produced from sea water onboard. <https://www.youtube.com/channel/UCxsiFyuV8VPJcnq5Y-C7Lw>
- Hydrogen, Scaling up – Hydrogen Council <https://www.youtube.com/watch?v=ELLWw7aTQqU&t=7s>

- Hydrogen – Zero carbon heating for the homes of the future <https://youtu.be/BZV0tSowX-8>

Articles

- Transport Awards, Transport Times <https://www.transporttimes.co.uk/awards-categories.php/Scottish-Transport-Awards-Summit-3/>
- WindFloat Chosen for Kincardine Wind Farm <https://www.worldenergynews.com/news/windfloat-chosen-for-kincardine-wind-farm-678892>
- Toyota breaks distance record for hydrogen vehicle <https://www.financialexpress.com/auto/car-news/toyota-mirai-breaks-hyundai-nexos-distance-record-of-887-km-for-hydrogen-powered-vehicles/2262126/>

Reports

- Aberdeen City Council Hydrogen Strategy and Action Plan 2015-2025 http://archive.northsearegion.eu/files/repository/20150918111637_AberdeenHydrogenStrategy_March2015.pdf
- Scottish Government Hydrogen Policy Statement, 2020 <https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/>
- North Sea Transition Deal, UK Gov <https://www.gov.uk/government/publications/north-sea-transition-deal>
- Comparison of hydrogen and battery electric trucks, Transport and Environment, 2020 https://www.transportenvironment.org/sites/te/files/publications/2020_06_TE_comparison_hydrogen_battery_electric_trucks_methodology.pdf
- Shell Hydrogen Study, Shell, 2017: <https://hydrogeneurope.eu/sites/default/files/shell-h2-study-new.pdf>
- Zero Emission HGV Infrastructure <https://www.theccc.org.uk/publication/zero-emission-hgv-infrastructure-requirements/>
- Air Pollution, World Health Organisation, https://www.who.int/health-topics/air-pollution#tab=tab_1
- Scottish Greenhouse Gas Emissions 2017, Scottish Government, 2019 <https://www.gov.scot/publications/scottish-greenhouse-gas-emissions-2017/#:~:text=In%202017%2C%20Scottish%20source%20emissions,MtCO2e%20%3B%20a%201.4%20MtCO2e%20decrease>



